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Improving sleep, cognitive functioning and academic performance with sleep education at school in children

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Abstract

We aimed at measuring the impact of a school-based sleep education program (ENSOM: 'EN' for 'ENfant' and SOM for 'SOMmeil' in French) on sleep, cognitive functioning and academic performance in children. In contrast with existing sleep education programs, ENSOM was designed by sleep experts with the intent of being autonomously achieved by teachers. One-hundred and thirty children aged 8-9 years took part in control versus ENSOM interventions. Compared to the control intervention, total sleep time was extended by 31 minutes per night, sleep efficiency improved by 2.9%, and sleep latency and wake after sleep onset were shortened by 7.7 and 4.5 minutes respectively after the ENSOM program. Sleep improvement remained significant at one-year follow-up. Attention, executive functioning, academic performance and parents' sleep knowledge also improved significantly. Given the frequency of sleep curtailment in children, school-based programs could be an efficient method to implement sleep education on a large scale.

Keywords: sleep education; cognition; academic performance; children

Abbreviations: TIB: Time in Bed, TST: Total Sleep Time, SE: Sleep Efficiency, SOL: Sleep Onset Latency, WASO: Wake After Sleep Onset, min: minutes

1. Introduction

While the U.S. National Sleep Foundation recommends that school-aged children should sleep 9-11 hours per day (Hirshkowitz et al., 2015), a substantial proportion of children do not spend as much time sleeping on school nights as seems to be required for a proper daytime functioning (Crabtree & Witcher, 2008). Cohort studies carried out by Spruyt et al. (2011) and Sadeh et al. (2000) reported a total sleep time between 8 hours and 8 hours 30 minutes in children aged 4 to 10 years.

Sleep disorders affecting quality, timing or amount of sleep, are estimated to affect 25 to 40% of healthy children and adolescents (Mindell & Meltzer, 2008; Owens, 2008). This observation is alarming given the negative impact of chronic sleep disturbances on cognitive development (Touchette et al., 2007) and school performance (Buckhalt, Wolfson, & El-sheikh, 2009; Dewald, Meijer, Oort, Kerkhof, & Bögels, 2010). A wide range of data have reported that inadequate sleep results in tiredness, attention and executive function deficits, impulsivity and difficulty in modulating emotions (Maski & Kothare, 2013; Short et al., 2018). Clinical observations and experimental approaches agree that sleep-deprived children exhibit cognitive and behavioral changes that can mimic Attention Deficit Hyperactivity Disorder (ADHD) (Touchette et al., 2009). A simple 30-minutes to 1-hour extension of sleep duration was shown to increase cognitive performance in school-aged children (Sadeh, Gruber, & Raviv, 2016; Vriend et al., 2013). It is therefore essential to promote sleep in this population before sleep difficulties become chronic.

Around three-quarters of parents underestimate their child's sleep needs (Owens & Jones, 2011; Schreck & Richdale, 2011) and overestimate their child's sleep time by 30-45 min per night (Nelson et al., 2014). Such misperceptions may, in part, explain why sleep is not always effectively promoted at the family level. Because schools are the place where all children dependably convene, health education programs in schools have the potential to play an important part in improving health and well-being of all children, and reducing inequalities in health (Basch, 2011). While several school-based sleep programs have been undertaken with adolescents (for a review, see Gruber, 2017), they have not provided evidence of immediate or long-term sleep behavior improvements. These

programs have been successful in improving sleep knowledge, but their impact on cognition or sleep timing, duration or quality was disappointing (Cain, Gradisar, & Moseley, 2011; Kira, Maddison, Hull, Blunden, & Olds, 2014; Rigney et al., 2015).

Few studies investigated the effect of sleep education in younger children. The Canadian program 'Sleep for Success' explored the effect of sleep education conducted in primary school. The program consisted of 6 interactive interventions of 2-hours duration given by 'sleep-experts' (physicians, researchers or trained teachers) over a 6-week period. This program succeeded in extending sleep duration, increasing sleep efficiency and improving results in mathematics and English in children who participated to the program compared to a control group matched in age (Gruber, Somerville, Bergmame, Fontil, & Paquin, 2016). However, the need of 'sleep-experts', who directly conduct the program or train teachers or parents, might prevent a wild use and dissemination of such programs.

We created a sleep education program (ENSOM program: 'EN' for 'ENfant' and SOM for 'SOMmeil' which means 'child' and 'sleep' in French) integrated into primary school curricula, which can be autonomously conducted by teachers, without the intervention of 'sleep-experts'. The aim of the present study was to objectively measure the impact of the ENSOM program on sleep, cognitive functioning and academic performance assessed with actigraphy, neuropsychological tests and third-grade report cards. To assess the long-term effect of the sleep education program, a subset of children also took part in a one-year follow-up evaluation of sleep parameters.

2. Methods

2.1. Participants

A total of 130 school children aged 8 to 9 years (M_{age} = 8.43, SD_{age} = 0.29; 62 girls), all in third grade of 5 primary schools, participated in the study ($N_{school\ 1}$= 26, $N_{school\ 2}$ = 25, $N_{school\ 3}$ = 25, $N_{school\ 4}$ = 28, $N_{school\ 5}$ = 26). There were two rural schools (schools 1 and 4) and three urban schools (schools 2, 3 and 5). Exclusion criteria were history of psychiatric or neurological illness, developmental disorder,

learning disability or reported sleep disorders, according to parental reports. One child initially included in the study was later diagnosed ADHD. As the other children, she took part in the lesson, but her data were excluded from the analyses. This experiment was approved by the Ethics Committee of [information removed for reasons of anonymity]. All the children and their parents gave their written informed consent. The director of the school 5 did not give consent to integrate the actigraph in the school due to potential device loss, or schoolyard conflict between children wearing or not the monitoring system. Hence, no actigraphy data was available for this school.

2.2. Design and procedure

We used a within-subjects design, as was required by the Ethics committee to prevent inequality of opportunities between children. Indeed, in a parallel group design the 'control' group should have waited more than one academic year to eventually benefit from the procedure, which broke the 'equal opportunity' design. Children followed first a nutrition education program (i.e. control period) and then, the sleep education program.

The two programs consisted of eight 50-minute education lessons taught by their usual teacher over a period of one month (2 sessions/week). The primary outcome measures were actigraphic sleep measures and cognitive functioning collected at 5 time points: before and after the control period (T1 and T2), before and after the sleep education program (T3 and T4), and one year later (T5). One month elapsed between the end of the control period (T2) and the initiation of the program (T3). Of the 130 children involved in the protocol, 85 were tested at T5. Children who changed school or teacher between the 3rd and 4th grade could not be included in the follow up, which explains attrition. The secondary outcome measures were third-grade report cards and parents' knowledge about sleep collected at T3 and T4 (see Fig 1).

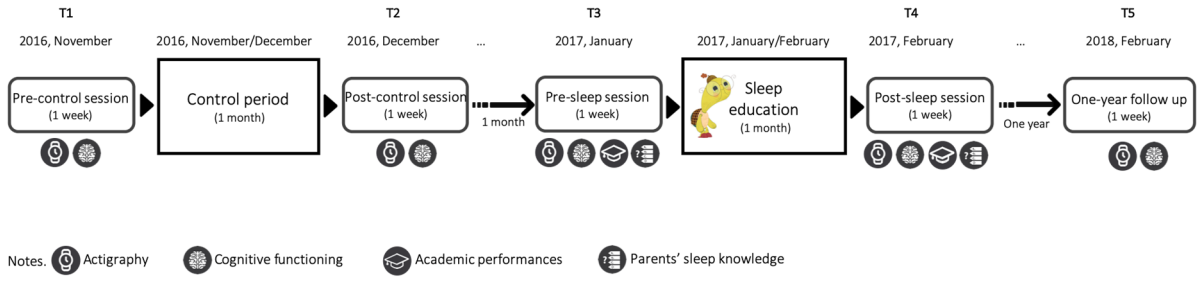


Figure 1. Illustration of the procedure.

2.3. ENSOM sleep education program

The ENSOM program was based on a multidisciplinary and collaborative approach involving children, parents, researchers, sleep physicians, primary school teachers, as well as art school students who produced the illustrations. During the construction process, each lesson was systematically pre-tested by the teachers with their students (N = 62) and, following their feedback, improvements were introduced when necessary. During this 'pre-testing', children evaluated their satisfaction about the program at 4.60/5 ± 0.05. The teachers involved in the construction of the ENSOM program were not the same than those who took part to the experimental protocol. The sleep education program was developed to build awareness and understanding of the importance of sleep in children and their teachers, but also to help children to become responsible for their sleep and health.

The ENSOM package contained a 30-page training manual for teachers with complete information about sleep, a step-by-step description of each lesson and eight structured lessons (8 cartoons and 8 comic-strips) covering four themes: the sleep rhythms, the role of sleep, the need for sleep and the friends and foes of sleep (2 lessons per theme). Sleep tips were presented to the children at the end of each lesson to promote good sleep practices (see Table 1). To encourage the interactions between children and their parents regarding the sleep education program, children had three occasions to collect at-home information about their own sleep and the sleep of family members.

Table 1. Sleep tips that were presented to the children at the end of the lessons.

Sleep tip #1	Tonight, I shall snuggle down in bed just like Granny Jammies! [the mascot of the ENSOM program]
Sleep tip #2	Tonight, I shall look out for the signs of sleepiness.
Sleep tip #3	If I wake up during the night, I'll think about the next little train to help me get back to sleep.
Sleep tip #4	Tonight, I think of something nice before going to bed!
Sleep tip #5	Tonight, I shall think of 3 things I like doing before going to sleep and I'll do them every evening this week.
Sleep tip #6	In the morning, I'm glad I've slept well, I feel rested and enjoy a good stretch.
Sleep tip #7	In the morning, I'll make my bed because it doesn't feel nice to sleep in an unmade bed.

The French and English versions of the ENSOM program are freely available on [information removed for reasons of anonymity, for an overview of the program, please see Supplementary material] under a Creative Commons License BY-NC-ND (Attribution, NonCommercial, NoDerivates).

2.4. Measurements

2.4.1. Sleep assessment

Each child was requested to wear a wristwatch-like device (Actiware 2, Philips Respironics, Bend, OR, USA) on the non-dominant wrist for 1 week (5 school days and 2 weekends) at the 5 time points. Sleep was recorded during nights preceding school days (Sunday through Thursday) and during weekends (Friday and Saturday). Actigraphy has been shown to provide a valid estimate of sleep patterns in children and adolescents (Meltzer, Montgomery-Downs, Insana, Salvatore, & Walsh, Colleen, 2012). The Actiware 2 devices are equipped with an event marker and a light sensor. At night, when children were in bed ready to fall asleep, they were told to use the event marker to indicate their bedtime. In the morning, when they woke up, they were instructed to mark the actigraph again. All actigraphy data were visually reviewed by a sleep specialist and bedtimes were checked according to the event marker, the sleep diaries completed by the children and the data from the light sensor (in particular when children forgot to push the 'bedtime button'). Actigraphic sleep data were analyzed in 30-sec epochs using Actiware Sleep software 6.0.9. Epochs with activity count equal or below the threshold sensitivity value set at 40 (medium sensitivity), were scored as

'sleep' whereas epochs exceeding this threshold were scored as 'waking'. Sleep start and end were determined automatically as the first and last 10 minutes period respectively in which no more than one epoch was scored as mobile. Automatic analyses were run to extract the following sleep parameters: a) bedtime (clock time attempt to fall asleep); b) wake-up time; c) Time in Bed (TIB - time between bedtime and wake-up time), d) Total Sleep Time (TST - estimated amount of time scored as sleep, according to the Actiware-Sleep Algorithm); e) Sleep Onset Latency (SOL - amount of time elapsing from bedtime to the first period of sleep); f) Sleep Efficiency (SE - ratio of sleep time over time in bed, i.e. (TST /TIB) x 100); g) Wake After Sleep Onset (WASO - number of minutes scored as wake time during sleep period), and h) Mid-sleep (i.e. midpoint between sleep onset and offset) corrected for sleep debt on school days (MSFsc = MSW - 0.5*(SDW - (5*SDS + 2*SDW)/7), where MSW is midsleep on weekends, SDS is sleep duration on weekends and SDW is sleep duration on school days; (5*SDS + 2*SDW)/7 represents the average weekly sleep duration) (Roenneberg, Keller, & Fischer, 2015). Analyses were performed on actigraphic data when at least four nights (including at least one during the weekend) were available. Among the 105 children recorded between T1 and T4, 79,5% reported usable data (T1= 76.2%; T2= 89%: T3= 88.6%; T4= 67.6%). From the 85 recordings at T5, 70,6% were usable. 89% of missing data resulted from partially missing data (< 4 nights), the remaining corresponded to a complete loss of the recordings.

2.4.2. Cognitive functioning

OpenSesame 3.1 was used to set up and to manage the experiment (Mathôt, Schreij, & Theeuwes, 2012). Each participant performed a 45-minute computerized evaluation on a tablet during the morning at school to enable us to measure executive functioning (inhibitory control, flexibility, mental planning and updating), sustained attention and delayed memory.

Inhibitory control and flexibility were measured using an adapted NEPSY-II 'Inhibition' task designed to assess the ability to inhibit automatic responses in favor of novel responses and the ability to switch between response types (Korkman, Kirk, & Kemp, 2007). The children looked at a

series of black and white circles or squares that appeared one-by-one on the screen. For the inhibitory control measure, they had to tap on the shape opposite to the one they saw as quickly as possible. For the flexibility measure, they had to tap on the same shape or on the opposite shape as quickly as possible depending on the color of the shape. Mental planning was measured with a computerized adaptation of the NEPSY-I 'Tower' task in which the children were asked to arrange three colored balls in target positions on three pegs in as few moves as possible (Korkman, Kirk, & Kemp, 2003). Running span was measured with a running span task in which the children had to recall the last three numbers in sequences of different length. Sustained attention was assessed with a task inspired by the Continuous Performance Test - 3rd edition (Conners, 2013). For 15 minutes, the children saw letters appearing one-by-one on the screen and they had to tap on each letter - apart from the letter 'X' - as quickly as possible. Memory was assessed with a recognition task inspired by the subtest 'word list' subtest of the Children Memory Scale (Cohen, 2001). Children were asked to memorize 14 sequentially presented words. Thirty minutes later, they had to indicate whether 28 words (14 old words and 14 new words) had or had not appeared in the previous phase. All children performed the task in the same order: learning phase of the memory test, inhibition task, updating task, recognition phase of the memory test, tower task and continuous performance test. The correct response rates were collected for all the tasks. A 'global cognitive' score was calculated as the average of all the above-mentioned scores.

Among the 130 children included between T1 and T4, 88.9 % completed the cognitive evaluation (119 were tested at T1; 114 at T2; 111 at T3; 109 at T4). All the children included at T5 performed the cognitive evaluation (N = 85).

2.4.3. Academic performance

Parents provided a copy of the children's third-grade report cards before and after the sleep education program (T3 and T4). Grades were indicated on a scale between 0 (non-acquired skill) and 3 (acquired skill) for academic performance in French, mathematics and sciences.

2.4.4. Parents' knowledge about sleep

The parents' knowledge about sleep was measured at T3 and T4 using a multiple-choice questionnaire devised by the experimenters. Seven questions were based on the material covered during the education program. Two versions were created to address the topics of sleep needs, sleep rhythms, sleep and health and chronotype. The analysis of parent's knowledge about sleep was conducted using a global score expressed as a percentage of correct responses. The response rate was 51.4%.

2.4. Statistical analyses

Statistical analyses were performed using RStudio version 3.2.2. Values are given as mean ± SEMs. Normality of distribution was tested using the Shapiro-Wilk test. Correlation analyses were performed between cognitive scores and sleep parameters at baseline (T1) and after the sleep education program (T4 and T5) using Spearman tests. Stepwise linear regression analyses were carried out to identify the set of sleep parameters (TIB, TST, bedtime, SE, SOL and WASO) that account for the variance of global cognitive functioning. A non-parametric repeated measure of variance (Mack-Skillings test, a Friedman-type statistic that can be used for block designs with missing data) was conducted on sleep parameters or cognitive functioning across each time. Post-hoc two-sided Wilcoxon tests with Bonferroni correction for multiple comparisons were performed to compare T1 and T2 (control period), T2 and T3, T3 and T4 (sleep education program) and T3 and T5 (one-year follow-up). Kruskall-Wallis tests were performed to compare the change in TST between the four classes. To assess the changes in sleep habits between school days and weekends, a repeated-measures analysis of variance (ANOVA) with a Greenhouse-Geisser correction was conducted with Time (T1, T2, T3, T4, T5) as within-subjects factor and Day (school days or weekends) as between-subjects factor for bedtime, waketime and TST. Chi-square (χ^2) tests were used to measure the changes in academic performance as a function of changes in sleep. Possible relations between academic performance and sleep parameters were assessed with Spearman's rho correlation

coefficient. Effect sizes were estimated using eta squared or Cohen's *d* and was interpreted as small (η^2 = .01 or $d \leq 0.3$), medium (η^2 = .06 or d = 0.5) or large (η^2 > .14 or d = 0.8). The level of significance was set at $\alpha < 0.05$, after correction. A power analysis based on the results of Gruber and colleagues (2016) indicated that, given a desired power of 0.80 and an alpha level of 0.05, a minimum sample size of 86 participants was sufficient to detect a difference.

3. Results

3.1. Sleep and cognitive functioning at baseline (T1)

At T1, the average TIB was 9 hours and 36 minutes (± 2 min) with an average TST of 8 hours and 36 minutes (± 3 min). On average, the children needed 21 minutes (± 0.9 min) to fall asleep. SE was 87.1% (± 0.4%) (Table 2). During school days, bedtime was 21:28 (± 4 min) with a TST of 08 hours and 05 minutes (± 4 min). During weekends, bedtime was 22:40 (± 6 min) with a TST of 09 hours and 08 minutes (± 3 min).

The global cognitive functioning score was positively correlated with SE (r = .50, p < .001) and TST (r = .28, p = .017), but negatively correlated with bedtime (r = -.26, p = .024), SOL (r = -.33, p = .004), WASO (r = -.27, p = .021) and mid-sleep (r = -.29, p = .012). A stepwise linear regression analysis showed that SE accounted for 18.8% of variance in the global cognitive score (adjusted R2 = .18, β = .45, p <.001). When correlations were performed on each cognitive function, TST was positively correlated with flexibility (r = .24, p = .036), sustained attention (r = .29, p = .012) and memory recognition (r = .23, p = .048). SE was positively correlated with inhibitory control (r = .63, p < .001), flexibility (r = .40, p < .001), mental planning (r = .29, p = .013) and sustained attention (r = .23, p = .047). SOL was negatively correlated with executive functioning (inhibitory control: r = -.36, p < .001, flexibility: r = -.34, p = .003, mental planning: r = -.33, p = .004) and sustained attention (r = .24, p = .039). WASO was negatively correlated with recognition (r = -.27, p = .02) and inhibitory control (r = -.33, p = .003). Bedtime was negatively correlated with inhibitory control (r = -.28, p = .017) and mid-

sleep was negatively correlated with inhibitory control (r = -.33, p = .004) and mental planning (r = -.28, p = .014, see the Appendix A for the correlation matrix at T1).

3.2. Sleep across time points

3.2.1. Global evolution of sleep parameters

Non-parametric repeated-measures analysis of variance (Friedman - Mack-Skillings test) revealed a significant effect of Time for all sleep parameters (see Table 2). While no significant difference was found between T1 and T2 or T2 and T3 (all *p*s > .05), post-hoc analyses showed that TIB, TST and SE increased significantly from T3 to T4, i.e. when the program was applied (all *p*s < .001; TIB: Cohen' *d* = .65; TST: *d* = 1.25, SE: *d* = 0.87). Mid-sleep moved earlier, SOL and WASO decreased from T3 to T4 (all *p*s < .001, mid-sleep: *d* = 0.51; SOL: *d* = 0.97, WASO: *d* = 0.47). The same results were observed between T3 and T5 (all *p*s < .002, TIB: *d* = .47, TST: *d* = 0.97, SE: *d* = 1.12; SOL: *d* = 0.60, WASO: *d* = 0.60, mid-sleep: d = 0.53).

Table 2. Mean (SEM) for sleep variables as measures by actigraphy before (T1, T2 and T3) and after (T4 and T5) the sleep education program.

	Control period		Sleep education program		One-year follow-up		
	T1 Pre-test (N = 80)	T2 Post-test (N = 93)	T3 Pre-test (N = 93)	T4 Post-test (N = 71)	T5 (N = 60)	MS	p
TIB (min)	571.8 (3.1)	571.2 (2.8)	570.8 (3.0)	589.4 (2.6)	583.2 (2.4)	250.2	<.001
TST (min)	516.7 (3.0)	517.3 (2.9)	516.3 (2.9)	547.4 (2.7)	539.0 (2.3)	201.6	<.001
SOL (min)	21.1 (0.9)	20.0 (0.8)	19.7 (0.8)	12.0 (1.0)	14.3 (1.3)	256.2	<.001
SE (%)	87.1 (0.4)	88.0 (0.3)	87.9 (0.3)	90.8 (0.4)	91.4 (0.4)	180.2	<.001
WASO (min)	34.0 (1.1)	33.9 (0.8)	34.7 (1.1)	30.2 (1.0)	29.8 (0.5)	195.5	<.001
Mid-sleep (hrs:min)	03:13 (00:07)	03:15 (00:06)	03:22 (00:06)	02:54 (00:06)	02:54 (00:05)	229.9	<.001

Note. MS: Mack-Skillings test. TIB: Time in Bed, TST: Total Sleep Time, SOL: Sleep Onset Latency, SE: Sleep Efficiency, WASO: Wake After Sleep Onset. SEM: Standard Error of the Mean. Cohen's d was provided in the text when comparisons were significantly different.

Sleep parameters did not differ between the 4 schools equipped with actigraphs (all *p*s >.05) or between urban and rural schools at the 5 time points (all *p*s >.80, see Figure 2 for an illustration of TST).

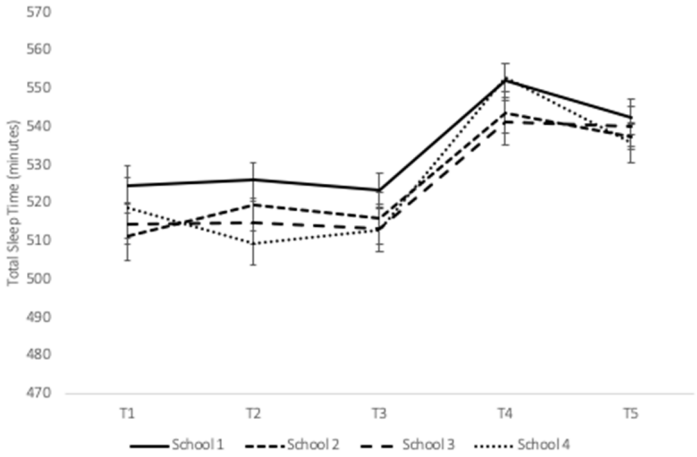


Figure 2. Evolution of Total Sleep Time in the 4 different schools at each time points

Changes in TST at T4 were dependent on sleep durations before sleep education. Significant negative correlations were found between the TST increase at T4 and the TST at T1 (r = -.720, p < .001), T2 (r = -.686, p < .001) and T3 (r = -.706, p < .001). Figure 3 illustrates the correlation between TST of children at T3 and the evolution of TST after the sleep education program (delta T4-T3).

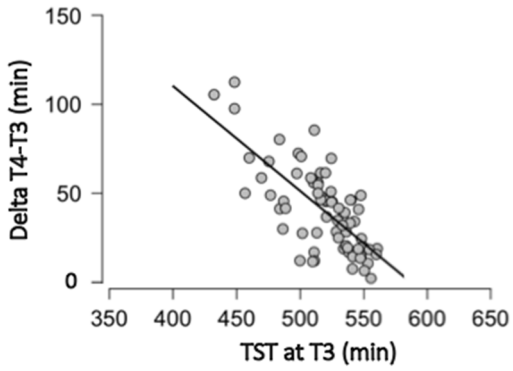


Figure 3. Correlation between the total sleep time (TST) of children before the sleep education program (T3) and the evolution of TST after the sleep education program (delta T4-T3).

The sleep time of the children with the smallest TST at T3 (in the lower half of the TST distribution, range: 448-513 min) increased by 42.3 min (± 4.2), while that of the children in the upper half (range: 533-560 min) increase by 17.7 min (± 3.1).

3.2.2. Sleep habits between school days and weekends during the sleep education program

Table 3. Sleep habits before (T3) and after sleep education (T4) for school days and weekends. Mean (SEM).

		School days	Weekends	Mean difference
Bedtime (hrs:min)	Before sleep education	21:43 (00:04)	22:51 (00:06)	01:08 (00:05)
	After sleep education	21:17 (00:05)	22:13 (00:06)	00:55 (00:06)
Wake time (hrs:min)	Before sleep education	07:17 (00:03)	08:16 (00:07)	00:52 (00:05)
	After sleep education	07:15 (00:03)	08:12 (00:06)	00:56 (00:06)
TST (min)	Before sleep education	480.5 (3.2)	552.1 (3.2)	71.6 (2.6)
	After sleep education	525.3 (2.7)	569.4 (2.7)	44.1 (1.8)

Note. TST: Total Sleep Time, SEM: Standard Error of the Mean.

To better understand changes in sleep habits before (T3) and after (T4) the sleep education program (see Table 3), a repeated-measures ANOVA was conducted. Regarding the TST during school days and weekends before and after sleep education, there were (i) a main effect of the 'Day' factor, reflecting longer sleep duration during weekends than school days ($F = 898.6$, $p < .001$, $\eta^2 = .93$; (ii) a main effect of 'Time of analysis' with longer sleep duration at T4 compared to T3 ($F = 93.05$, $p < .001$, $\eta^2 = .57$), and (iii) a significant Time x Day interaction ($F = 71.6$, $p < .001$, $\eta^2 = .51$) indicating a greater post-sleep education TST increase on school days than on weekends. ANOVA on bedtimes showed a significant main effect of Day with earlier bedtime during school days than weekends ($F = 219.6$, $p < .001$, $\eta^2 = 77$) and a main effect of Time with earlier bedtime at T4 compared to T3 ($F = 21.5$, $p < .001$, $\eta^2 = .25$), but no interaction ($p = .32$). Lastly, ANOVA on wake times revealed a significant effect of Day with earlier wake times on school days compared to weekends ($F = 96.7$, $p < .001$, $\eta^2 = .72$), but no effect of Time ($p = .97$) or interaction ($p = .82$).

3.3. Cognitive functioning

A significant effect of Time period was observed for all cognitive parameters (all *p*s < .007, see Table 4), except for delayed memory (*p* = .90). Post-hoc analyses performed between T1 and T2 only showed a significant decrease of inhibitory control (*p* = .01, *d* = 0.02) and no difference between T2 and T3 (*p* > .05). Inhibitory control, cognitive flexibility, mental planning and running span scores significantly increased from T3 to T4 (all *p*s < .001, *d* >.33) and from T3 to T5 measured one year later (all *p*s < .004, *d* >.35).

Table 4. Mean (SEM) for scores obtained in the cognitive tests before and after the control period and the sleep education program.

	Control period		Sleep education program		One-year follow-up		
	T1 Pre-test (*N* = 119)	T2 Post-test (*N* = 114)	T3 Pre-test (*N* = 111)	T4 Post-test (*N* = 109)	T5 (*N* = 85)	*MS*	*p*
Executive functioning							
Inhibitory control	92.5 (0.8)	92.3 (0.7)	92.3 (0.8)	94.7 (0.6)	96.0 (4.6)	171.6	.007
Cognitive flexibility	88.6 (1.0)	89.0 (0.9)	90.1 (0.9)	94.6 (0.5)	94.6 (4.3)	266.9	< .001
Mental planning	38.7 (1.8)	39.3 (1.8)	42.4 (2.0)	51.2 (2.0)	51.2 (2.3)	285.2	< .001
Running span	15.5 (1.3)	13.6 (1.2)	17.4 (1.5)	29.4 (1.6)	39.3 (2.3)	210.3	< .001
Delayed memory							
Recognition	81.7 (1.2)	81.6 (1.3)	81.8 (1.4)	81.8 (1.1)	81.9 (1.2)	.09	.87
Attention							
Sustained attention	83.0 (1.1)	83.2 (1.0)	82.3 (0.8)	91.5 (0.8)	92.7 (0.7)	246.7	< .001
Global score	66.8 (0.8)	66.5 (0.7)	67.9 (0.7)	73.9 (0.6)	76.6 (0.8)	347.8	< .001

Note. MS: Mack-Skillings test. SEM: Standard Error of the Mean. Cohen's d was provided in the text when comparisons were significantly different. Cohen's d was provided in the text when comparisons were significantly different.

Correlations found between sleep parameters and cognitive performance at baseline (see section 3.1) were no longer significant after the sleep education program (T4 or T5, all *p*s > .05, see the Appendices B and C for the correlation matrix at T4 and T5 respectively).

We examined sleep and cognitive characteristics of the children lost in the follow-up at T4. For this purpose, we averaged their TST, sleep efficiency (SE) and global cognitive performance measured at T1, T2 and T3 and compared these values to those observed in children who completed

the 4 time-points. There was no significant difference between the two groups for TST (respectively, 513.2 min ± 4.6 vs. 516.8 min ± 3.1; p = .58), SE (respectively, 87.3% ± 0.6 vs. 87.7% ± 0.4; p = .58) and cognitive functioning (respectively, 66.9% ± 0.8 vs. 67.5% ± 0.6; p = .52).

3.4. Academic performance

No significant correlation between sleep parameters and academic performance was found at T3 or T4 (all ps > .05). However, children whose sleep efficiency improved after sleep education (beyond 90%) were also more likely to exhibit improved academic performance than those in whom it did not (respectively, 83% and 62%, p < .001).

3.5. Parents' knowledge about sleep

The percentage of correct responses significantly increased after the sleep education program compared to T3 (M_{before} = 51.1% ± 3.1, M_{after} = 67.5% ± 2.9 of correct responses, W = 93, p < .001). 83% of the parents (N = 54) who completed the questionnaire improved their knowledge about sleep after the sleep education program.

4. Discussion

The overall aim of this study was to evaluate the beneficial effect of a school-based sleep education program conducted by teachers without sleep expert's intervention on children sleep and on their cognitive and academic performance. Our main findings are that the ENSOM program was effective in inducing changes in sleep habits and increasing cognitive and school performance. Children's sleep duration was significantly extended by an average of 31 min per night following sleep education, and this improvement was maximal in children with shorter sleep duration at baseline. This beneficial effect was also larger during school days than weekends. Sleep efficiency was enhanced by 2.9 %, due to a significant shortening of 12.2 min in the time spent awake after bedtime (SOL and WASO). After the sleep education program, children also exhibited earlier bedtimes. Even if actigraphic recordings do not bring information about sleep stages, the lengthened sleep duration, together with an earlier

sleep onset, is likely to increase the time spent in deep sleep, which predominates during the first part of the night (Kurth et al., 2012). Increase in sleep duration has been associated with improved daytime performance (Gruber, Cassoff, Frenette, Wiebe, & Carrier, 2012; Sadeh, Gruber, & Raviv, 2003), and indeed we also found that sleep efficiency was the parameter that had the greatest impact on the variation in cognitive scores at baseline. These results are consistent with previous studies suggesting that sleep quality (as indexed by sleep efficiency and WASO) and sleep regularity (i.e. consistent bedtime schedules or sleep duration) play a critical role in cognitive and academic performance (Buckhalt, 2011; Kelly, Kelly, & Sacker, 2013; Matricciani, Blunden, Rigney, Williams, & Olds, 2013). As was the case for, our results suggest that the children whose sleep efficiency improved also progressed more the others in terms of cognitive and academic performance. Improvements were found in attention and executive functioning, consistent with the role of sleep in high-level cognitive processes associated with frontal lobe functioning (Astill, Van der Heijden, Kristiaan, Van IJzendoorn, Marinus, & Someren, 2012; Jones & Harrison, 2001).

Behavioral and emotional self-regulation difficulties are common in children with sleep difficulties (e.g., Taveras, Rifas-Shiman, Bub, Gillman, & Oken, 2018; Wang et al., 2018). Because executive functioning is also crucial for emotional and behavioral self-regulation, it would be interesting to evaluate whether the ENSOM program results in behavioral changes at school. In our study, memory performance was the only cognitive measure that failed to improve after the sleep education program. While the improvement in executive functioning and attention resulting from sleep may be big enough to be detected with relatively simple tests, the change in memory performances may have been too subtle to be detected with our tasks, which involving only a relatively low cognitive load (Blunden, 2017). Alternatively, of course, it may well be that memory performances were genuinely unchanged despite the improvement in sleep.

To fully assess the preventative potential of school-based programs, studies need to determine if the effect on sleep persists in the years beyond those of the intervention. In our study, parameters recorded one year after the end of the ENSOM intervention suggested a long-lasting

beneficial effect on sleep. This persistent gain in sleep is all the more relevant that several studies showed a significant decrease of TST by 20 to 50 minutes between the age of 8-9 and 10-11 (Crabtree & Williams, 2009). As this sleep restriction was associated with morning sleepiness, this behavioral change may not be in accordance with their physiological needs (Sadeh et al., 2000). In other studies, changes in sleep duration following a school-based sleep education failed to persist for more than a few weeks (Blunden, 2017; Gruber et al., 2012). This discrepancy might not reflect a real difference between programs but instead a lack of objective sleep measurements tools in most previous studies. Indeed, purely introspective data (questionnaires or diaries) may fail to detect significant improvements in sleep duration or efficiency, including in the long term, that can easily be observed with actigraphy.

The co-construction of the ENSOM program with educational professionals, researchers and families was, in our opinion, the key factor in its success (e.g., Mcdowall, Galland, Campbell, & Elder, 2017). Several studies conducted in schools reported difficulties in engaging schools, teachers and parents (Gruber et al., 2016). Interestingly, while our program was performed during school time, it also increased parents sleep knowledge. The present study does not allow determining by what means parents increased their sleep knowledge and how this contributed to improve their children sleep habits. However, this improvement is important for the recognition of healthy sleep patterns and the adoption of long-lasting changes in their children's behavior (Kopasz et al., 2010). Since only a few parents participated to this evaluation, we cannot exclude that responding parents may have been the most concerned about their child's sleep.

Although the goal of the ENSOM program was to increase children's sleep literacy and help them develop good practices, we could not identify which specific topics addressed in the ENSOM program promote the change in sleep behavior. Different behavioral changes may have contributed to the overall effect, including the reduction in screen time before bedtime, the reinforcement of relaxing sleep rituals, improved parental monitoring of bedtimes, promotion of physical activities or

possibly other factors. Further studies might provide some indications about some of these specific aspects.

This study has a number of limitations. Due to ethical recommendation, we were bound to use a within-subjects design rather than a parallel before-and-after study, and this increased the risk of testing effects and time-varying confounders. Moreover, the reported correlation of T3-T4 changes with TST before sleep education has to be interpreted cautiously as we cannot exclude that a regression to the mean might explain the observed pattern of results. However, a within-subjects design also shows advantages: the subjects act as their own control, which reduces the amount of error arising from natural variance between children. Moreover, our results showed no cognitive or sleep improvement whatsoever during the control period (between T1 and T2) or during the period without intervention (between T2 and T3), which reasonably excluded a significant effect due to spontaneous improvement with time or any testing effect. Actigraphy recordings were used to assess sleep parameters. Actigraphy shows limitation to estimate sleep onset latency and wake during the sleep period (Meltzer et al., 2016). Nevertheless, the use of objective sleep measures is an important strength of the present study, and its use has been endorsed by the American Academy of Sleep Medicine.

Conclusion

Studies covering a full century indicate a disconcerting reduction in the habitual sleep duration of children (Galland, Taylor, Elder, & Herbison, 2012; Iglowstein, Jenni, Molinari, & Largo, 2011). Parents, teachers, policy makers and, above all, children must be aware about the close link between sleep restriction, learning and behavioral problems. Studies such as the current one demonstrates that a sleep education program integrated into school curricula can improve sleep habits and school performance. Because it can be autonomously conducted by teachers, the ENSOM program is easy to implement into school's health curriculum and is both a feasible and efficient method to promote sleep in a large scale.

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Appendices

A. Correlation matrix for sleep and cognitive parameters at baseline (T1)

	Sleep parameters						Cognitive parameters					
	TIB	TST	SOL	SE	WASO	Mid-sleep	Inhibitory control	Cognitive flexibility	Mental planning	Running span	Recogni-tion	Sustained attention
TIB	1.00											
TST	.446***	1.00										
SOL	-.053	-.264*	1.00									
SE	.187	.514***	-587***	1.00								
WASO	.204	-.022	.031	-.482**	1.00							
Mid-sleep	.009	-.077	.360**	-.607***	.364***	1.00						
Inhibitory control	.091	.189	-.362**	.633***	-.334**	-.325**	1.00					
Cognitive flexibility	.059	.243*	-.337**	.402***	-.096	-.159	.714***	1.00				
Mental planning	-.015	.086	-.330**	.285*	-.115	-.284*	.277**	.258*	1.00			
Running span	.076	-.158	.070	-.014	-.125	-.009	.220*	.205*	.191	1.00		
Recognition	-.006	.230*	-.011	.198	-.268*	-.148	.118	.230*	.167	.020	1.00	
Sustained attention	.164	.288*	-.239*	.231*	-.007	-.122	.220*	.226*	.147	.350***	.102	1.00

Note. TIB: Time in Bed, TST: Total Sleep Time, SOL: Sleep Onset Latency, SE: Sleep Efficiency, WASO: Wake After Sleep Onset, *p>.05, **p<.01, ***p<.001

B. Correlation matrix for sleep and cognitive parameters after sleep education (T4)

	Sleep parameters						Cognitive parameters					
	TIB	TST	SOL	SE	WASO	Mid-sleep	Inhibitory control	Cognitive flexibility	Mental planning	Running span	Recogni-tion	Sustained attention
TIB	1.00											
TST	.677***	1.00										
SOL	.166	-.227	1.00									
SE	.285*	.599***	-.548***	1.00								
WASO	-.045	-.095	-.014	-.320**	1.00							
Mid-sleep	.077	-.212	.265*	-.333*	.116	1.00						
Inhibitory control	.152	.054	.196	-.016	-.127	-.149	1.00					
Cognitive flexibility	.210	.212	-.040	.020	-.114	.047	.460***	1.00				
Mental planning	.122	-.038	.163	-.110	-.124	-.139	.339**	.345**	1.00			
Running span	.070	-.027	.083	.001	.001	-.033	.127	-.163	.139	1.00		
Recognition	-.150	-.125	.058	-.241	.094	-.095	.113	.189	.294**	-.084	1.00	
Sustained attention	-.094	-.233	-.127	-.065	-.190	-.084	-.038	.181	.382**	.167	.203	1.00

Note. TIB: Time in Bed, TST: Total Sleep Time, SOL: Sleep Onset Latency, SE: Sleep Efficiency, WASO: Wake After Sleep Onset, *p>.05, **p<.01, ***p<.001

C. Correlation matrix for sleep and cognitive parameters after one-year follow-up (T5)

	Sleep parameters						Cognitive parameters					
	TIB	TST	SOL	SE	WASO	Mid-sleep	Inhibitory control	Cognitive flexibility	Mental planning	Running span	Recogni-tion	Sustained attention
TIB	1.00											
TST	.240	1.00										
SOL	-.051	-.343**	1.00									
SE	.031	.353**	-.517**	1.00								
WASO	.108	.331**	-.545***	.768***	1.00							
Mid-sleep	.169	-.023	.136	-.370**	-.111	1.00						
Inhibitory control	-.030	-.126	.154	-.269	-.175	.208	1.00					
Cognitive flexibility	-.020	-.073	-.001	-.087	.112	-.111	.206	1.00				
Mental planning	-.139	.144	.077	-.195	-.073	.050	-.039	-.006	1.00			
Running span	-.010	-.045	.204	-.109	-.131	.196	.138	.023	.021	1.00		
Recognition	.149	.112	-.118	.103	.130	.063	-.092	.049	.163	-.165	1.00	
Sustained attention	.095	.221	-.189	.277	.189	.125	-.027	.044	.115	.100	.212	1.00

Note. TIB: Time in Bed, TST: Total Sleep Time, SOL: Sleep Onset Latency, SE: Sleep Efficiency, WASO: Wake After Sleep Onset, *p>.05, **p<.01, ***p<.001