http://dx.doi.org/10.5665/sleep.3496

Sleep Cyclic Alternating Pattern in Otherwise Healthy Overweight School-Age Children

Rodrigo Chamorro, MS, PhD[1]; Raffaele Ferri, MD[2]; Cecilia Algarín, MD[1]; Marcelo Garrido, MSc[1]; Betsy Lozoff, MD, MSc[3]; Patricio Peirano, MD, PhD[1]

[1]Sleep Laboratory, Institute of Nutrition and Food Technology (INTA), University of Chile, Santiago, Chile; [2]Sleep Research Center, Department of Neurology IC, OASI Research Institute (IRCCS), Troina, Italy; [3]Center for Human Growth and Development and Department of Pediatrics and Communicable Diseases, University of Michigan, Ann Arbor, MI

Study Objectives: To compare sleep microstructure (cyclic alternating pattern, CAP) characteristics in otherwise healthy overweight (OW) and normal weight (NW) children

Design: Polysomnographic cross-sectional study

Setting: Sleep laboratory

Participants: Fifty-eight (26 NW and 32 OW) 10-year-old children

Interventions: N/A

Measurements and Results: Participants were part of a longitudinal study beginning in infancy and free of sleep disorders. Groups were based on body-mass index (BMI) z-score. From polysomnographic overnight recordings, sleep-waking states were scored according to international criteria. CAP analysis was performed visually during NREM sleep.

Conventional sleep parameters were similar between groups. BMI was positively related to CAP rate and CAP sequences but inversely related to CAP B phase duration. Differences between groups were confined to slow-wave sleep (SWS), with OW children showing higher CAP rate, CAP cycles, and CAP A1 number and index and shorter CAP cycles and B phase duration. They also showed more CAP class intervals shorter than 30 s, and a suggestive trend for fewer intervals longer than 30 s.

Conclusions: Cyclic alternating pattern characteristics in children related to nutritional status and were altered in overweight subjects during slow-wave sleep. We suggest that the more frequent oscillatory pattern of electroencephalographic slow activity in overweight subjects might reflect less stable slow-wave sleep episodes.

Keywords: Cyclic alternating pattern, sleep microstructure, overweight, body-mass index, children

Citation: Chamorro R; Ferri R; Algarin C; Garrido M; Lozoff B; Peirano P. Sleep cyclic alternating pattern in otherwise healthy overweight school-age children. *SLEEP* 2014;37(3):557-560.

INTRODUCTION

Chronic and moderate sleep debt is an increasingly common feature across societies and age groups.[1,2] There is mounting evidence that nighttime sleep patterns relate to body weight in pediatric groups. Epidemiological studies in children consistently show an inverse relation between sleep duration and body mass index (BMI).[3-7] Polysomnographic (PSG) studies show decreased sleep amount, sleep efficiency, and REM sleep in overweight (OW) subjects.[8-11] However, few studies have assessed sleep patterns within the sleep-obesity frame in the absence of apparent sleep alterations.

Sleep cyclic alternating pattern (CAP) is a physiologic oscillatory phenomenon occurring during NREM sleep.[12] The relevance of CAP for pediatric sleep is highlighted by age-related changes and alterations in several health conditions.[13-15] Even in the absence of disrupted conventional sleep organization, CAP is sensitive in identifying different patterns of stability within NREM sleep[16,17] but has not been investigated in otherwise healthy OW children. We aimed to fill this gap by comparing CAP patterns in otherwise healthy OW and normal weight (NW) 10-year-old children. We predicted that CAP features would indicate higher instability of NREM sleep episodes in OW children.

Submitted for publication June, 2013
Submitted in final revised form September, 2013
Accepted for publication October, 2013

Address correspondence to: Patricio Peirano, MD, PhD, Sleep Laboratory, INTA, University of Chile, Av. El Líbano 5524 – P.O. Box 138-11, Santiago, Chile; Tel: +56 2 2978 1447; Fax: +56 2 2221 4030; E-mail: ppeirano@inta.uchile.cl

METHODS

Participants

As part of the assessment at 10 years of age in an ongoing follow-up study of iron-deficiency anemia in infancy,[18,19] we compared CAP patterns during NREM sleep in otherwise healthy children: 32 OW and 26 NW subjects. Parents provided signed informed consent and children signed informed assent. Both the original infant study and follow-up protocols were approved by the Institutional Review Boards of the Institute of Nutrition and Food Technology (INTA), University of Chile, Santiago, and the University of Michigan, Ann Arbor. All children were healthy and not taking any medications at the time of PSG. The distribution of children with and without iron-deficiency anemia in infancy was similar in both groups, as was also the case for several family characteristics and background variables in infancy and childhood (see Table S1, supplemental material). By design, groups differed in anthropometric variables (weight, height, and BMI).

PSG Recordings

Full details of the set-up and data processing have been described previously.[19] Briefly, children underwent an overnight PSG evaluation following the individual's sleep schedule. Weight and height were measured before the PSG

recording, and BMI was calculated (weight [kg] / height [m^2]). Nutritional classification was done according to age- and sex- BMI z-score following international criteria.[20] PSG montage included 6 EEG channels (F3, F4, C3, C4, O1, O2 referred to the contralateral earlobe), left and right electro-oculogram, chin and leg electromyograms, electrocardiogram, nasal pressure and thermistor, thoracic and abdominal respiratory efforts, peripheral oxygen saturation, and snoring and position sensors. All recordings continued until spontaneous awakening the next morning. Sleep signals were sampled at 200 Hz and stored in European data format[21] for further analysis. Sleep was subdivided into 30-s epochs, and sleep stages were scored according to Rechtschaffen and Kales[22] using the sleep analysis software Hypnolab 1.2 (SWS Soft, Italy). After automated detection of apnea/hypopnea events, visual editing of the whole recording was performed to add, confirm, or reject respiratory events before computing a final result.[23] Subjects with an obstructive apnea-hypopnea index (OAHI) ≥ 1.5 were not included. Sleep measures were processed without knowledge of OW or NW status. The duration of the diurnal waking episode was calculated from the child's wake-up time as reported by the mother and the sleep-onset time as determined by PSG.

CAP Analysis

Visual CAP detection and analysis was conducted during NREM sleep stage 1 (S1), stage 2 (S2), and slow-wave sleep (SWS, or NREM sleep stages 3 and 4) using the software HypnoLab (SWS Soft, Italy, v1.2.).[24] CAP cycles are composed of a phase A and the following phase B. CAP A phase is characterized by a transitory and abrupt change in amplitude (and often frequency) of the background EEG activity and divided into 3 subtypes (A1, A2, and A3) based on frequency and/or amplitude EEG criteria.[25] CAP B phase represents the return to background EEG activity and is defined as the time interval between two A phases.[25] Recurrent CAP cycles throughout NREM sleep constitute CAP sequences (succession of CAP cycles).[12,25]

Statistics

For the whole sample, the relation between CAP and nutritional parameters was evaluated by bivariate Pearson correlation. Significant associations between relevant individual/family background variables and CAP parameters were found only for birth weight and gestational age ($P < 0.05$). Partial correlation (controlling for age, sex, iron status in infancy, diurnal waking duration, birth weight, and gestational age) was used to test relations between CAP and nutritional parameters. Between-group differences in sleep and CAP parameters were tested using Student independent t-test or Mann-Whitney U-test, pending on variable distribution. One-way ANOVA was used to compare CAP parameters between NREM sleep stages, with Dunnett-T3 post hoc test. For CAP interval class distribution, the analysis was done after normalizing the individual interval distribution, i.e., calculating the individual percentage of each interval (5-s duration) class for each subject relative to total individual count.[26] The Student independent t-test was used to compare each interval class between NW and OW groups. Statistical analyses used SPSS v.15.0 (Chicago, IL), with statistical significance set at α level ≤ 0.05.

RESULTS

Conventional sleep patterns were similar between groups (Table S2, supplemental material). Both groups showed that (a) total CAP rate was higher in SWS (S1 < S2 < SWS; $P < 0.0001$), and CAP time and CAP number were higher in S2 (S2 > SWS > S1, $P < 0.0001$; see Table S3, supplemental material); and (b) CAP A1, A2, and A3 subtype indexes were higher in SWS, S2, and S1, respectively (all P values < 0.0001; see Table S3). In OW subjects, CAP cycle duration (S1 > S2 > SWS, $P < 0.01$) and B phase duration (S1 and S2 > SWS, $P < 0.001$) presented a decreasing trend from S1 to SWS. In NW subjects these CAP patterns were similar in all NREM sleep stages.

CAP time and CAP rate showed significant associations with BMI z-score (see Table S4, supplemental material). CAP A phases in sequence or isolated had direct or inverse relations with BMI z-score, respectively (see Table S4). During SWS, there were direct relations between BMI and CAP rate ($r = 0.41$, $P < 0.002$), CAP number ($r = 0.41$, $P < 0.003$), CAP time ($r = 0.40$, $P < 0.003$), CAP A1 number ($r = 0.39$, $P < 0.004$) and index ($r = 0.36$, $P < 0.009$), and CAP sequences duration ($r = 0.41$, $P < 0.002$). Between group differences in CAP parameters were mainly observed during SWS (see Table S3), with OW children presenting higher CAP rate ($P < 0.04$) and number (suggestive trend, $P < 0.07$), shorter duration of CAP cycles ($P < 0.01$), and a suggestive trend for higher CAP time and shorter B phase duration ($P < 0.07$). Also during SWS, CAP A1 number and index were higher in OW children (P values < 0.03; see Table S3). In both groups, CAP interval duration prevailed in the range of 15-45 s for S1 and S2 and 15-35 s for SWS. However, during SWS, OW children showed more intervals in the range < 30 s (in particular at 15 and 25 s), with a suggestive trend for fewer intervals > 35 s, reaching significance at 40 and 100 s (see Figure 1).

DISCUSSION

In this study of sleep microstructure characteristics in otherwise healthy OW children, differences between groups were mostly apparent during SWS and not during NREM sleep as a whole. During SWS, OW children had higher CAP rate, CAP number, and CAP A1 index, compared with NW children, and shorter CAP cycles (mainly due to a reduced B phase duration) and a modified distribution of CAP interval duration. Some CAP features (CAP rate, CAP time, and CAP sequences) related to BMI across the full range. These findings indicate that (a) CAP features relate to nutritional parameters in 10-year-old children, regardless of OW or NW, and (b) CAP differences between OW and NW groups suggest more frequent EEG oscillations during SWS in OW children.

CAP organization in children and adolescents is modified by several health conditions.[17] Because children in our study were free from pathologies that could modify CAP, it is unlikely that such factors accounted for the findings. Differences between our results and others studies could reflect the influence of age, sex and/or demographic characteristics. In our study, the age range was narrow, and age and sex distribution were similar across groups. The CAP rate of 42.2% for NREM sleep reported here is in between the rates of 34.1% and 62.1% already published at this age.[27] However, the higher CAP

rate in one study[27] appears largely influenced by CAP rate during SWS (almost 90%). In our study, CAP cycles and CAP time as a function of NREM stages showed the same trend reported by Bruni et al.[28] Finally, given that the CAP rate for NREM sleep of 43.3% reported in a sample composed mostly of adolescents[29] was similar to the 42.2% we observed and the dissipation of sleep pressure is stable throughout adolescence,[30] it is tempting to argue that the CAP rate for NREM sleep may remain stable during the second decade of life.

In a previous report, CAP cycle and B phase durations were similar in all NREM stages, whereas phase A duration was longer during SWS than S1 and S2.[28] In our study, these duration patterns were observed only in the NW group; CAP cycle duration was shorter in SWS relative to S1 and S2 in the OW group. This shorter CAP cycle duration in SWS due to reduced length of B phase could suggest more unstable SWS episodes and fragmented slow wave EEG activity in OW subjects. The interruption of the ongoing slow wave EEG activity during SWS in sleep terrors patients has been interpreted as a slow wave EEG activity deficit leading to a continuous reappearance of this activity throughout the sleep episode.[31] Considering that CAP A1 clearly prevails during SWS and CAP rate is higher at this age in childhood,[32] we speculate that OW children could require longer and more frequent EEG oscillations to consolidate SWS.[17,32] Our findings regarding interval class distribution, with more intervals shorter than 30 s and a tendency for fewer intervals longer than 30 s in OW children, provide support for this interpretation. Given the role of CAP in autonomic activity, metabolic regulation,[33] and cognitive functions,[34] which are domains often altered in OW subjects, we suggest that CAP analysis might contribute to the understanding of weight gain and related morbidity throughout human development.

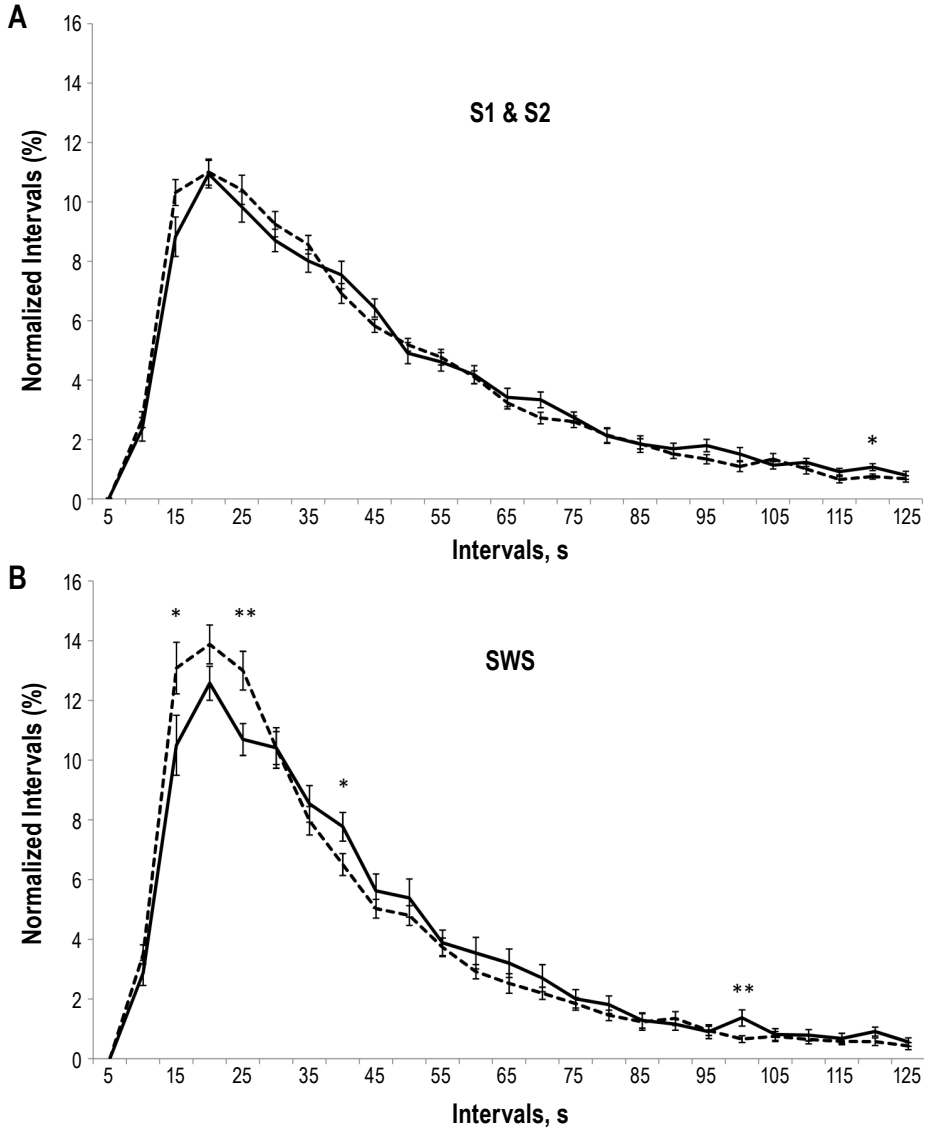

Figure 1—CAP interval distribution in NREM sleep stages 1 and 2, and SWS. Normalized interval class (5 s) distribution of CAP sequences during NREM sleep stages 1 and 2 **(A)**, and slow-wave sleep **(B)** for normal weight (solid line) and overweight (dashed line) children groups. Data presented as mean ± SEM. S1 & S2, NREM sleep stages 1 and 2. SWS, slow-wave sleep (or NREM sleep stages 3 and 4). Significant differences between groups in **(A)**: *P < 0.038, and **(B)**: *P < 0.05; **P < 0.015.

Our study was limited in that PSG was performed only one night. Bedtime followed the individual child's routine. This approach was chosen for child comfort, but it could introduce more variability in the time of going to bed and falling asleep.

In summary, our results show that CAP characteristics related to nutritional status and were altered in otherwise healthy OW children during SWS. Since CAP differences between groups were apparent in the absence of disrupted conventional sleep patterns or sleep pathologies, we suggest that the more frequent oscillatory pattern of EEG slow activity in OW subjects might reflect less stable SWS episodes.

ABBREVIATIONS

CAP, cyclic alternating pattern
OW, overweight
PSG, polysomnography
NW, normal weight
S1, NREM sleep stage 1
S2, NREM sleep stage 2
SWS, slow-wave sleep
EEG, electroencephalographic
BMI, body mass index
W, wakefulness

TIB, time in bed
SPT, sleep period time
TST, total sleep time
OAHI, obstructive apnea-hypopnea index

ACKNOWLEDGMENTS

The authors are indebted to the children and parents whose ongoing participation made this follow-up possible. We also thank the technicians who contributed to nighttime recordings and Debora Aricò for her valuable assistance in CAP analysis. We are grateful to CONICYT and the Graduate Department of the University of Chile for the financial support provided to RC.

DISCLOSURE STATEMENT

This was not an industry supported study. The work was performed at the Institute of Nutrition and Food Technology (INTA), University of Chile, Santiago, Chile. Financial support from Fondecyt 1110513 and NIH HD 33487 grants. The content of this article is solely the responsibility of the authors and does not necessarily represent the official views of the National Institute of Child Health and Human Development or the National Institutes of Health. Dr. Ferri has consulted for Merck & Co., Sapio Life, and EB Neuro. Dr. Lozoff has participated in speaking engagements supported by Vifor Pharma and Lee's Pharm. The other authors have indicated no financial conflicts of interest.

REFERENCES

1. Van Cauter E, Knutson KL. Sleep and the epidemic of obesity in children and adults. Eur J Endocrinol 2008;159 Suppl 1:S59-66.
2. Rajaratnam SM, Arendt J. Health in a 24-h society. Lancet 2001;358:999-1005.
3. Chaput JP, Brunet M, Tremblay A. Relationship between short sleeping hours and childhood overweight/obesity: results from the 'Quebec en Forme' Project. Int J Obes (Lond) 2006;30:1080-5.
4. von Kries R, Toschke AM, Wurmser H, Sauerwald T, Koletzko B. Reduced risk for overweight and obesity in 5- and 6-y-old children by duration of sleep--a cross-sectional study. Int J Obes Relat Metab Disord 2002;26:710-6.
5. Chen X, Beydoun MA, Wang Y. Is sleep duration associated with childhood obesity? A systematic review and meta-analysis. Obesity (Silver Spring) 2008;16:265-74.
6. Taveras EM, Rifas-Shiman SL, Oken E, Gunderson EP, Gillman MW. Short sleep duration in infancy and risk of childhood overweight. Arch Pediatr Adolesc Med 2008;162:305-11.
7. Bell JF, Zimmerman FJ. Shortened nighttime sleep duration in early life and subsequent childhood obesity. Arch Pediatr Adolesc Med 2010;164:840-5.
8. Resta O, Foschino Barbaro MP, Bonfitto P, et al. Low sleep quality and daytime sleepiness in obese patients without obstructive sleep apnoea syndrome. J Intern Med 2003;253:536-43.
9. Dixon JB, Schachter LM, O'Brien PE. Polysomnography before and after weight loss in obese patients with severe sleep apnea. Int J Obes (Lond) 2005;29:1048-54.
10. Liu X, Forbes EE, Ryan ND, Rofey D, Hannon TS, Dahl RE. Rapid eye movement sleep in relation to overweight in children and adolescents. Arch Gen Psychiatry 2008;65:924-32.
11. Wojnar J, Brower KJ, Dopp R, et al. Sleep and body mass index in depressed children and healthy controls. Sleep Med 2010;11:295-301.
12. Terzano MG, Mancia D, Salati MR, Costani G, Decembrino A, Parrino L. The cyclic alternating pattern as a physiologic component of normal NREM sleep. Sleep 1985;8:137-45.
13. Kheirandish-Gozal L, Miano S, Bruni O, et al. Reduced NREM sleep instability in children with sleep disordered breathing. Sleep 2007;30:450-7.
14. Miano S, Donfrancesco R, Bruni O, et al. NREM sleep instability is reduced in children with attention-deficit/hyperactivity disorder. Sleep 2006;29:797-803.
15. Pereira AM, Bruni O, Ferri R, Palmini A, Nunes ML. The impact of epilepsy on sleep architecture during childhood. Epilepsia 2012;53:1519-25.
16. Bruni O, Ferri R, Miano S, et al. Sleep cyclic alternating pattern in normal preschool-aged children. Sleep 2005;28:220-30.
17. Bruni O, Novelli L, Miano S, Parrino L, Terzano MG, Ferri R. Cyclic alternating pattern: A window into pediatric sleep. Sleep Med 2010;11:628-36.
18. Lozoff B, De Andraca I, Castillo M, Smith JB, Walter T, Pino P. Behavioral and developmental effects of preventing iron-deficiency anemia in healthy full-term infants. Pediatrics 2003;112:846-54.
19. Peirano PD, Algarin CR, Garrido MI, Lozoff B. Iron deficiency anemia in infancy is associated with altered temporal organization of sleep states in childhood. Pediatr Res 2007;62:715-9.
20. de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. Bull World Health Org 2007;85:660-7.
21. Kemp B, Varri A, Rosa AC, Nielsen KD, Gade J. A simple format for exchange of digitized polygraphic recordings. Electroencephalogr Clin Neurophysiol 1992;82:391-3.
22. Rechtschaffen A, Kales A. A manual of standardized terminology, techniques and scoring system for sleep stages of human subjects. Los Angeles, CA: Brain Information Service/Brain Research Institute, University of California, 1968.
23. Berry RB, Budhiraja R, Gottlieb DJ, et al. Rules for scoring respiratory events in sleep: update of the 2007 AASM Manual for the Scoring of Sleep and Associated Events. J Clin Sleep Med 2012;8:597-619.
24. Ferri R, Bruni O, Miano S, Smerieri A, Spruyt K, Terzano MG. Inter-rater reliability of sleep cyclic alternating pattern (CAP) scoring and validation of a new computer-assisted CAP scoring method. Clin Neurophysiol 2005;116:696-707.
25. Terzano MG, Parrino L, Sherieri A, et al. Atlas, rules, and recording techniques for the scoring of cyclic alternating pattern (CAP) in human sleep. Sleep Med 2001;2:537-53.
26. Ferri R, Bruni O, Miano S, et al. The time structure of the cyclic alternating pattern during sleep. Sleep 2006;29:693-9.
27. Lopes MC, Rosa A, Roizenblatt S, et al. Cyclic alternating pattern in peripubertal children. Sleep 2005;28:215-9.
28. Bruni O, Ferri R, Miano S, et al. Sleep cyclic alternating pattern in normal school-age children. Clin Neurophysiol 2002;113:1806-14.
29. Parrino L, Boselli M, Spaggiari MC, Smerieri A, Terzano MG. Cyclic alternating pattern (CAP) in normal sleep: polysomnographic parameters in different age groups. Electroencephalogr Clin Neurophysiol 1998;107:439-50.
30. Tarokh L, Carskadon MA, Achermann P. Dissipation of sleep pressure is stable across adolescence. Neuroscience 2012;216:167-77.
31. Guilleminault C. Hypersynchronous slow delta, cyclic alternating pattern and sleepwalking. Sleep 2006;29:14-5.
32. Parrino L, Ferri R, Bruni O, Terzano MG. Cyclic alternating pattern (CAP): the marker of sleep instability. Sleep Med Rev 2012;16:27-45.
33. Ferri R, Parrino L, Smerieri A, et al. Cyclic alternating pattern and spectral analysis of heart rate variability during normal sleep. J Sleep Res 2000;9:13-8.
34. Smith E, Hay P, Campbell L, Trollor JN. A review of the association between obesity and cognitive function across the lifespan: implications for novel approaches to prevention and treatment. Obes Rev 2011;12:740-55.

SUPPLEMENTAL MATERIAL

Table S1—Background and anthropometric characteristics

Background variables	Normal weight (n = 26)	Overweight (n = 32)	P-value
Age, years	10.2 ± 0.1	10.3 ± 0.2	0.54
Sex, n males (%)	18 (69.2)	19 (59.4)	0.43
Weight, kg	33.3 ± 3.4	47.0 ± 7.5	0.0001
Height, m	1.39 ± 0.1	1.43 ± 0.1	0.003
BMI[a]	17.2 ± 0.9	22.7 ± 2.8	0.0001
BMIz[b]	0.5 ± 0.5	2.1 ± 0.7	0.0001
Birth weight, kg	3.4 ± 0.4	3.5 ± 0.4	0.14
Birth height, cm	50.5 ± 2.4	50.7 ± 1.9	0.69
Gestational age, weeks	39.4 ± 0.9	39.2 ± 0.9	0.66
Cow milk/formula consumption, mL/day[c]	342.2 ± 158.0	308.0 ± 199.9	0.52
Maternal BMI[d]	27.8 ± 4.5	29.6 ± 4.7	0.16
Maternal obesity, n (%)	7 (27)	14 (43.7)	0.31
Iron-deficiency anemia in infancy, yes n (%)	11 (42.3)	17 (53.1)	0.41
Iron sufficiency at 10 years, n (%)	26 (100)	28 (88)	0.24

Data presented as mean ± SD. [a]BMI, body-mass index (kg/m^2). [b]BMIz, BMI z-score adjusted by age and sex, according to World Health Organization growth charts.[20] [c]This is the average daily intake throughout the supplementation study. [d]Maternal BMI measured at children's 10-year assessment.

Table S2—Conventional sleep parameters

PSG parameters	Normal weight (n = 26)	Overweight (n = 32)	P-value
Sleep onset, hh:mm	23:09 ± 0:38	23:08 ± 0:45	0.91
Sleep offset, hh:mm	7:22 ± 0:43	7:17 ± 0:51	0.67
TIB, min	614.7 ± 68.5	603.1 ± 40.5	0.45
SPT, min	492.8 ± 47.9	488.8 ± 61.5	0.78
TST, min	458.8 ± 61.7	441.0 ± 76.7	0.33
Sleep efficiency, %[a]	92.9 ± 7.1	90.1 ± 10.2	0.22
Stage shifts, n/hour	40.4 ± 10.6	40.7 ± 9.4	0.91
Sleep cycles, n	4.6 ± 1.0	4.6 ± 1.6	0.80
Sleep latency, min[b]	13.7 (8.2-40.4)	9.9 (4.9-18.5)	0.11
REM sleep latency, min	125.6 ± 51.6	125.5 ± 43.2	0.99
W, %[b]	3.4 (1.1-12.9)	6.5 (1.7-14.6)	0.31
S1, %[b]	9.4 ± 4.5	9.1 ± 3.8	0.75
S2, %	51.0 ± 7.6	51.9 ± 5.1	0.61
SWS, %[b]	20.9 ± 5.9	21.1 ± 5.2	0.94
REM sleep, %	18.5 ± 3.7	17.8 ± 4.5	0.56
OAHI (n/TST h)[b]	0.3 (0.1-0.8)	0.5 (0.2-0.7)	0.39
Daytime waking time, min	828.4 (746.4-883.4)	859.4 (801.8-924.8)	0.20

Data presented as mean ± SD, unless otherwise specified. [a]Sleep efficiency = [(TST / TSP) × 100]. [b]Data presented as median (interquartile range). PSG, polysomnographic; TIB, time in bed; SPT, sleep period time; TST, total sleep time; W, wakefulness; S1, NREM sleep stage 1; S2, NREM sleep stage 2; SWS, slow wave sleep (or NREM sleep stages 3 and 4); OAHI, obstructive apnea-hypopnea index (n/TST h) = number of events/hour of TST.

Table S3—CAP parameters during NREM sleep and its stages

CAP parameters	Normal weight (n = 26)	Overweight (n = 32)	Student t-test P value
CAP rate, %			
NREM sleep	39.5 (12.1)	44.4 (13.1)	0.15
S1	22.3 (12.5)	21.1 (13.5)	0.86
S2	39.7 (14)	43.9 (14.7)	0.20
SWS	48.4 (15)	55.4 (15.3)	**0.04**
CAP number, n			
NREM sleep	397.6 (99.8)	438.2 (109.5)	0.14
S1	29.7 (15.9)	31.1 (16.7)	0.80
S2	239.7 (79.8)	243.5 (67.2)	0.59
SWS	133.4 (48.1)	163.6 (56.1)	**0.04**
CAP A1 index, n/h			
NREM sleep	40.8 (16.5)	48.3 (20.1)	0.12
S1	8.2 (8.8)	7.5 88.5)	0.76
S2	41.6 (17.9)	46.4 (21.1)	0.39
SWS	74.6 (21.3)	87.5 (21.8)	**0.01**
CAP A2 index, n/h			
NREM sleep	7.3 (2.8)	7.7 (3.6)	0.64
S1	7.6 (6.7)	6.0 (4.7)	0.59
S2	12.4 (6.1)	12.8 (5.5)	0.37
SWS	3.9 (3.3)	3.8 (2.7)	0.58
CAP A3 index, n/h			
NREM sleep	7.7 (3.8)	8.3 (4.4)	0.65
S1	28.9 (11.8)	28.7 (11.8)	0.93
S2	12.9 (6.5)	13.2 (7.5)	0.72
SWS	1.3 (1.5)	0.8 (0.9)	0.31
Phase A duration, s			
NREM sleep	6.3 (0.7)	6.2 (0.7)	0.59
S1	9.1 (1.5)	9.1 (1.8)	0.93
S2	6.2 (0.9)	6.1 (0.7)	0.54
SWS	5.8 (0.8)	5.7 (0.8)	0.81
Phase B duration, s			
NREM sleep	23.5 (2.2)	22.5 (2.2)	0.07
S1	23.6 (6.7)	24.3 (4.8)	0.77
S2	24.0 (2.5)	23.5 (2.3)	0.34
SWS	23.0 (3.2)	21.1 (2.9)	**0.01**
CAP cycle duration, s			
NREM sleep	29.6 (2.4)	28.5 (2.2)	0.07
S1	31.9 (8.1)	33.2 (5.6)	0.59
S2	30.3 (2.7)	29.6 (2.4)	0.27
SWS	28.5 (3.2)	26.6 (2.8)	**0.01**
CAP sequence duration in NREM sleep, s	213.3 (49.6)	239.9 (72.3)	0.07

Data presented as mean (SD). Significant differences between groups are highlighted in bold. CAP, cyclic alternating pattern; S1, NREM sleep stage 1; S2, NREM sleep stage 2; SWS, slow wave sleep (or NREM sleep stages 3 and 4).

Table S4—Bivariate and partial[a] correlations analyses between CAP and anthropometric variables

	Body weight		BMI[b]		BMIz[c]	
CAP parameters	**Bivariate**	**Partial**	**Bivariate**	**Partial**	**Bivariate**	**Partial**
CAP time, min	**0.25*** (0.05)	0.26 (0.06)	0.24 (0.07)	0.25 (0.06)	**0.26*** (0.04)	0.25 (0.07)
CAP rate, %	**0.25*** (0.05)	0.25 (0.06)	0.25 (0.06)	0.26 (0.06)	**0.28*** (0.03)	0.26 (0.06)
CAP rate S1, %	-0.14	-0.12	-0.12	-0.07	-0.08	-0.05
CAP rate S2, %	0.22	0.21	0.20	0.21	0.23	0.20
CAP rate SWS, %	**0.35*** (0.007)	**0.33*** (0.01)	**0.38*** (0.003)	**0.37*** (0.007)	**0.41*** (0.002)	**0.37*** (0.007)
Phase B duration, s	-0.25	-0.22	-0.21	-0.19	-0.24	-0.19
Phase B duration in S1, s	0.03	0.05	0.11	0.14	0.13	0.15
Phase B duration in S2, s	-0.16	-0.15	-0.12	-0.12	-0.14	-0.11
Phase B duration in SWS, s	**-0.26*** (0.04)	-0.21	**-0.26*** (0.05)	-0.24 (0.08)	**-0.28*** (0.03)	-0.25 (0.07)
CAP sequences duration, s	0.23 (0.08)	0.23	**0.26*** (0.05)	**0.27*** (0.04)	**0.29*** (0.02)	**0.29*** (0.03)
A phase in sequence, %	**0.29*** (0.02)	**0.30*** (0.02)	**0.26*** (0.04)	**0.28*** (0.04)	**0.28*** (0.03)	**0.28*** (0.04)
A phase isolated, n	-0.23	-0.26	**-0.26*** (0.05)	**-0.29*** (0.03)	**-0.27*** (0.04)	**-0.29*** (0.03)

[a]Partial correlation analyses controlling for demographic (age, sex) and background (birth weight, gestational age, iron-deficiency anemia in infancy) variables, and diurnal waking duration. Values are r coefficient and level of statistical significance in (); significant correlations are indicated by * and bold. [b]BMI, body-mass index (kg/m^2); [c]BMIz, BMI z-score adjusted by age and sex, according to World Health Organization growth charts.[20] CAP, cyclic alternating pattern; S1, NREM sleep stage 1; S2, NREM sleep stage 2; SWS, slow wave sleep (or NREM sleep stages 3 and 4).