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**Early polysomnographic characteristics associated with neurocognitive  
development at 36 months of age**

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**Abbreviations:**

AS-Active Sleep;

BMI – Body Mass Index;

FSIQ - Full Scale intelligence quotient;

HAD - Hospital Anxiety and Depression scale;

IQ - intelligence quotient;

PIQ - performance intelligence quotient;

PSG- polysomnography recording

QS- Quiet Sleep

SD – Standard Deviation;

VIQ - verbal intelligence quotient;

WPPSI-III - Weschler Preschool and Primary Scale Intelligence test

## ABSTRACT

**Background.** Few studies on the relationship between sleep quantity and/or quality and cognition have been conducted among preschoolers from the healthy general population. We aimed at identifying, among 3-year-old children, early polysomnography (PSG) sleep factors associated with intelligence quotient (IQ) estimated using the Weschler Preschool and Primary Scale Intelligence-III test (WPPSI-III) and its indicators: full-scale (FISQ), verbal (VIQ), and performance (PIQ) intelligence quotients.

**Methods.** We included full-term children from the French birth-cohort AuBE with both PSG recording at term (M0) or 6 months (M6) and available WPPSI-III scores at 3 years. Sleep and arousal characteristics of these infants were evaluated during day and night sleep periods. Relationships between IQ scores and sleep parameters were estimated using models with child as repeated effect adjusted for time (night/day), maturation (M0/M6), tobacco exposure (yes/no), anxiety depressive scores during pregnancy, maternal age, duration of breastfeeding and child gender.

**Results.** A total of 118 PSG recordings were included, representing a total 78 unique children (38 with one PSG and 40 with 2 PSG). No correlations were found between night and day sleep durations at M0 or M6. Mean VIQ, PIQ, and FISQ scores were within normal ranges. In multivariate models, longer sleep duration, higher sleep efficiency during day were negatively associated with all IQ scores. More frequent arousals during night were associated with lower VIQ scores.

**Conclusion.** Early sleep characteristics such as night sleep fragmentation or longer naps could be associated with impaired cognitive function at 3 years of age.

### Keywords:

sleep; intelligence quotient; preschoolers; cohort study; arousal; infant

## 1. INTRODUCTION

Sleep is a highly dynamic development process, particularly in the first year of life. Multiple studies have found relationships between sleep and cognitive benefits in school-aged children [1-4], however, there have been fewer studies regarding the effects of sleep in infants on cognitive outcomes [5].

Two cross-sectional studies that included typically developing infants evaluated this relationship via questionnaires, sleep logs, and actigraphic recordings [6, 7]. The authors reported that greater sleep efficiency measured via sleep actigraphic data was positively correlated with mental development in 10-13 month-old infants [6, 7], and that greater number of movements or activity during sleep and a greater number of awakenings after sleep onset were negatively correlated with cognitive function [6]; in both studies there were no significant associations between parental sleep reports and any of the cognitive measures.

Longitudinal studies conducted by Bernier et al. found that a higher proportion of night sleep (with regard to total sleep) at 12-13 and 18 months of age predicted better executive functioning at 18, 26, and 48 months of age [8, 9]; these studies found no relationship between sleep duration at 12 months of age and general cognitive functioning at 48 months [8]. These results were independent of confounders such as socioeconomic status. Contrary to the latter studies, Sheridan et al. reported that the relationship observed between sleep disturbance at 12 and 18 months and lower intelligence quotient (IQ) scores at 5 years of age, was no longer statistically significant after adjusting on psychosocial adversity [10]. Recently, we evaluated the relationship between sleep data collected via questionnaires at birth, 6, 12, 18, and 24 months and the Weschler Preschool and Primary Scale Intelligence-III (WPPSI-III) scores at 3 years of age in 194 children from the French birth-cohort AuBE [11]. We found that night wakings at 6 months of age and frequent snoring at 18 months of age were negatively associated with performance IQ (PIQ) at 3 years of age. We also found a positive association between day/night sleep ratio at 12 months and PIQ. Conversely, in a longitudinal

study that included 1029 twins, Dionne et al. found that day/night sleep ratio at 6 and 18 months of age were negatively associated with language skills at 5 years of age [12]. However, the sleep data in all these longitudinal studies were only obtained from parental reports.

The objective of the present study was to identify, in 3-year-old children from the French birth-cohort AuBE, macro and microstructure sleep characteristics during day and night at term (M0) and 6 months of age (M6) associated with IQ estimated through WPPSI-III and its indicators: full-scale (FSIQ), verbal (VIQ) and performance (PIQ) and their sub-scale scores such as the general language composite score (GLC). Confounders such as the child's age in days and period at PSG recording (M0) /M6), maternal age at delivery, tobacco consumption during pregnancy, anxiety depressive score on questionnaire during pregnancy, socioeconomic level, child gender, and duration of breastfeeding were also taken into account.

## **2. METHODS**

### **2.1. Study design and questionnaires**

The Autonomic Baby Evaluation (AuBE) study was a prospective study to assess the relationship between autonomic and sleep maturation on psychometric development in a cohort of term and preterm newborns at 3 years of age. The study design has previously been published [13]. The AuBE study was conducted at the University Hospital of Saint-Etienne (France), a level III university maternity ward with neonatal intensive care units and 3,500 births annually. Infants were included in the study over a 24-month period from September 2009 to September 2011. Only healthy infants who were born with a term  $\geq 37$  weeks gestational age were included in this study (N=299). Pregnancy data was collected from mothers following births (parity, maternal age at delivery, maternal tobacco consumption or

nicotine substitutes during pregnancy, as well as the assessment of an anxiety and depression trends by the Hospital Anxiety Depression (HAD) self-administered questionnaire. The socioeconomic level of the mothers was coded as follows: 0 (no qualifications, unemployed, or manual), 1 (employed, manager). Child gender, gestational age, birth weight, and duration of breastfeeding (never,  $\leq 3$  months,  $> 3$  months) were also collected.

## **2.2. Polysomnograms**

24h-polysomnograms were performed following birth (usually the second day; M0) in the maternity unit and at 6 months (M6) at home and analyzed as previously described [14]. Briefly, the polysomnograph (Dreem<sup>®</sup>, Medatec, Bruxelles, Belgium) simultaneously recorded frontal, central and occipital leads (FP2, C4, O2, A1), two electrooculograms, 1 chin electromyogram and 1 electrocardiogram, chest and abdominal respiratory movements by inductance plethysmography, as well as noninvasive arterial oxygen saturation using an oximetry probe placed on the foot. Polysomnograms of newborn children were analyzed at 30-second intervals and classified as Quiet Sleep (QS), Active Sleep (AS), or Indeterminate Sleep (IS) according to Guilleminault and Souquet criteria [15]. Since we wanted to evaluate sleep maturation from birth to 6 months of age, we used the same criteria to score sleep stages at 6 months: QS for Non Rapid Eye Movement (NREM) Sleep and AS for Rapid Eye Movement (REM) sleep. Sleep stages were expressed as a percentage of total sleep time. Time awake represented the proportion of total recording time. Sleep efficiency was defined by dividing total sleep time by total recording time, multiplied by 100. Arousability is not a state but a continuous process from subcortical to cortical area; cortical arousal was scored if there was an occurrence of an abrupt change in EEG background frequency of at least 1 Hz for a minimum of 3 seconds, while at least two of the following changes occurred at the same time: 1) a large body movement detected by movement sensors or seen as an artifact movement in the somatic channels (ECG, EEG, respiratory parameters), 2) changes in heart

rate, at least 10% of baseline values; 3) changes in breathing pattern, frequency and/or amplitude, in QS, or increase in chin EMG tonus in AS [16]. The frequencies of arousal events were measured by dividing the total number of episodes by the total sleep time in minutes and multiplying by 60. Baseline sleep states that preceded arousals were established during 30-second time periods. At least 10 seconds of uninterrupted state was required between arousals. Awakening was defined as a cortical arousal, as defined above, lasting 1 minute or more and meeting the Anders, Emde and Parmelee criteria for wakefulness [17]. We compared the sleep and arousal results between 8:00 PM to 8:00 AM (night) and 8:00 AM to 8:00 PM (day).

### **2.3. Psychometric assessment**

One psychologist administered the WPPSI-III test to all children followed-up to 36 months of age (N=195) avoiding test administrator variability. Children were evaluated using the five subtests as recommended for their age band (30 to 47 months): Receptive Vocabulary, Block Design, Information, Object Assembly, and Picture Naming. The whole WPPSI-III test provided subtest and composite scores that represented intellectual functioning in verbal and performance cognitive domains (further named VIQ and PIQ, respectively), and a composite score that represented the child's general intellectual ability (i.e., Full Scale IQ or FSIQ). In addition an ancillary index score was calculated: the general language composite score (GLC).

### **2.4. Ethics**

The local research ethics committee approved the study. Written informed consent was obtained at enrolment for the parents. The study was registered in the International Clinical Trials Registry (ClinicalTrials.gov, ID NCT00951860).



## **2.5. Statistical analyses**

Only infants who had at least one available PSG recording at M0 or M6 and a WPPSI test at age 3 years of age were included in the current study. Descriptive analyses were performed using Chi-square and *t*-tests. Fisher's exact test was used when needed. Pearson correlations were estimated between sleep characteristics. Multivariable analyses were performed to estimate relationships between IQ scores and sleep characteristics. Thus, the response variables were the variables of interest, i.e. the IQ scores (VIQ, PIQ, FISQ, GLC). The explicative variables were time (night/day), maturation (M0/M6), tobacco exposure (yes/no), HAD, maternal age, breastfeeding duration, child gender. Models were performed considering in addition as explicative variable one sleep parameter at a time (Total Sleep Time – TST, Sleep Efficiency – ES, AS%, QS%, Arousals/h, Arousals in AS/h and in QS/h) and including two or more of them when correlations between sleep characteristics were observed. Generalized linear models were constructed, with child as repeated effect. Statistical significance was defined with a level of  $p < 0.05$ . All analyses were performed using SAS software (version 9.4, SAS Institute, Cary, NC, USA).

## **3. RESULTS**

### **3.1. Population characteristics**

A total of 118 PSG recordings were included in the current study representing a total of 78 unique children (38 children with one PSG recording and 40 with 2 PSG recordings).

Included children (N=78) compared to the initial AuBE sample (N=221) were breastfed for a longer period (36% vs. 21% were breastfed for more than 3 months,  $p=0.02$ ), had a greater gestational age (mean  $\pm$  SD:  $40\pm 1$  vs.  $39\pm 3$  weeks,  $p=0.0005$ ), had lower mean FSIQ ( $95 \pm 13$  vs.  $102 \pm 12$ ,  $p=0.0007$ ), VIQ ( $103 \pm 16$  vs.  $108 \pm 13$ ,  $p=0.01$ ), PIQ ( $89 \pm 10$  vs.  $94 \pm 13$ ,  $p=0.0009$ ) but similar GLC ( $104 \pm 15$  vs.  $108 \pm 13$ ,  $p=0.06$ ). No difference in gender,

maternal age, maternal parity, maternal professional activity, maternal anxiety or depressive evaluation (HAD scores) were observed. Characteristics of the included population are presented in Table 1.

### **3.2. Sleep characteristics**

Table 2 presents the PSG characteristics according to the time of recording. There was no significant correlation between night and day sleep durations at M0 or M6 ( $p > 0.25$ ). As already published before [14], compared to day sleep, night sleep was significantly longer and more efficient at both M0, but especially at M6 at which time there was also a significantly greater proportion of quiet sleep (QS) and a significantly smaller proportion of active sleep (AS). There were also significantly more arousals in AS during day sleep at M0 and during night sleep at M6. Table 3 presents correlations between main sleep characteristics. At M0, night sleep duration was significantly correlated with night and day sleep efficiency and inversely correlated with night and day arousals (MA). Night sleep efficiency (SE) was inversely correlated with night and day MA. Day sleep had also the same effects on SE and MA but only on day sleep periods. There was a positive correlation between MA during night and day sleep. At M6, the effects were less marked with a positive correlation between sleep duration and sleep efficiency in both night than day sleep periods.

### **3.3. Multivariable analysis**

Longer day sleep duration was negatively associated with FSIQ score at 36 months, especially in verbal performances (VIQ and GLC), and higher SE during day sleep was associated with lower score for all IQ scales. More frequent MA during night was associated with lower VIQ and GLC scores. However, more frequent MA during day were also associated with higher verbal scores (VIQ and GLC scores) and with a tendency to higher FISQ (Table 4). When TST and SE were included together (with or without MA),

associations between day sleep duration, day SE and FSIQ were no longer significant suggesting that they in fact predict the same phenomenon while the other initially observed associations remained (data not shown/supplemental table) suggesting independent predictions.

## 4. DISCUSSION

### 4.1. Night sleep fragmentation and neurocognitive development at 36 months

We report for the first time an association between night sleep fragmentation, objectively measured by polysomnography in the early months of life and lower verbal performance scores at 36 months of age. These results are in agreement with other studies that used objective sleep evaluation such as actigraphy [6, 7], but also with a previous study that we reported which used parental night awakening reports at 6 months [11]. Other authors reported that fragmented sleep has been associated with memory difficulties and poorer academic achievement in older children[18] probably due to lower sleep efficiency tracking throughout childhood [19].

Numerous mechanisms could be implicated in the relationship between sleep quality and cognitive function.

Sleep is described as a powerful aid in memory consolidation [20]; performance obtained during cued-recall of verbal (word-pairs) or visuospatial (pair of cards) material are better after post learning sleep than after a similar period spent awake in adults [21-23]. A preserved sleep organization, characterized by uninterrupted cycles of slow wave (SWS) and paradoxical sleep (PS), seems to be a necessary frame for effective sleep-dependent memory consolidation processes [24]. The experimental disturbance of sleep architecture [25] or the disorganization of sleep cycles observed during elderly [26, 27] are detrimental to verbal memory consolidation. During this cyclic succession of SWS and PS periods, a complex dialogue between the hippocampus and the neocortex leads to memory trace consolidation [28].

As observed in adults, sleep seems to have also a beneficial effect on the consolidation of several episodic learnings in infants [29] and in children [23, 30, 31]. Contrary to adults, no sleep consolidation effect has been found for procedural memory in children [23, 32]. Thus, when sleep is fragmented or disturbed, sleep dependent memory consolidation processes are also disturbed in children, as shown in children with attention-deficit/hyperactivity disorder [31] or with sleep-disordered breathing (SDB) [32]. Children with SDB exhibited lower performances than control children during both learning and recall sessions of a story recall test [32], greater attention deficit, reduced IQ scores and low school performance [33].

Unfortunately, due to the AuBe study schedule, we did not have thermistors or nasal canulae to evaluate the presence of obstructive breathing potentially responsible for respiratory-related arousals. Indeed, using over-night PSG in 8-month old infants, Montgomery-Downs et al. showed that snore-related arousals in the absence of apneas or hypopneas, are negatively correlated with mental scores [34]. In the previous study that we reported, frequent snoring signaled by parents at 18 months was associated with lower PIQ and Block design scores at 3 years of age [11].

However, the exact mechanisms relying sleep and cognition still remain to be understood and in particular, why early sleep characteristics could impact cognitive development during childhood. For some authors, it is possible that low sleep quality during infancy could predict low sleep efficiency during childhood, and thus low cognitive function [35]. Moreover, cognitive acquisitions could be significantly impeded by chronically altered sleep duration or quality throughout childhood. Another possibility would be that there is a critical period in early childhood where the lack of sleep quality or quantity could be particularly detrimental to various aspects of brain development, even if sleep duration normalizes later on [35]. This later hypothesis, studied in preterm children and children with obstructive sleep apnea

syndrome [36], is it in accordance with the Barker hypothesis, now called the Developmental Origins of Health and Disease (DOHaD) that linked several exposures during development and latter health troubles [37].

#### **4.2. Sleep duration/quality during the day and neurocognitive development at 36 months**

In the present study, we also found that longer sleep duration and higher sleep efficiency during daytime were negatively associated with all IQ scales. There are controversial results in favor of the benefits of napping for learning and memory, especially among younger children [38].

Some authors suggest an important role for daytime sleep to consolidate performance memory during the first years of life.

Gomez and al. showed that 15-month-old infants who napped were able to abstract the general grammatical pattern of a briefly presented artificial language [39] and to remember the general grammatical pattern 24h later, while those who did not nap showed no evidence of remembering anything [40]. More recently Giganti et al. reported that nap benefits in explicit memory consolidation among children aged 3 to 6 years but not in implicit perceptual learning (naming pictures) [41]. Kurdziel et al. reported that naps help in memorization and learning especially regarding visuospatial task (Memory game) among preschoolers aged between 36 and 67 months, with long-term benefits on memory consolidation and benefit of the nap relative to wake greatest for children who napped habitually [42]. Even more, when considering naturally occurring sleep, Lukowski et al. showed that nap duration was positively associated with both immediate imitation encoding, particularly encoding in a correct temporal order and with delayed recall in generalization of temporal order information

in 10 months infants, while night-time sleep duration was not associated with immediate or delayed recalls [43].

Inversely for other authors, day sleep could be a negative factor or marker for cognitive function.

The progressive disappearance of nap in favor of night sleep (called sleep consolidation) could be seen as a global marker of brain maturity [6,7]. Bernier et al. showed among 65 children that an increase % of sleep during night related to day at 12 months of age was associated to a better executive functioning (Matrix Reasoning subscale from the WPPSI III) at 4 years of age, taking into account previous socioeconomic status and prior cognitive functioning measured at 1 and 2 years of age [8]. While Dione et al. showed, among 1029 twins, that more day sleep related to night at 6 and 18 months of age was negative associated with language skills at 30 and 60 months of age [12].

Excessive long nap duration may also interfere with children's exploration of their physical and social environment and thereby possibly impede their optimal development [44].

However, the most consistent finding in literature was a negative association between day and night sleep. More daytime sleep is associated with later onset, shorter duration and poorer quality of night sleep, with strongest evidence beyond the age of 2 years [38]. However, in the present study, we did not find a correlation between night and day sleep duration.

Discrepancies between the positive and negative effects of nap on cognition could also be explained by the differences in the performed tests but also the variables considered for adjustment. In our study all cognitive functions were impaired. Day sleep duration affected more specifically verbal cognition although day sleep efficiency influenced the performance quotient. Another important factor could be the changing value of napping over time. The present study refers to the first 6 months of life, as in the study reported by Dione et al. [12]; at this age, nap has more AS and less QS than later in the life.

Most studies reported the effects of nap duration on cognitive function and development. How could we explain the negative effect of early nap sleep efficiency on cognition?

Indeed, we found a positive association between day sleep quality (high sleep efficiency and fewer arousals) and lower verbal and full IQ. The first possibility is an incidence on sleep duration. In both night and day sleep, we found a positive correlation between sleep duration and sleep efficiency. A better sleep quality is related to longer sleep duration. Our results showed that, indeed, when TST and SE predict the same outcome they in fact represent the same phenomenon and are not independent while arousals, whatever the model, is an independent predictor of IQs. Complex mechanisms relate external and internal stimulations to arousals. Arousal process do not always proceed to completion (full awakenings) [45, 46], for that it does not represent the same measure than awakenings and sleep efficiency.

As a reflect of general status of arousability, we found a positive correlation between the frequency of arousals during the night and during the day. Frequent arousals could have deleterious effect of night sleep efficiency. Indeed, we showed that higher sleep efficiency during the night was negatively correlated with the arousals during the night and the day. These results were only found at term and not at 6 months. As shown in our previous work, maturation of spontaneous arousals from sleep differed between day and night sleep [14]. With age, arousals especially in AS/REM increased during night sleep but decreased during the day. Further studies should be conducted to better understand the underlying mechanisms of arousals and their maturation.

### **4.3. Limitations**

First, the present study included a small number of subjects. This may lead to lack of power to detect an effect (i.e. effect of night sleep duration [44, 47], sleep stages [35], gender..).



Furthermore, from the first months of life girls sleep longer than boys [48] and impairment in sleep duration and quality could have different effect according to gender [49]. Secondly, we did not have thermistor or nasal canula to detect sleep disorders breathing; we did not use more sophisticated markers of sleep fragmentation such as Cycling Alternating Patterns [50]. Third, due to the recruitment method, based on voluntary participation in the study, and to the attrition during follow-up, there is over-representation of middle-high working class mothers, compared to the national population [51], limiting the generalization of the results. Four, these were secondary analyses and only partial information was available regarding some potential risk factors. In addition, no information on parental origins or ethnic group was collected, and no information on maternal IQ or educational level were available that was approximated via work category. Finally, the maturation of central nervous system structures such as hypothalamus or the neurotransmitter system underlies both cognitive development and the regulation of sleep/wake cycles [50]. However, the exact mechanisms relying sleep and cognition still remain to be understood.

## **5. CONCLUSION**

For the first time with objective sleep data obtained by polysomnography recordings in early age, we found that sleep characteristics such as night sleep fragmentation or day sleep duration/quality could be associated with impaired cognitive function at 3 years of age. Further studies are needed to confirm these results in larger samples of children from the general healthy population and to examine whether these modifications track throughout childhood. This is important to understand as sleep is one early life factor that can be targeted for intervention to optimize early development.

**Table 1. Maternal and children' characteristics**

	% (N) or Mean ( $\pm$ SD)
<b>Maternal characteristics</b>	
Socioeconomic level	
unemployed/manual worker	24.4 (19)
employed/manager	75.6 (59)
Age at delivery	31 ( $\pm$ 4)
Parity	
1st child	38.5 (30)
2nd child	37.1 (29)
$\geq$ 3rd child	24.4 (19)
Tobacco consumption during pregnancy	30.8 (24)
Depressive score (HAD $\geq$ 8)	5.1 (4)
Anxiety score (HAD $\geq$ 8)	35.9 (28)
<b>Child characteristics</b>	
Gender (Girls)	47.4 (37)
Gestational age (WA)	39.7 ( $\pm$ 1)
Birth weight (g)	3263 ( $\pm$ 388)
Breastfeeding duration	
Never	33.3 (26)
$\leq$ 3 months	30.8 (24)
>3 months	35.9 (28)
IQ scores	
FSIQ	95 ( $\pm$ 13)
PIQ	89 ( $\pm$ 10)
VIQ	103 ( $\pm$ 16)
GLC	104 ( $\pm$ 15)

**Table 2.** Polysomnographic data: night and day sleep characteristics of the infants at M0 and M6

Mean (SD)	M0			M6		
	NIGHT	DAY	p-value	NIGHT	DAY	p-value
TST	417 (116)	248 (79)	<10 <sup>-4</sup>	534 (128)	94 (63)	<10 <sup>-4</sup>
SE	57.7 (14.7)	51.5 (16.2)	0.01	83.4 (13)	23.5 (14)	<10 <sup>-4</sup>
QS%	49.8 (16.6)	48.8 (15.7)	0.16	57.9 (9.5)	67.3 (26.3)	0.003
AS%	49.2 (15.8)	46.3 (18.9)	0.84	41.6 (9.3)	28.2 (23.6)	0.03
MA	20 (8.1)	33 (19.9)	<10 <sup>-4</sup>	14.9 (6.0)	12.8 (8.4)	0.34
MA-AS	30.4 (14.1)	36.1 (14.4)	0.06	25.1 (9.7)	17.7 (13.4)	0.003
MA-QS*	10.7 (0 - 49)	12.2 (0 - 66)	0.30	6.7 (0.5 - 35.7)	4.5 (0 - 51.4)	0.02

M0: term; M6: 6 months; TST: total sleep time; SE: sleep efficiency; AS%: active sleep; QS%: quiet sleep; MA: micro-arousals; MA-AS: micro-arousals in Active Sleep; MA-QS: micro-arousals in Quiet Sleep. MA-QS had non-Gaussian distribution and was summarized by median and range (minimum-maximum).

**Table 3.** Correlations between sleep characteristics

		M0						M6					
		TST		SE		MA		TST		SE		MA	
		Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day
TST	Night	1.00	0.13	<b>0.89***</b>	<b>0.35***</b>	<b>-0.71***</b>	<b>-0.66***</b>	1.00	0.10	<b>0.57***</b>	0.22	0.12	0.07
	Day		1.00	0.05	<b>0.65***</b>	-0.02	-0.08		1.00	0.10	<b>0.79***</b>	-0.05	0.25
SE	Night			1.00	0.18	<b>-0.65***</b>	<b>-0.66***</b>			1.00	0.08	0.04	0.15
	Day				1.00	-0.26	<b>-0.27*</b>				1.00	0.16	0.29
MA	Night					1.00	<b>0.83***</b>					1.00	0.24
	Day						1.00						1.00

\* p<0.05, \*\*p<0.01, \*\*\*p<0.001

M0: term; M6: 6 months; TST: total sleep time; SE: sleep efficiency; MA: micro-arousals

**Table 4.** Multivariable models coefficients and p-values with IQ scores as response and each night- and day-sleep characteristic (TST, SE, AS%, QS%, MA, MA-AS or MA-QS) as explicative variables. Each model additionally accounted for the child’s age in days and period at EEG recording (M0/M6) and was adjusted on maternal age at delivery, tobacco consumption during pregnancy, anxiety score on HAD questionnaire during pregnancy, socioeconomic level, child’s gender, gestational age and breastfeeding duration.

	FISQ		PIQ		VIQ		GLC	
	Beta (95%CI)	p-value	Beta (95%CI)	p-value	Beta (95%CI)	p-value	Beta (95%CI)	p-value
TST								
Night	0.006 (-0.01 ; 0.02)	0.49	0.003 (-0.01 ; 0.02)	0.64	0.006 (-0.02 ; 0.03)	0.57	0.005 (-0.02 ; 0.03)	0.66
Day	<b>-0.03 (-0.05 ; -0.001)</b>	<b>0.05</b>	-0.01 (-0.03 ; 0.01)	0.36	<b>-0.04 (-0.07 ; -0.003)</b>	<b>0.03</b>	<b>-0.04 (-0.07 ; -0.01)</b>	<b>0.01</b>
SE								
Night	0.08 (-0.08 ; 0.24)	0.33	0.05 (-0.06 ; 0.16)	0.39	0.07 (-0.14 ; 0.29)	0.49	0.08 (-0.14 ; 0.29)	0.49
Day	<b>-0.14 (-0.26 ; -0.02)</b>	<b>0.02</b>	<b>-0.13 (-0.22 ; -0.04)</b>	<b>0.005</b>	-0.12 (-0.29 ; 0.04)	0.13	<b>-0.20 (-0.35 ; -0.05)</b>	<b>0.01</b>
AS%								
Night	-0.14 (-0.36 ; 0.08)	0.21	-0.03 (-0.19 ; 0.13)	0.72	-0.19 (-0.45 ; 0.06)	0.14	-0.19 (-0.46 ; 0.08)	0.17
Day	0.06 (-0.09 ; 0.21)	0.44	-0.009 (-0.13 ; 0.11)	0.88	0.09 (-0.09 ; 0.273)	0.31	0.04 (-0.15 ; 0.23)	0.66
QS%								
Night	0.06 (-0.13 ; 0.24)	0.55	-0.02 (-0.16 ; 0.13)	0.81	0.11 (-0.12 ; 0.33)	0.36	0.11 (-0.13 ; 0.35)	0.36
Day	0.02 (-0.08 ; 0.12)	0.69	0.06 (-0.03 ; 0.15)	0.21	-0.008 (-0.13 ; 0.12)	0.91	0.02 (-0.12 ; 0.16)	0.76
MA								
Night	-0.39 (-0.80 ; 0.02)	0.06	-0.16 (-0.54 ; 0.22)	0.42	<b>-0.49 (-0.93 ; -0.05)</b>	<b>0.03</b>	<b>-0.60 (-1.05 ; -0.15)</b>	<b>0.01</b>
Day	<b>0.18 (-0.003 ; 0.37)</b>	<b>0.05</b>	0.07 (-0.10 ; 0.24)	0.43	<b>0.24 (0.03 ; 0.44)</b>	<b>0.02</b>	<b>0.27 (0.03 ; 0.51)</b>	<b>0.03</b>
MA-AS								
Night	-0.09 (-0.30 ; 0.12)	0.39	-0.07 (-0.27 ; 0.12)	0.45	-0.08 (-0.33 ; 0.17)	0.52	-0.13 (-0.38 ; 0.12)	0.30
Day	0.05 (-0.12 ; 0.23)	0.57	0.04 (-0.14 ; 0.23)	0.64	0.04 (-0.14 ; 0.23)	0.65	0.08 (-0.15 ; 0.31)	0.48
MA-QS								
Night	0.57 (-1.13 ; 2.26)	0.51	0.23 (-1.20 ; 1.67)	0.75	0.95 (-1.19 ; 3.09)	0.38	1.22 (-0.92 ; 3.35)	0.26
Day	-0.34 (-1.66 ; 0.98)	0.61	-0.22 (-1.54 ; 1.09)	0.74	-0.62 (-2.13 ; 0.89)	0.42	-0.95 (-2.59 ; 0.68)	0.25

TST: total sleep time; SE: sleep efficiency; AS%: active sleep; QS%: quiet sleep; MA: micro-arousals; MA-AS: micro-arousals in Active Sleep; MA-QS: micro-arousals in Quiet Sleep. MA-QS had non-Gaussian distribution and was log base 2 transformed.

**Suppl. Table.** Multivariable models coefficients and p-values with IQ scores as response. Model included two or three correlated night- and day-sleep characteristic (TST, SE, MA,) as explicative variables. Each model additionally accounted for the child's age in days and period at EEG recording (M0/M6) and was adjusted on maternal age at delivery, tobacco consumption during pregnancy, anxiety score on HAD questionnaire during pregnancy, socioeconomic level, child's gender, gestational age and breastfeeding duration.

	FISQ		PIQ		VIQ		GLC	
	Beta (95%IC)	p-value	Beta (95%IC)	p-value	Beta (95%IC)	p-value	Beta (95%IC)	p-value
Model								
TST								
Night	0.004 (-0.02 ; 0.03)	0.74	0.01 (-0.02 ; 0.04)	0.42	-0.0002 (-0.03 ; 0.03)	0.99	0.01 (-0.03 ; 0.04)	0.72
Day	-0.01 (-0.05 ; 0.03)	0.58	0.02 (-0.01 ; 0.05)	0.26	-0.03 (-0.08 ; 0.01)	0.17	-0.02 (-0.06 ; 0.03)	0.47
SE								
Night	0.05 (-0.19 ; 0.29)	0.67	-0.02 (-0.24 ; 0.20)	0.86	0.08 (-0.21 ; 0.37)	0.59	0.04 (-0.28 ; 0.35)	0.82
Day	-0.11 (-0.31 ; 0.08)	0.25	<b>-0.20 (-0.36 ; -0.04)</b>	<b>0.01</b>	-0.02 (-0.26 ; 0.22)	0.85	-0.16 (-0.42 ; 0.10)	0.22
Model								
TST								
Night	0.012 (-0.01 ; 0.03)	0.22	0.01 (-0.01 ; 0.02)	0.46	0.0139 (-0.01 ; 0.04)	0.27	0.01 (-0.02 ; 0.04)	0.41
Day	<b>-0.03 (-0.06 ; -0.01)</b>	<b>0.01</b>	-0.01 (-0.03 ; 0.01)	0.26	<b>-0.04 (-0.07 ; -0.01)</b>	<b>0.01</b>	<b>-0.05 (-0.07 ; -0.02)</b>	<b>0.001</b>
MA								
Night	<b>-0.39 (-0.77 ; -0.02)</b>	<b>0.04</b>	-0.16 (-0.52 ; 0.21)	0.40	<b>-0.5 (-0.91 ; -0.1)</b>	<b>0.02</b>	<b>-0.62 (-1.02 ; -0.23)</b>	<b>0.002</b>
Day	<b>0.22 (0.02 ; 0.42)</b>	<b>0.03</b>	0.09 (-0.10 ; 0.27)	0.35	<b>0.29 (0.07 ; 0.5)</b>	<b>0.01</b>	<b>0.31 (0.06 ; 0.57)</b>	<b>0.01</b>
Model								
SE								
Night	0.12 (-0.05 ; 0.30)	0.17	0.06 (-0.06 ; 0.19)	0.34	0.13 (-0.11 ; 0.37)	0.28	0.12 (-0.12 ; 0.35)	0.34

Day	<b>-0.15 (-0.27 ; -0.04)</b>	<b>0.01</b>	<b>-0.14 (-0.24 ; -0.04)</b>	<b>0.005</b>	-0.14 (-0.29 ; 0.02)	0.08	<b>-0.23 (-0.38 ; -0.08)</b>	<b>0.003</b>
MA								
Night	<b>-0.39 (-0.77 ; 0.003)</b>	<b>0.05</b>	-0.17 (-0.56 ; 0.22)	0.40	<b>-0.48 (-0.90 ; -0.07)</b>	<b>0.02</b>	<b>-0.62 (-1.0 ; -0.18)</b>	<b>0.005</b>
Day	<b>0.21 (0.02 ; 0.40)</b>	<b>0.03</b>	0.08 (-0.1 ; 0.26)	0.39	<b>0.27 (0.05 ; 0.48)</b>	<b>0.02</b>	<b>0.29 (0.04 ; 0.53)</b>	<b>0.02</b>
Model								
TST								
Night	0.01 (-0.02 ; 0.03)	0.52	0.01 (-0.01 ; 0.04)	0.35	0.006 (-0.02 ; 0.03)	0.57	0.01 (-0.02 ; 0.04)	0.56
Day	-0.02 (-0.05 ; 0.02)	0.40	0.02 (-0.02 ; 0.05)	0.33	-0.04 (-0.07 ; -0.003)	0.03	-0.02 (-0.07 ; 0.02)	0.28
SE								
Night	0.08 (-0.15 ; 0.32)	0.49	-0.01 (-0.23 ; 0.2)	0.91	0.12 (-0.17 ; 0.41)	0.41	0.07 (-0.24 ; 0.38)	0.67
Day	-0.11 (-0.31 ; 0.08)	0.24	<b>-0.21 (-0.37 ; -0.05)</b>	<b>0.01</b>	-0.02 (-0.26 ; 0.22)	0.87	-0.17 (-0.42 ; 0.09)	0.20
MA								
Night	<b>-0.39 (-0.76 ; -0.01)</b>	<b>0.05</b>	-0.16 (-0.54 ; 0.23)	0.43	<b>-0.49 (-0.89 ; -0.09)</b>	<b>0.02</b>	<b>-0.62 (-1.02 ; -0.21)</b>	<b>0.003</b>
Day	<b>0.23 (0.03 ; 0.42)</b>	<b>0.03</b>	0.08 (-0.11 ; 0.27)	0.43	<b>0.30 (0.07 ; 0.52)</b>	<b>0.01</b>	<b>0.31 (0.06 ; 0.56)</b>	<b>0.01</b>



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