Four Years Old Children's Sleep: What can we obtain by using wearable measuring devices at their home?

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What short sleep duration causes

Short sleep duration and poor sleep quality may negatively affect physical health, such as obesity, diabetes, cardiovascular disease and hypertension, and psychological health, such as anxiety symptoms, depressed mood, concentration, performance, behavior, emotional instability .

A cohort study about the effect of longitudinal sleep duration patterns to the obesity reported persistently short sleep duration (<10 h) during early childhood (from 2.5 to 6 years old (y.o.)) significantly increases the risk of excess weight or obesity at age 6 y.o.

A cross-sectional study of the relationship between short sleep duration and obesity-related variables in children (5-10 y.o.) reported that when compared to children reporting12–13 h of sleep per day, the adjusted odds ratio for childhood overweight/obesity was 1.42 for those with 10.5–11.5 h of sleep and 3.45 for those with 8–10 h of sleep.

Sleep durations used in these important studies were parental reports (PARD) .

Difference in sleep durations measured by three different methods

Sleep durations used in these important studies were parental reports (PARD) , i.e., times in bed of their children.

Also, many reports of actigraphic sleep duration (ACTD) , and comparisons of sleep durations for children around 4 y.o. indicated that 10-11 h by PARD corresponded to 8-9 h by ACTD.

On the other hands, several polysomnographic (PSG) sleep-disordered breathing (SDB) studies of children also reports sleep duration of normal children as 7.6 h (mean 4.4 y.o.) , 6.6 h (mean 9.8 y.o.) and 7.6 h (mean 6.5 y.o.) . Sleep durations with PSG examinations (PSGDs) were shorter than ACTDs.

Our policy

Develop a wearable acceleration and ECG measuring device (M-BIT), and collect objective data of children's

1) Physical activities,
2) Sleep behaviors,
3) *Activity of autonomic nervous systems,*

and educate them and their parents.

M-BIT

a four years old boy wearing M-BIT

He can enter sleep without paying attention to M-BIT.

He can do everything he wants.

Times in bed and sleeping postures

Posture vectors (up-down, left-right, anterior-posterior) of subject's thorax, M-BIT attaching portion, were derived from 3-axes acceleration. We obtained their epoch averages, and searched "in bed" area - the area where horizontal postures of up-down direction were continued. As for "in bed" area, we classified sleeping posture as follows: supine, left lateral, prone, right lateral, and obtained their distributions and numbers of changing.

Sleep/awake identification by body movement

Our epoch duration for analysis was 1 minute.

For sleep/awake estimation, we classified epochs with and without body movement at first. For each sampling, we selected “sampling difference” as maximum value among 3-axes difference of acceleration with previous sampling, and put “epoch difference (EPD)” as the epoch maximum of sampling difference. We set threshold for with or without movement based on the average of EPD within whole analyzed area, and judged epoch without movement (ENMV) when EPD was less than the threshold.

Then we searched “inactive areas (IAAs)”, areas where ENMV were continued, and combined two successive IAAs if the duration of separation between them was one epoch or average of ENMV during separation was less than four times the threshold. Finally, we selected sleep area among these IAA, details for this selection is publicly available.

原著論文　全面発達の展開　2(1)：8—18, 2012

Analysis of ECG data

We detected time locations of the R waves on the ECG signal based on a robust real time QRS detection algorithm currently in broad use worldwide.

We re-sampled RR interval time series with a re-sampling frequency of 4Hz, and performed time frequency analysis with SPWV (Smoothed Pseudo Wigner-Ville) method, and obtained time frequency map.

For the index of autonomic nervous systems activity, we calculated LF (0.04Hz-0.15Hz), HF (0.15Hz-0.40Hz) as the sum of the absolutes of mapped values of corresponding frequency bands along the frequency axis and their average along the time over the map. We calculated an instantaneous central frequency (CFR) from 0.15 Hz (lower limit of high frequency band) to the half frequency of the average heart rate for the epoch. We set HF and LF/HF as indexes of para-sympathetic (PSNS) and sympathetic (SNS) nervous systems activity representing this epoch, together with average heart rate (HR). We defined “row respiration frequency (RRF)“, as 10 seconds average of these CFRs, and set RFRE and VRFRE as the epoch average and difference between the epoch maximum and minimum of RRFs, respectively.

原著論文　全面発達の展開　2(1)：8—18, 2012

Example of comparison with polygraph sleep stages

Polygraph

M-BIT

sleep/awake

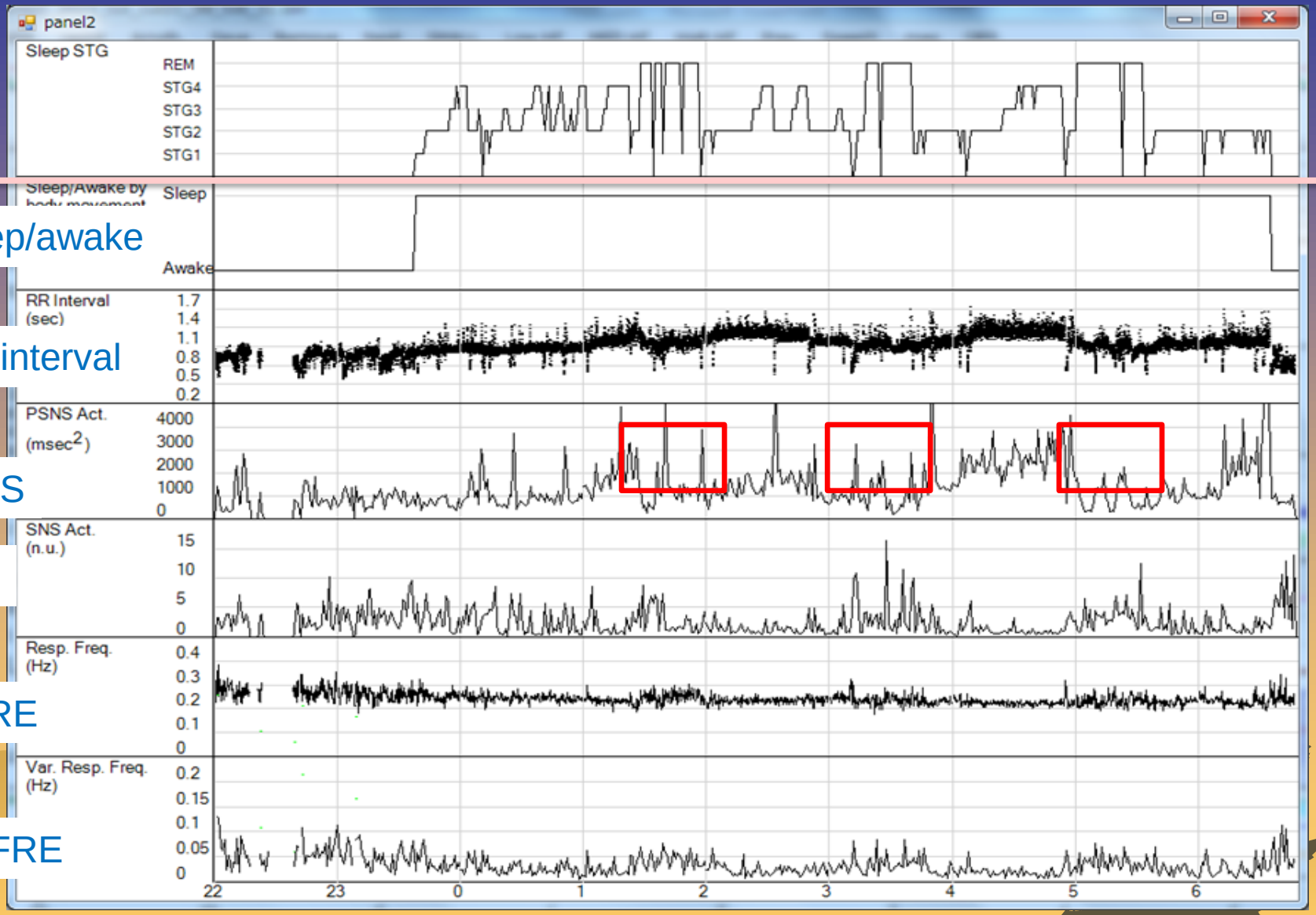
RR interval

PSNS

SNS

RFRE

VRFRE



from 原著論文 全面発達の展開 2(1)：8—18, 2012

Time difference of sleep onset time and end time

	Sleep Start Time			Sleep End Time		
	M-BIT	Polygraph	difference	M-BIT	Polygraph	difference
ST2	23:53	23:55	0:02	6:29	6:30	0:01
ST3	23:53	23:59	0:06	6:32	6:34	0:02
ST4	23:49	23:58	0:09	6:37	6:39	0:02
ST7	23:37	23:39	0:02	6:34	6:36	0:02
ST8	23:47	23:53	0:06	6:26	6:30	0:04
ST9	23:31	23:50	0:19	6:48	6:50	0:02
ST10	22:45	22:55	0:10	6:13	6:16	0:03
ST11	22:57	23:15	0:18	6:23	6:17	0:06
			0:09			0:02:45

"A case Study Comparison of Sleep Stages from Polygraph Data Based on the International Standardized Scoring System, and Sleep Analysis Results from a Small, Lightweight ECG and Acceleration Data Logger (M-BIT)," Human Development for ALL, vol.2, pp.8-18, No.1, 2012.

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原著論文　全面発達の展開　2(1)：8—18, 2012

Estimation of NREM area and Modification of actigraphic sleep/awake estimation by VRFRE value

In principle, NREM sleep area is a low VRFRE area. At first, using trial threshold, we preliminary classified whether each epoch was NREM sleep epoch based on their VRFRE values. Then we searched NREM sleep areas (NSAs) where more than 15 NREM epochs were successively continue, and obtained averages of VRFRE values of each NSA. We set the real threshold as the 90% value of the maximum of NSA VRFRE values. We performed classification and NSAs search again with this real threshold.

Trial threshold were decided based on VRFRE average value over the actigraphic sleep duration, and details are publicly available.

Awaken epochs after actigraphic sleep onset and before sleep end were reassigned to sleep epochs if their VRFRE values were below the threshold for NREM detection.

原著論文　全面発達の展開　2(2)：83—90, 2013

S. Shirouzu, H. Kondo, K. Mori et al., “Estimation of NREM Sleep Area Based on the Variation of Respiration Frequency Variation Width derived from RR Interval Variation,” Human Development for ALL, vol.2, pp.83-90, No.2, 2013.

からんこ山の野遊び
Playing at a hill with natural woodland
(Named Karanco mountain)

Playing Indoors

Nazareth Kindergarten

Playing at Kindergarten's Garden

Lessons

The difference of physical activity due to the difference of educational program

Large PA day — 46 children

- Playing at Kindergarten's Garden
- Lessons
- Playing at Karanco mountain
- Lessons
- Playing at Kindergarten's Garden
- Home
- Playing at Kindergarten's Garden

Normal PA day — 39 children

- Playing Indoors (A rainy day)
- Lessons
- Playing Indoors (A rainy day)
- Home
- Playing at Kindergarten's Garden

Answer sheet to children and their parents (originally Japanese) for quick report and their education.

Activity and Sleep of Mr. daito_4f_nazareth3_0642_

Physical Activity (PA)

METs is a measure of the intensity of phycial activity.

One MET is defined as the energy it takes to sit quietly.

Slow walking is 2.5 METs, the ratio of its energy consumption to sit quietly is 2.5.

Physical Activity Guidelines for Preschoolers
(National Association for Sport and Physical Education)

Physical activities and METs

PA category	METs	Physical Activity
sedentary PA	1−1.5	TV watch, game, study
light PA	1.5−2	standing, indoor walking
	2.5	slow walking (outside)
MVPA	3	walking
	4	faster walking, bicycling
	5	fast walking, dancing
	6	jogging
VPA	7	fast jogging
	8	running, stairway ascending

Preschoolers participate in 120 min of MVPA or VPA daily.

PA category	Time(min)	Heart Rate
sedentaly PA	450	103.4
light PA	263	116.4
MVPA	101	121.6
VPA	38	124.2

You partcipated in 139 minutes of MVPA and VPA.

GOOD JOB!

Results of only one time measurement is strongly affected by the events or body condition of measuring day.Measure several times, and know your usual activity and

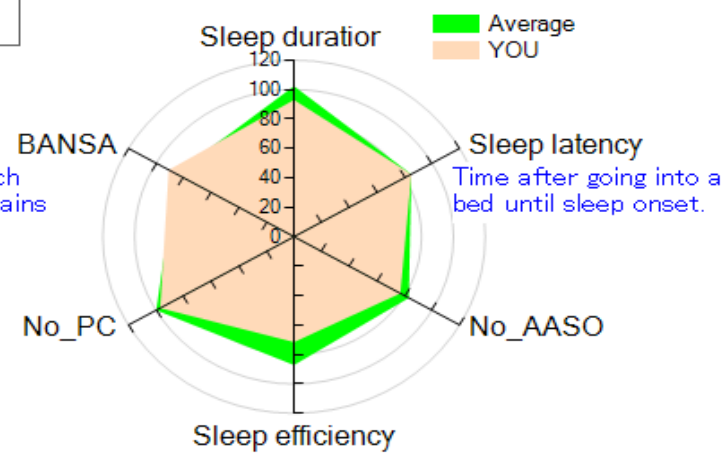
Sleep

button1

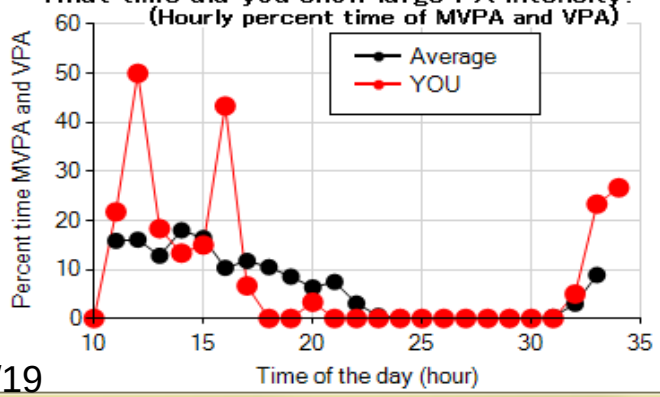
parameters	YOU	Average
Bedtime	20:13	21:38
Sleep Onset time	20:27:	21:52
Awake time	7:15	7:24
Rise time	7:16	7:32
Sleep duration	7:45	8:31
Sleep Latency	15minutes	15minutes
No. of awake after sleep onset (No_AASO)	23	16
Sleep efficiency	0.716	0.872
No. of psotural change (No_PC)	27	29
Balance of autonomic nervous system's activity(BANSA)	0.460	0.720

Parameters represdenting quality of Sleep

The more outside, the better.



What time did you show large PA intensity?
(Hourly percent time of MVPA and VPA)



Large PA day

What we can obtain about sleep by using M-BIT

Physical Activity

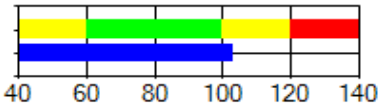
PA category	Time (min)	Heart Rate
Awake_total	852	109.3
sedentary PA	450	103.4
light PA	263	116.4
MVPA	101	121.6
VPA	38	124.2
EFEPA	139	

OK!

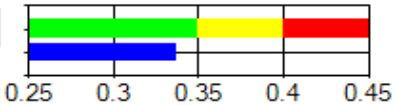
Awake_total_METs: 1850.2METs

sedentary PA

Heart Rate 103.4



Resp. Freq. 0.34Hz

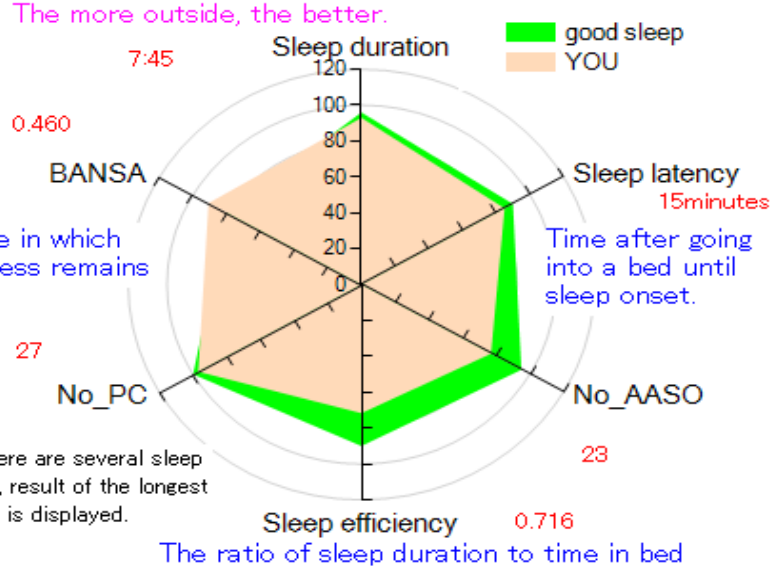


Sleep apnea safety index (SASI)

87.0
safe level OSA

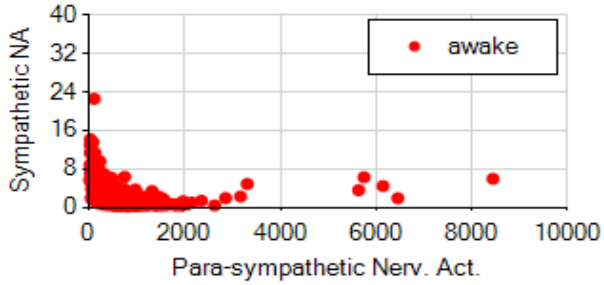
Parameters represdenting quality of Sleep

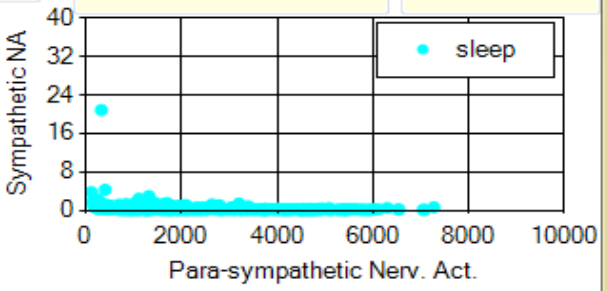
The more outside, the better.

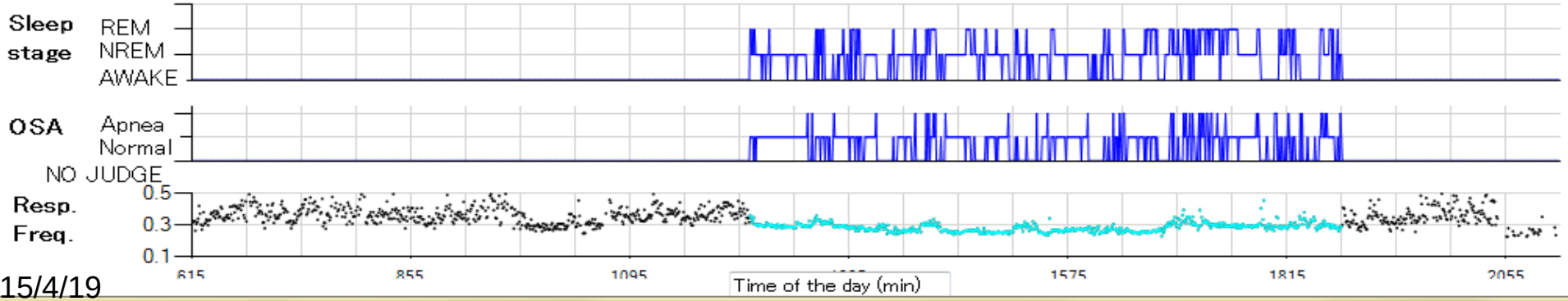


parameters	
Bedtime	20:13
Sleep Onset time	20:27
Awake time	7:15
Rise time	7:16
Sleep duration	7:45
Sleep Latency	15minutes
No. of awake after sleep onset (No_AASO)	23
Sleep efficiency	0.716
No. of psotural change (No_PC)	27
NREM Ratio	0.714
PSNS	2391.7msec2
SNS or Balance of autonomic nervous system's activity (BANSA)	0.460
Resp. Freq.	0.286Hz
VRFRE	0.027Hz
HR	80.3

Autonimic nervous system's activity maps



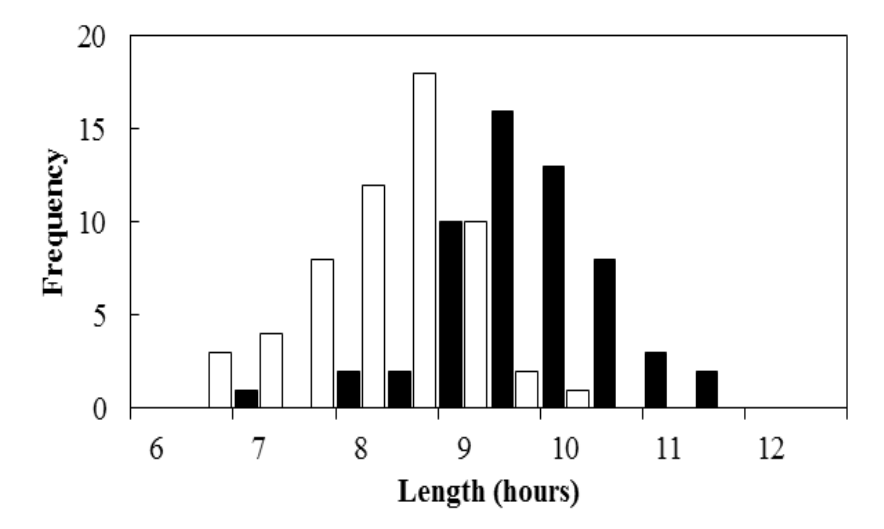




Sleep variables

Times in bed, sleep duration, latency, efficiency and numbers of awake after sleep onset are listed in Table Ⅰ. Two way ANOVA (L and N × girls and boys) revealed that two main effects and the interaction were not significant. Times in bed ranged from 9.7h to 10.4h, and sleep duration range from 8.3 h to 8.6h. These value of times in bed and sleep durations and their distribution shown in Fig.1 indicated that our time in bed and sleep duration were correspond well with reported parental reports and actigraphic sleep durations.

	unit	Large PA day				Normal PA day			
		girls		boys		girls		boys	
		mean	SD	mean	SD	mean	SD	mean	SD
Times in Bed	h	10.4	1.3	9.9	0.9	9.7	1.1	10.0	0.6
Sleep duration	h	8.6	0.6	8.3	0.7	8.5	0.8	8.5	0.9
Sleep latency	min	19.2	15.2	17.2	18.5	12.1	6.5	16.3	12.5
Sleep efficiency	%	85.4	9.1	86.0	5.2	89.0	3.2	86.4	7.7
No of awake after sleep onset		18.8	4.2	16.5	4.3	15.6	6.4	17.3	5.2



Distribution of times in bed and sleep duration (ACTD).
White: sleep duration, Black: times in bed.

Postures during sleep

Postural information during sleep were listed in Table Ⅱ. Although numbers of changes ranged from 26.8 to 30.0, two -way ANOVA (L and N × girls and boys) revealed that two main effects and the interaction were not significant. The largest proportion of posture detected as supine which ranged from 27.6% (L-boys) to 37.8% (N-girls). The smallest is left lateral for N-girls (15.5%) and prone for L-boys (23.2%), N-boys (12.4%) and L-girls (11.8%).

	unit	Large PA day				Normal PA day			
		girls		boys		girls		boys	
		mean	SD	mean	SD	mean	SD	mean	SD
Number of Change		26.8	13.8	29.1	9.0	29.5	10.1	30.0	9.4
right lateral	%	23.4	21.8	25.6	13.4	26.5	14.6	24.4	15.1
supine	%	36.7	18.2	27.6	14.8	37.8	22.6	31.6	22.3
left lateral	%	27.8	18.0	23.3	17.4	15.5	10.9	31.3	16.8
prone	%	11.8	14.6	23.2	18.1	20.0	13.4	12.4	11.1

NREM sleep area estimation

Duration and percentage of NREM sleep, VRFRE values of real threshold used for NREM area search, average of whole sleep area, NREM sleep area and non-NREM sleep area are listed. Two-way ANOVA (L and N × girls and boys) revealed that two main effects and the interaction were not significant.

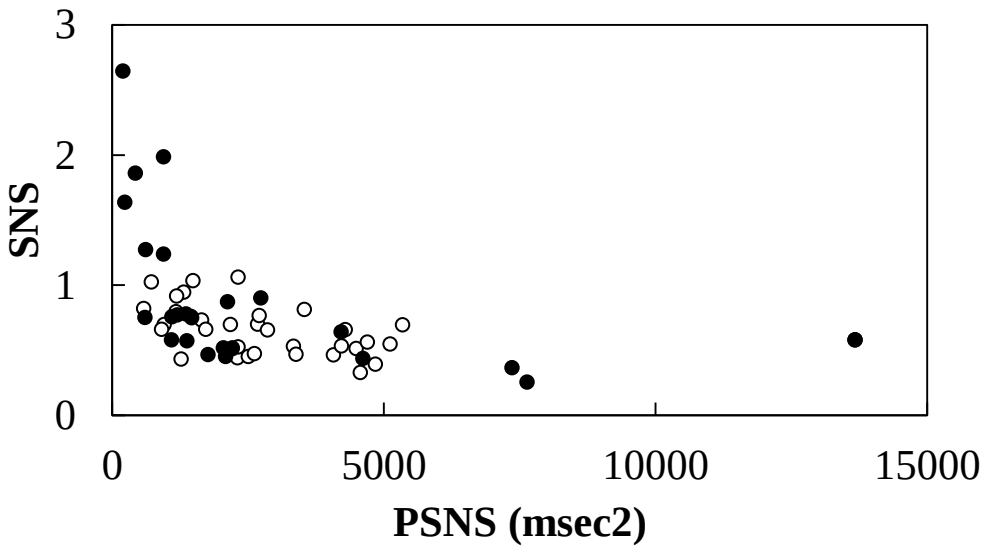
	unit	Large PA				Normal PA			
		girls		boys		girls		boys	
		mean	SD	mean	SD	mean	SD	mean	SD
Duration of NREM Sleep	min	343.1	55.1	322.3	47.4	346.5	48.8	348.6	52.8
Percentage of NREM sleep	%	67.0	13.1	64.9	8.1	68.0	7.1	68.1	8.6
VRFRE values									
threshold	Hz	0.074	0.023	0.069	0.011	0.073	0.010	0.065	0.010
whole sleep area	Hz	0.040	0.014	0.037	0.007	0.040	0.007	0.034	0.006
NREM area	Hz	0.031	0.012	0.028	0.006	0.030	0.005	0.026	0.006
non-NREM area	Hz	0.063	0.021	0.057	0.011	0.063	0.009	0.055	0.010

The comparison of VRFRE values of NREM and non-NREM area indicates that epochs have been well separated by their VRFRE values suggesting that the NREM area search were succeeded. The proportions of NREM sleep ranging from 64.9% to 68.1% which is close to commonly known value of 70%, suggesting our ACTD is well corresponded to PSGD.

Autonomic system's activity and respiration frequency

	unit	Large PA				Normal PA			
		girls		boys		girls		boys	
		mean	SD	mean	SD	mean	SD	mean	SD
PSNS	$msec^2$	1919.9	1306.8	2798.7	1650.4	2050.1	1340.3	3193.0	3316.1
SNS	n.u.	0.828	0.602	0.760	0.411	0.830	0.446	0.671	0.273
RFRE	Hz	0.304	0.046	0.291	0.034	0.294	0.019	0.279	0.031
HR	bpm	85.4	9.0	77.6	8.1	78.9	7.3	80.1	7.5

Since SD values of PSNS and SNS comparing to their mean values were rather large, indicating the largeness of the individual difference, we plotted all individual values to autonomic system's activity map



Autonomic system's activity map. ○:SEFC below 0.880, ●:SEFC above 0.880.

As shown left, all the data formed a curve. Hence, the position on this map, can be determined by one value, SNS. This is the reason we call SNS as the balance of autonomic nervous system's activity (BANSA).

Sleep efficiency (SEFC) below 0.880, data points concentrated in relatively narrow area.

SEFC above 0.880, the distribution of data points extended to both direction.

Automatic sleep apnea detections

Sleep-disordered breathing (SDB) is another important issue of children's sleep. Habitual snoring is a relatively common occurrence for healthy children, and the prevalence of habitual snoring has been reported at 6%~27%, or 3%~15% rates, and obstructive sleep apnea is estimated to affect about 1%~4% of children

Usually, for automatic sleep apnea detections, both of ECG derived respiration which based on the variation of R wave heights, and detection of Cyclic Variation of Heart Rate (CVHR) were used and high accuracy of 83.0%-89.4% were achieved.

T. Penzel, J. McNames, P. de Chanzal et al., "Systematic Comparison of Different Algorithms for Apnoea Detection Based on Electrocardiogram Recordings," Med. & Bio. Eng. & Comput., vol.40, pp.402-407, 2002.

.However, since R wave height is not always quantitatively reliable over the sleep duration in M-BIT measurement, we automatically detected SA only from RRIV based on CVHR. Our accuracy was 75.6%.

S. Shirouzu, H. Kondo and S. Katayama, "Automatic Detection of Sleep Apnea Based on RR Interval Variation," Human Development for ALL, vol.3, pp.25-30, No.1, 2013.

Sleep apnea

We judged apnea or normal epoch by epoch, and defined sleep apnea safety index (SASI) as the proportion of normal epochs to the total epochs. Previously we reported SASIs about university students (age 21.6±3.2), whose sleep and respiration during sleep were judged normal by PSG examination, calculated by sleep PSG ECG data as 81±8(%).

S. Shirouzu, H. Kondo and S. Katayama, “Sleep Behaviors of Healthy University Students,” Human Development for ALL, vol.3, No.2, 2014. (in press)

Hence, the level of SASI below which considerable amount of SA exist was thought to be 73%. Average SASI values of this study were 84.8 (6.6)% and 85.5 (7.6)%, respectively, and numbers of children whose SASI were below 73% were 2 (L, SASIs were 64.9% and 72.6%) and 3 (N, SASIs were 65.9%, 66.7% and 72.5%). There was no child whose SASI were below 73% in both measurements. Children measured in our studies were free from the anxious about SA.

Summary and Future issues

By using M-BIT, we could obtain rich information about sleep, enough for guiding people to better life style.

Since M-BIT seems only the method to obtain information of very small children's sleep and activity, we are planning a cohort study from 6 month to 5 years old.

In this study, no difference in sleep behavior was observed between large and normal PA days. However, we believe there may exist a relationship between daytime PA and sleep behavior, and in this study the level of PA were both enough level. We are planning to measure children who are attending various preschools with different educational programs and systems, i.e., level of PAs.

Also, we are making manuscripts on the comparison of depth of sleep discrimination PSG method and our M-BIT method.