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Article

# Characteristics and Transition of Sleep-Wake Rhythm during Nursery School Children and Sleep Hygiene Guidance

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**Abstract:** We investigated the sleep-wake rhythm of nursery school children with the aim of supporting their health and balanced mental/physical development. We analyzed 4881 children from infant to 6 years of age, using 2-week sleep tables recorded by their guardians. The table contains sleep onset times, wake times, nighttime/daytime sleep duration, and the differences in these between weekdays and weekends. The total sleep decrement of children with age is due to a decrease in daytime sleep only, and nighttime sleep duration remains almost unchanged at about 10 hours, and is therefore called the nighttime basic sleep duration (NBSD). While sleep onset time stabilizes at around 9:30 pm by the age of 2, wake-up times to be before 7 am, resulted in weekdays sleep insufficiency. This lack of sleep is compensated by long naps on weekdays and by catching up sleep on weekends morning, which may be the background to future social-jet-lag. Guardians are encouraged to know their children's exact NBSD and set an appropriate bedtime to maintain it on weekdays, which prevent sleep debt and form a daily rhythm of waking up at the same time both on weekdays/weekends. These conditions are believed to maintain balance in mental/physical development and school-social-adaptation.

**Keywords:** sleep-wake rhythm; nursery children; nighttime basic sleep duration; catch up sleep; social jet lag; sleep hygiene

## 1. Introduction

The nursery staffs recently concern that quite number of children attending nurseries cannot easily start their daily routines, in other words, they “lack energy”, “cannot exchange morning greetings” or “take a long time to become active”, especially in the morning. They found, for example, a child who was dragged to the nursery by his/her guardians without smile or who was loafing around on the floor and could not play with others during morning activities. In the daily life of such children, conditions that make them go to sleep late at night from 23:00 to 24:00, such as watching displays of smartphones or playing games at night, are commonly found.

Nowadays, nocturnal life of modern people working or acting late at night under a bright light has become daily routine not only in Japan but also in other countries across the world. The sleep-onset time of children involved in such late-night life style is apt to get late even near to midnight. On the other hand, such parents and children are required to get up from 6 to 7 o'clock in the morning in the present-day school and social life and chronic sleep deprivation and its accumulation are a more serious concern for children than their parents.

For example, in Japan, the most common sleep onset time in infancy was around 8 pm in the 1960s, while at present, 10–30% of children fall asleep after 10 pm [1], which equates to a more than 2 h shift. Meanwhile, wake-up times have remained the same for decades, resulting in continuous sleep deprivation and ultimately the potential for “sleep debt”. Modern nocturnal lifestyle is widespread all over the world, involves children and forces them to sleep late/get up early to deteriorate their sleeping environment.

According to the background, the sleep issues of modern people have been attracting attention, and the amount of coverage in the media has increased. However, most of them focus on adult sleep issues mainly shortage of duration, and little consideration is given to those of children and/or human biological rhythms.

It has long been said that getting a good night's sleep is important for children's growth. A study warned that small amounts of sleep restriction in children could cause a risk of unpredictable disorder of their emotional and cognitive functioning [2]. Particularly in the childhood sleep is associated with brain (e.g., development, growth, repair of damage, protection of function, and further evolution), indicating that adequate sleep is much more important for children than that of adult. As mentioned above, that a certain amount of longer nighttime sleep is better for children's growth. Additionally, it is also known that appropriate biological rhythm is quite important for children's balanced mental/physical development because, the sleep/wake rhythm is controlled by the biological clock. Therefore, sleep affects children emotionally and behaviorally [3], and sleep disorders may lead to anxiety, hyperactivity, aggression, and ultimately negative effects on mental/physical development [4].

Additionally, children's sleep problems are commonly found and a study reported that chronic sleep deprivation may shift their biological clock and could lead even to neuronal loss [5]. Furthermore, the circadian rhythm's biological clock controls not only the sleep/wake rhythm, but the so-called life support systems (e.g., the autonomic nervous system, hormone secretion, thermoregulation, energy metabolism, the immune system, coordinated movement, and maintenance of brain function balance) [6,7]. Therefore, it is meaningful to consider children's daily life rhythms in order to support their health and physical/mental development. [8].

Based on the information, we realized that knowing the actual sleep/wake rhythms of children is necessary to monitor the physical and mental growth of nursery school children and their future health. According to this purpose, we planned to investigate and analyze the actual rhythm of daily life using two weeks of sleep records

## 2. Results

### 2.1. Night Sleep-Onset Time and Morning Wake Time (Table 1 and Figure 1)

[Comparison between Age Groups]

1) The average sleep-onset time of the nocturnal sleep duration on weekdays of the 0 (<1)-year-old group was 20:57; that of the 1-year-old group, 21:11; that of the 2-year-old group, 21:32; that of the 3-year-old group, 21:40; that of the 4-year-old group, 21:35; that of the 5-year-old group, 21:38; and that of the 6-year-old group, 21:38. The average sleep-onset time of the nocturnal sleep duration on weekends of the 0-year-old group was 20:57; that of the 1-year-old group, 21:14; that of the 2-year-old group, 21:32; that of the 3-year-old group, 21:35; that of the 4-year-old group, 21:35; that of the 5-year-old group, 21:41; and that of the 6-year-old group, 21:40. Although the sleep-onset time grew late with the age (trend test:  $p < 0.001$ ), no difference was found ( $p = 0.751$ ) in the sleep-onset time of the same group between weekdays and weekends.

Focusing on the change with age, the average night sleep-onset time of the children aged 2 years was more than 30 minutes later comparing to that of the children aged 0 year. On the other hand, the sleep-onset time of the children older than 2 years did not change with age to show no difference between the age groups.

Comparisons between all age groups, adjusted for multiplicity of the night sleep-onset time on weekdays and weekends, are a significant difference in the night sleep-onset time on weekdays

between the 0-year-old group and other age groups, between the 1-year-old group and other age groups and between the 2-year-old group and 3-year-old group ( $P < 0.001$ ); and a significant difference in the night sleep-onset time on weekends between the 0-year-old group and other age groups and between the 1-year-old group and other age groups ( $p < 0.001$ ). The result also shows a tendency of significant difference in the night sleep-onset time on weekends between the 2-year-old group and 3-year-old group ( $p < 0.05$ ).

2) The average morning wake time on weekdays of the 0-year-old group was 6:32; that of the 1-year-old group, 6:37; that of the 2-year-old group, 6:49; that of the 3-year-old group, 6:55; that of the 4-year-old group, 6:54; that of the 5-year-old group, 6:52; and that of the 6-year-old group, 6:50. The average morning wake time on weekends of the 0-year-old group was 6:49; that of the 1-year-old group, 6:57; that of the 2-year-old group, 7:12; that of the 3-year-old group, 7:18; that of the 4-year-old group, 7:16; that of the 5-year-old group, 7:19; and that of the 6-year-old group, 7:17. The wake time grew late with the age (trend test:  $p < 0.001$ ) from 0 year to 6 years of age and a significant difference ( $p < 0.001$ ) was found in the tendency of later wake time on weekends. Thus, the wake time of all the age groups on weekends was significantly later than that on weekdays.

Focusing on the change with age, the wake time of the children aged 3 years was about 30 minutes later than that of the children aged 0 year as well as the sleep-onset time. On the other hand, the wake time of the children from the age of 3 years to 6 years did not change with age.

Comparisons between all age groups, adjusted for multiplicity of the morning wake time on weekdays and weekends, are a significant difference ( $p < 0.001$ ) in the morning wake time on weekdays between the 0-year-old group and other age groups, between the 1-year-old group and other age groups and between the 2-year-old group and 3-year-old group; and a significant difference in the morning wake time on weekends between the 0-year-old group and other age groups and between the 1-year-old group and other age groups. The result also shows a tendency of significant difference ( $p < 0.05$ ) in the morning wake time on weekends between the 2-year-old group and 3-year-old group.

#### [Comparison between Weekdays and Weekends]

The difference in night sleep-onset time and morning wake time between weekdays and weekends was studied.

##### 1) Night sleep-onset time

The difference in the average sleep-onset time between weekends and weekdays of each subject was calculated and the difference in sleep-onset time between adjacent age groups was confirmed. Although the sleep-onset time on weekends of the children aged 3 years was earlier than that on weekdays, the difference in sleep-onset time between weekends and weekdays of all the age groups was small and exhibited no significant differences.

**Table 1. Night Sleep-onset Time and Morning Wake Time of the Age Groups on Weekdays and Weekend** This is a cross tabulation table comparing the time of falling asleep and the time of waking up in the morning between weekdays and weekends of the subjects divided into several age groups. The average times, 1st quartiles, medians, and 3rd quartiles are indicated by hours and minutes, and SDs (standard deviations) are by minutes.

**Figure 1. Night Sleep-Onset Time and Morning Wake Time of Each Age Group on Weekdays and Weekends** The point at the center of each vertical line represents the average time and the lines extending above and below the point represent the SD (standard deviation). The pairs of lines on the lower side represent the morning wake time of each age group where the left line of each pair represents the wake time on weekdays and the right line of each pair represents the wake time on weekends. The pairs of lines on the upper side represent the night sleep-onset time of each age group where the left line of each pair represents the sleep-onset time on weekdays and the right line of each pair represents the sleep-onset time on weekends. The time scale for the sleep-onset time is given on the left of the ordinate and that for the wake time is given on the right of the ordinate. Although the sleep-onset time grows late with the age by 2 years ( $p < 0.001$ ), that of the children older than 2 years did not change with age. No difference is found ( $p = 0.751$ ) in the sleep-onset time of the same group between weekdays and weekends. On the other hand, the wake time of all the groups on weekends is significantly later ( $p < 0.001$ ) than that on weekdays and the difference increases with age.

## 2) Morning wake time

The wake time of all the groups on weekends was significantly later ( $p < 0.001$ ) than that on weekdays and the difference increased with age.

## II. Nocturnal Sleep Duration and Daytime Sleep Duration (Table 2 and Figure 2)

[Comparison between Age Groups]

The average nocturnal sleep duration on weekdays of the 0-year-old group was 9 hrs and 22 min; that of the 1-year-old group, 9 hrs and 22 min; that of the 2-year-old group, 9 hrs and 17 min; that of the 3-year-old group, 9 hrs and 17 min; that of the 4-year-old group, 9 hrs and 20 min; that of the 5-year-old group, 9 hrs and 16 min; and that of the 6-year-old group, 9 hrs and 12 min. On weekends, the average nocturnal sleep duration of the 0-year-old group was 9 hrs and 36 min; that of the 1-year-old group, 9 hrs and 37 min; that of the 2-year-old group, 9 hrs and 39 min; that of the 3-year-old group, 9 hrs and 43 min; that of the 4-year-old group, 9 hrs and 42 min; that of the 5-year-old group, 9 hrs and 40 min; and that of the 6-year-old group, 9 hrs and 36 min. Although their nocturnal sleep duration did not change with age (trend test:  $p=0.425$ ) from 0 year to 6 years old, their nocturnal sleep duration on weekends was significantly longer than that on weekdays ( $p<0.001$ ).

2) The average daytime sleep duration on weekdays of the 0-year-old group was 2 hrs and 44 min; that of the 1-year-old group, 2 hrs and 20 min; that of the 2-year-old group, 2 hrs and 4 min; that of the 3-year-old group, 1 hr and 41 min; that of the 4-year-old group, 1 hr and 16 min; that of the 5-year-old group, 1 hr and 0 min; and that of the 6-year-old group, 0 hr and 53 min. On weekends, the average daytime sleep duration of the 0-year-old group was 2 hrs and 31 min; that of the 1-year-old group, 1 hr and 57 min; that of the 2-year-old group, 1 hr and 35 min; that of the 3-year-old group, 1 hr and 7 min; that of the 4-year-old group, 0 hr and 42 min; that of the 5-year-old group, 0 hr and 26 min; and that of the 6-year-old group, 0 hr and 16 min.

Their daytime sleep duration significantly decreased with age (trend test:  $p<0.001$ ) from 0 year to 6 years old and their daytime sleep duration on weekends was significantly shorter than that on weekdays ( $p<0.001$ ). In addition, it was found that the difference in their daytime sleep duration between weekdays and weekends significantly increased with age (Table 2 and Figure 2).

The daytime sleep duration of the children decreased with age from 0 year to 6 years of age. Comparisons between all age groups, adjusted for multiplicity of the daytime sleep duration on weekdays and weekends, are shows the significant difference ( $p<0.001$ ) in the daytime sleep duration between any of the adjacent age groups except between the 5-year-old and 6-year-old groups.

**Table 2. Nocturnal Sleep Duration, Daytime Sleep Duration and Total Sleep Duration of the Age Groups on Weekdays and Weekends.** This is a cross tabulation table comparing the daytime sleep duration, nocturnal sleep duration and total sleep duration between weekdays and weekends. The average durations, first quartiles, medians and third quartiles are indicated by hour and minutes, and SDs (standard deviations) are by minutes.

	Age	Number of subjects	Daytime Sleep Duration (hr:min)					Nocturnal Sleep Duration (hr:min)					Total Sleep Duration (hr:min)				
			Ave.	SD	1st quartile	Median	3rd quartile	Ave.	SD	1st quartile	Median	3rd quartile	Ave.	SD	1st quartile	Median	3rd quartile
Weekdays	0 mo. to 11mos.	236	2:44	45	2:18	2:39	3:09	9:22	46	8:51	9:21	9:51	12:06	59	11:30	12:00	12:39
	1 yr. to 1yr. & 11 mos.	1532	2:20	30	2:06	2:21	2:37	9:22	36	9:00	9:23	9:45	11:42	41	11:18	11:42	12:09
	2 yrs. to 2 yrs. & 11 mos.	1319	2:04	29	1:48	2:06	2:24	9:17	33	8:54	9:18	9:39	11:21	37	10:57	11:23	11:45
	3 yrs. to 3 yrs. & 11 mos.	842	1:41	32	1:21	1:42	2:03	9:17	34	8:57	9:18	9:39	10:58	38	10:33	10:57	11:21
	4 yrs. to 4 yrs. & 11 mos.	478	1:16	36	0:54	1:21	1:42	9:20	34	8:57	9:18	9:42	10:36	39	10:09	10:36	11:02
	5 yrs. to 5 yrs. & 11 mos.	355	1:00	37	0:30	1:07	1:30	9:16	38	8:51	9:15	9:42	10:16	43	9:45	10:18	10:48
	6 yrs. to 6 yrs. & 11 mos.	119	0:53	38	0:15	0:57	1:24	9:12	35	8:47	9:06	9:33	10:04	39	9:39	9:57	10:32
All the age groups	4881	1:56	43	1:30	2:00	2:24	9:19	35	8:57	9:18	9:42	11:15	51	10:42	11:18	11:48	
Weekends	0 mo. to 11mos.	236	2:31	62	1:53	2:30	3:00	9:36	53	9:00	9:38	10:08	12:07	81	11:15	12:15	12:53
	1 yr. to 1yr. & 11 mos.	1532	1:57	45	1:30	2:00	2:23	9:37	45	9:08	9:38	10:08	11:34	57	11:00	11:38	12:08
	2 yrs. to 2 yrs. & 11 mos.	1319	1:35	45	1:08	1:38	2:08	9:39	42	9:08	9:38	10:08	11:14	51	10:45	11:15	11:53
	3 yrs. to 3 yrs. & 11 mos.	842	1:07	45	0:30	1:08	1:38	9:43	45	9:15	9:45	10:08	10:51	52	10:15	10:53	11:23
	4 yrs. to 4 yrs. & 11 mos.	478	0:42	42	0:00	0:30	1:08	9:42	43	9:15	9:45	10:08	10:24	49	9:53	10:23	10:58
	5 yrs. to 5 yrs. & 11 mos.	355	0:26	34	0:00	0:15	0:38	9:40	40	9:08	9:45	10:08	10:06	47	9:30	10:08	10:30
	6 yrs. to 6 yrs. & 11 mos.	119	0:16	26	0:00	0:00	0:23	9:36	45	9:04	9:38	10:00	9:53	46	9:21	9:53	10:23
All the age groups	4881	1:28	56	0:45	1:30	2:08	9:39	44	9:08	9:38	10:08	11:07	63	10:23	11:08	11:53	
																	SD : Standard deviation

**Figure 2. Nocturnal Sleep Duration and Daytime Sleep Duration of the Age Groups on Weekdays and Weekends.** The bar graph shows the average duration and the lines extending above the bar graphs show the SDs (standard deviations). The four bars of each age group represent, from the left to right, the nocturnal sleep duration on weekdays, daytime sleep duration on weekdays, nocturnal sleep duration on weekends and daytime sleep duration on weekends. Although the nocturnal sleep duration on weekends is clearly longer than that on weekdays (\*\* $P < 0.01$ , \*\*\* $P < 0.001$ ), the average nocturnal sleep durations on both weekdays and weekends do not change with age and is almost the same. On the other hand, daytime sleep duration clearly decreases with age. Since the nocturnal sleep duration does not decrease with age, shortening of total sleep duration in a day is associated with the decrease in daytime sleep duration.

[Comparison between Weekdays and Weekends]

The difference in nocturnal sleep duration and daytime sleep duration between weekdays and weekends was studied.

1) Nocturnal sleep duration

The nocturnal sleep duration of all the age groups on weekends was significantly longer than that on weekdays (with the significant difference indicated by  $p < 0.01$  of the 0-year-old group and by  $p < 0.001$  of the groups from 1 to 6 years old).

2) Daytime sleep duration

The daytime sleep duration of all the age groups on weekdays was significantly longer than that on weekends (with the significant difference indicated by  $p < 0.01$  of the 0-year-old group and by  $p < 0.001$  of the groups from 1 to 6 years old). The result is opposite to their nocturnal sleep duration. The difference in daytime sleep duration between weekdays and weekends increased with age (in other words, the children of older age groups take less or almost no daytime sleep on weekends while they take daytime sleep on weekdays).

### 2.3. Relation between Night Sleep-Onset Time and Morning Wake Time (Table 3 and Figure 3A,3B)

The relation between the night sleep-onset time and morning wake time on weekdays was studied and the tendency of later sleep-onset time to lead to later wake time was found (Figure 3A). The subjects were divided into four groups by the sleep-onset time not later than 21:00 or after 21:00 and the wake time not later than 7:00 or after 7:00. The four groups were classified as 1) the group

with sufficient sleep whose sleep-onset time was not later than 21:00 and wake time not later than 7:00, 2) the group with excessive sleep whose sleep-onset time was not later than 21:00 and wake time after 7:00, 3) the group with sleep deprivation whose sleep-onset time was after 21:00 and wake time not later than 7:00, and 4) the group with delayed sleep phase whose sleep-onset time was after 21:00 and wake time after 7:00.

Then the relation between the sleep-onset time on weekdays and the wake time on weekends was studied, 80.3% of the weekday sufficient sleep group remained there on weekends, and 85.1% of the weekday excessive sleep group also remained in the same group on weekends. On the other hand, 48.8% of the weekday sleep deprivation group delayed waking time on weekends. It was found that the children with later sleep-onset time on weekdays were apt to wake later on weekends (Table 3 and Figure 3B).

**Table 3.** Shift to weekend sleep categories by weekday sleep category.

**Figure 3. A-3B: Relation between Sleep-onset Time on Weekdays and Wake Time on Weekdays and Weekends.** The graph was a heat map plotting on the x-axis the sleep-onset time of all the subjects on weekdays, and on the y-axis the wake time of all the subjects on weekdays (A) and on weekends (B). The vertical line separates the groups that started sleep not later than 21:00 and after 21:00 and the horizontal line separates the groups that woke not later than 7:00 and after 7:00. The lower right quarter of the graph suggests a tendency of chronic sleep deprivation, and the upper right quarter suggests a backward shift in life (chronobiological) rhythm.

### 3. Discussion

When evaluating sleep-wake rhythm, it is difficult to understand the entire daily life rhythm of subjects only by frequently-used sleep-onset and wake-up time records. In this study, we used 2-week sleep record tables which enabled the overview of the entire daily life rhythm of the subjects [9].

The evaluation of time spending and life rhythm on weekends was an important part of the study and sleep records of at least two weekends were required considering that special events, such as trips, might occur on weekends. On the other hand, it was pointed out that sleep records of children reported by their guardians could be less accurate than the records by an actigraphy and the sleep time recorded by parents was longer (by 24 to 45 min) than that by an actigraphy [10–12]. However, in another study, sleep record tables were considered clinically useful enough with recognition of the shortcoming [13,14]. Indeed, in our previous study, we observed that the actigraphy judged motionless subjects as sleeping and recorded longer sleep times than the actual sleep time.

In Japan, it is common for guardians (mainly parents) to share a bedroom with their infants and young children, and it is estimated that such parental observations are relatively more accurate. According to these factors, it is conceived that the use of sleep record charts in clinical settings is meaningful enough at this time.

In this study, sleep onset time and wake up time gradually shifted after birth, becoming just over 30 and 20 minutes more later by age 2, respectively. On the other hand, almost no changes were observed in these items after that (Figure 1, Table 1). It is speculated that this phenomenon may be due to the circadian rhythm formation is completed by about one and a half years of age [15,16], and/or the influence of the daily living environment after birth [17–19], but we have no definitive explanation.

The night sleep-onset time was not different between weekdays and weekends while the morning wake-up time on weekends was significantly later than that on weekdays. Along with the later wake-up time on weekends, nap on weekends was obviously shorter than that on weekdays. This will be explained as that the children compensated for their night time sleep deprivation on weekdays by taking longer nap on weekdays and slept longer on weekends morning [12,20]. There is an idea that the sleep-wake rhythm on weekends is suitable as an index to express the original life rhythm for many children. In our data, the total sleep on weekends of the subjects 6 years of age, who are supposed to have no day time sleep in preparation for future school life, is approximately 10 hours on both weekdays and weekends.

The data showed that the decline in total daily sleep time with age was due to a decrease in daytime sleep time, which began to disappear at age 3, while nighttime sleep time remained constant across all age groups. This average 10 hours sleep duration is considered to be required by Japanese children as basically necessary nighttime sleep, so we defined it as “nighttime basic sleep duration (NBSD) [4]”.

Almost similar results have been reported in Switzerland [21], England [22] and Canada [16]. In Switzerland, the average nighttime sleep duration for children aged 1 to 5 years is more than 11 hours (11.7 to 11.1 hours), in the United Kingdom, that for children aged 1 to 6 years is approximately 11 hours, and in Canadian, that for children aged 6 months to 4 years is 10 hours (47.6%) or 11 hours (42.8%), respectively. Interestingly, these papers report that total sleep time decreases with age, but nighttime sleep time shows little change. The report from Switzerland [21] found that nighttime sleep duration increased slightly from infancy to 1-3 years of age, then returned to the infant level by 5-6 years of age. This can be interpreted as meaning that there was no significant increase or decrease in the overall 1-6 year of age group.

Although neither report pays particular attention to this almost fixed nighttime sleep duration, the data in these reports commonly show that nighttime sleep duration does not change much from early childhood to 6 years of age and daytime sleep duration gradually decreases to disappear at the age of 2-5 [23], at latest 7 year of age [24].

The duration of nighttime sleep in the above countries is mainly 11 hours, which is slightly longer than 10 hours in this report. Longer sleep time of Caucasian children than children in Asian countries was also reported by Mindell et al. in 2010 [25]. The report mentioned that the average nighttime sleep duration of Japanese children aged 0-3 years was 9 hours and 42 minutes, which is almost the same as weekends sleep duration in this study.

It is speculated that the reason why Western parenting books recommend that infants fall asleep between 7-8 p.m. is due to the length of nighttime sleep. The difference of sleep duration may be ascribed to cultural difference, such as bedroom sharing, and difference between races. Further, the difference may be derived from difference in the temperature of living environment between Asia having comparatively warm weather and Europe or the United States locating more north, because human beings sleep shorter in summer and longer in winter. Actually, a survey of sleep time (of people aged from 16 to 65) by NHK (NIPPON HOSO KYOKAI: Japan Broadcasting Corporation) in 1960 reported that the average sleep time in summer was 8 hours and 4 minutes and that in winter was 8 hours and 40 minutes.

In this report, children were divided into the following four groups based on average about 10 hours NBSD and their daily life rhythms (Fig. 3-A,B) : 1) Group with sufficient sleep, 2) Group with excessive sleep, 3) Group with sleep deprivation, 4) Group with delayed sleep phase. Group 1 is children who fall asleep before 9 pm and wake up by 7am; group 2 is children who fall asleep before 9pm but wake up after 7am, indicating that they need more than 10 hours of sleep; Group 3 is children who fall asleep after 9pm and wake up by 7am, their daily sleep is clearly less than 10 hours and there are concerns about lack of sleep; and group 4 is a group of children who fall asleep after 9pm and wake up after 7am, indicating that there is a shift in their daily rhythm backwards. These data show that number of children need some adjustment in their daily life rhythm.

For example, children in Group 2 need to have more than 10 hours of sleep before waking up in the morning, so they need to get into the habit of falling asleep earlier, such as at 7 or 8 pm to avoid sleep loss, while children in Group 3 need to get into the habit of falling asleep by 9 pm. It is particularly important to understand the NBSD of each child in all group, especially in Group 4, and ensuring that each NBSD is met by an appropriate time to wake up in the morning is necessary for maintaining healthy, socially well-adjusted, and balanced mental/physical development.

The children who woke late for compensation of their sleep shortage on weekends, mainly belong to group 3) and 4), were found to falling asleep later usually and have insufficient sleep until 7 am (refer to Figure 3-A,B).

In addition, some children waking late on weekends kept unbalanced sleep-onset time and wake time. In a few cases, children with almost proper night sleep-onset time, such as 21:00, could not take sufficient sleep because of their early morning wake time, such as 5:00, due to the schedule of their families. One of the reasons of the obviously later wake time on weekends than weekdays is that the subjects are the children going to nurseries. A study reported that children who go to nurseries because of their parents leaving home early in the morning for their works are more apt to have nocturnal life habits than children going to kindergartens and having either of parents always staying at home. The situation, however, is estimated to be common not only to the children going to nurseries but also to all children in Japan [26]. The current sleep-onset time of 30 % [1] of children in Kizugawa, Japan, has been reported to be later than 22:00. In our study, the sleep-onset time of 10 % or more of the subjects on weekdays and the sleep-onset time of 15 % or more of the subjects on weekends were later than 22:00. Such children are required to wake up from 6:00 to 7:00 in the morning in the present-day school-social life and the decreased sleep time causes chronic sleep deprivation. As mentioned above, even small amounts of sleep restriction in children could cause a risk of unpredictable disorder of their emotional and cognitive functioning [2].

The late morning wake time on weekends, which is usually seen in Japanese society, is also common in the world as reported from Hong Kong, Korea, Canada, Norway, U.S.A., and Australia [20,27–31]. It has been estimated that the daily life rhythm of children is strongly influenced by the daily life rhythm of their family to result in their sleep deprivation on weekdays which is compensated by extended nap time on weekdays and late morning wake time on weekends [9,20].

The study showed that sleep duration on weekend nights was statistically longer than on weekdays for all age groups, suggesting that preschool children are persistently slightly sleep deprived on weekdays.

Considering that the weekend sleep duration is more appropriate for children, the sleep duration at least 9 hours and 40 minutes is necessary every night, in our data. In addition, it implies the importance of sufficiently long nighttime sleep duration [32,33].

Nap-time sleep usually shortens with age and tends to be shorter on weekends than weekdays. In other words, nighttime sleep duration is longer and nap-time sleep is shorter on weekends. This means that securing individual NBSD leads to shorter nap-time sleep [34]. A study reported that the youngest age of the children who stopped napping was 2 years [23], and in our study the youngest children who stopped napping was about 3 years old. Nurseries in Japan are apt to encourage children to take naps and even children aged 5 or 6 years usually take naps at nurseries. However, many children aged 5 or 6 years do not take naps at home on weekends, and a study reported that 90% or more of children stop napping at the age of 5 years [24].

At nurseries, children taking insufficient nocturnal sleep can compensate the shortage by taking naps. However, the children aged 5 or 6 years would enter primary school (school starts in April in Japan) 6 months after the study (in September) to start a life without daytime sleep. Therefore, sleep time required for children must be covered by nighttime sleep without compensation by napping. It is adequate to consider that the sufficient sleep for children should not be satisfied by the total of nighttime sleep plus nap-time sleep but must be basically satisfied by appropriate individual NBSD and, if necessary, by nap. A former study reported that all children stop napping by the age of 7 [24] and it is construed that those children cannot take naps at school. Children better stop napping before entering elementary school and securing NBSD is the required condition to stop napping in Japan. Such life habit without napping cannot be achieved in a short period of time but rather needs to be gradually formed into a daily rhythm from an early stage in infancy.

In another study, we found that the average nighttime sleep duration of children of early elementary grades (6 to 9 years of age) in Japan is about 9 hours and 45 minutes (the data not shown herein) and almost similar to that of on weekends of the nursery children of this study. The finding implies that the nocturnal sleep time of young children on weekends in this study is similar to the sleep time naturally required for children. To put it the other way around, the data in this study prove that some children have insufficient sleep time on weekdays or have a habit of waking after 7 a.m. in the morning due to a shift in their living hours. Life rhythm is the basic factor to create biological clock of children and we cannot ignore the number of children whose biological clocks have shifted [4,5].

In the preparation of entering elementary school, it is important for children to make the habit of waking by themselves at 6 to 7 a.m. in the morning in order to enable the attendance to classes beginning at around 8:00~8:30. For securing NBSD (about 10 hours on average in Japan and 10 to 11 hours in Western countries)[16,21–23] before waking at 6 to 7 a.m., the appropriate sleep-onset time falls within the range from 7 to before 9 p.m.

A life rhythm with no difference in sleep-onset and wake times between weekdays and weekends and with sufficient sleep secured before 6 or 7 a.m. in the morning is necessary for children to adapt to their school/social life and it protects their mental and physical health through their life.

The result of this study proves that the period of a day to take sleep is important for considering children's sleep rather than paying attention only to the shortage of total sleep time. Children are involved in school/social life in the society and cannot ignore the schedule of their school life for creating their biological clock. When children acquired properly created circadian rhythm which is mainly composed of sleep-wake rhythm and conformable to their school life, they can live healthy school/social life physically and mentally. A gap between their biological clock and the schedule of school activities causes social-jet-lag that leads to many problems they face in school life. Greater the jet-lag, more overload they feel to follow school life. This will finally cause confusion of the biological clock of all parts of their bodies [35–38].

Recently, it has been reported that biological clock created in childhood including fetal and neonatal periods affects the future development and physical and mental health of the children. Thus, the importance of biological clock creation has been discussed [39,40]. The background of the discussion includes several reports mentioning that shifted or disturbed circadian rhythm increases

the risks of future health damage. For example, several studies reported that disturbed circadian rhythm induces chronic inflammation in the body to shorten its life [41], infants completing their life rhythm to match circadian rhythm have low risk of receiving medical treatment for diseases at the age of 6 years [42], changes in sleep behavior of young children significantly relate to the changes in their emotional functioning, attentiveness and physical behavior in the daytime [43–45], and solving sleep problems is important to improve the behaviors of children with neurodevelopmental disorder [46–48]. These studies have proved the importance of creating circadian sleep-wake rhythm in infancy and childhood.

In fact, many of the children with the problems mentioned in the introduction are included in groups 2)-4), and it is speculated that the disruption of daily rhythms has a negative impact on the balance of children's mental and physical development and emotional balance. Conversely, it has been suggested that these disruptions to daily rhythms suggest variations in children's vital functions, and that this irregularity in daily rhythms may actually impair the balance of children's mental and physical development [4]. In addition, in clinical terms, it has been reported that correcting disruptions to daily rhythms can restore balanced mental and physical functions [49]. Through this study, we would like to emphasize that the establishment of a daily rhythm centered on the time of daily life is an important factor for the mental and physical growth of children.

#### 4. Conclusions

It is suggested that not only the length of sleep duration but also the appropriate sleep time-zone is an important factor in supporting children's balanced physical/mental development. Guardians should first know their child's required exact nighttime basic sleep duration (NBSD) and establish an appropriate bedtime that ensures that NBSD by the time they should wake up in the morning (before 7am in Japan), thereby preventing the accumulation of sleep deprivation and shifts in daily rhythms, including social jet lag.

We would like to emphasize that this proper daily rhythm is may be essential for maintaining a balanced mental/physical development and school-social adaptation, since it synchronizes all the gears of the life sustaining biological clock. Furthermore, these recommended daily rhythms are best introduced before 18 months and 2 years of age, when the central circadian rhythm is established in the suprachiasmatic nucleus, which has a positive impact on the mental and physical health of not only the children but also, ultimately, their guardians.

#### 5. Methods

We intended to study about all the young children aged from 2 months to 6 years and 7 months who were attending, in 2013, 2014 and 2016, the licensed nurseries, nurseries authorized by Tokyo Metropolitan Government, in-hospital childcare centers and corporate nurseries operated by A-Childcare Corporation (ACC). The data of 4881 children were analyzed. (They were 236 babies aged less than 1 year, 1,532 children aged 1 year to less than 2 years, 1,319 children aged 2 years to less than 3 years, 842 children aged 3 years to less than 4 years, 478 children aged 4 years to less than 5 years, 355 children aged 5 years to less than 6 years and 119 children aged 6 years to less than 7 years.) The study complies with the Declaration of Helsinki and was approved by the ethics committees of the ACC and H- Prefectural Central Rehabilitation Hospital. All the parents of the children provided written informed consent prior to their enrollment in the study. All analyses were performed in accordance with the Ethical Guidelines for Epidemiological Research in Japan.

[Period of Measurement]

The state of sleeping and waking of the subjects were recorded for two weeks (14 days), from the 2nd to 15th in September 2013, from the 2nd to 15th in September 2014 and from the 5th to 18th in September 2016.

[Measurement Data]

The data of sleep-wake state was obtained using a sleep log form in which cells representing every 30 minutes in 24 hours were filled out to record sleep time continuously for two weeks. The sleep log forms were handed to the parents before starting the sleep measurement and they were

asked to fill the form to record the sleep-wake state of their children at home for two weeks. The sleep-wake state of the children at nurseries were recorded by the staff and the record was transcribed to their sleep log forms after the sleep measurement period.

The birth dates of the subject children and the names of the nurseries where they were attending were recorded as the basic data.

[Definition of Analysis Items]

### 5.1. Night Sleep-Onset Time

The night sleep-onset time was defined as a time after 18:00 in the evening after which the children were sleeping 1.5 hours or longer. If a sleep-onset time by the definition was 24:30 or later, the earlier of the two shown below was recorded as the night sleep-onset time.

1) A time after 18:00 when the children fell asleep and continued to sleep for 0.5 hours followed by waking for 0.5 hours or longer and then sleeping for 0.5 hours or longer.

2) A time after 18:00 when the children fell asleep and continued to sleep for 1 hour or longer.

If the children slept only for 0.5 hours during the period from 19:00 to 7:00 in the next morning, the time when the children started sleeping was recorded as the night sleep-onset time.

If a night sleep-onset time was after 24:00, the time was reported by adding 24. For example, the sleep-onset time at 1:30 in the morning was reported as 25.5.

### 5.2. Morning Wake Time

The morning wake time was defined as a time after 4:00 in the morning when the children woke and continued to wake for 2 hours or longer. If a wake time by the definition was 7:30 or later, a time after 4:00 in the morning after which the children was waking continuously for 1.5 hours or longer was recorded as the morning wake time. Further, if a wake time by the definition was 10:30 or later, a time after 4:00 in the morning after which the children was waking continuously for 1 hour or longer was reported as the morning wake time.

### 5.3. Total Sleep Duration

If sleeping or waking of a subject is recorded at each of 48 points of time (where a period between two adjacent points of time equals to 30 minutes) from 0:00 to 23:30 on the day of measurement and is described to be  $S(t)$ , total sleep duration is represented by the following formula, where it is the points of time mentioned above and  $S(t)$  is 1 (sleeping) or 0 (waking)).

$$\text{Total sleep duration} = \frac{\sum_{t=0:00}^{23:30} S(t)}{2}$$

### 5.4. Nocturnal Sleep Duration

The sleep time from the night sleep-onset time to the morning wake time is the nocturnal sleep duration and represented by the following formula.

$$\begin{aligned} & \text{Nocturnal sleep duration} \\ &= \frac{\sum_{t=\text{Night sleep-onset time}}^{23:30} S(t) + \sum_{t=0:00}^{\text{Morning wake time}-30} S(t)}{2} \end{aligned}$$

### 5.5. Daytime Sleep Duration

The daytime sleep duration is calculated by subtracting the nocturnal sleep duration from the total sleep duration.

[Statistical Analysis]

We analyzed the sleep logs of the young children whose age at the survey was recorded and whose data included analyzable sleep logs of at least 8 weekdays and at least 3 weekend days.

The summary statistic values (number of cases, average, standard deviation (SD), first quartiles, medians, and third quartiles) of the night sleep-onset time, morning wake time, total sleep duration, nocturnal sleep duration and daytime sleep duration were calculated. The statistical test was conducted by two-way analysis of variance (ANOVA), in which the factors were the day (weekdays and weekends) of the measurement, the age of the subjects and interaction, and multiplicity between time points was adjusted by Tukey-Kramer's method. R Version 4.0.2 (R Foundation for Statistical Computing, Vienna, Austria.) was used for the analysis with the significant difference of  $\pm 5\%$ .

**Author Contributions TH:** SM, TK, KO AT, KT, MN, YK and TM, drafted the manuscript; TH conceptualized and designed the study and protocols, collected data, directed data analysis, drafted the initial manuscript, and approved the final manuscript; SM conceptualized and designed the study and protocols, collected data, reviewed the manuscript, and approved the final manuscript; TK performed the statistical analysis of the data, reviewed and revised the manuscript, and approved the final manuscript; KO performed the statistical analysis of the data, reviewed and revised the manuscript, and approved the final manuscript; AT reviewed and revised the manuscript, and approved the final manuscript; KT reviewed the manuscript, and approved the final manuscript; MN critically reviewed the manuscript, and approved the final manuscript; YK performed the initial analyses, reviewed the manuscript, and approved the final manuscript. All authors contributed to the interpretation of results, reviewed and revised the manuscript critically, and approved the final version, and TM conceptualized and designed the study and protocols, collected data, directed data analysis, drafted the initial manuscript, and approved the final manuscript;

**Informed Consent Statement:** All parents of children provided written informed consent prior to enrollment in the study. Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** The data presented in this study are available on request from the corresponding author due to privacy.

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## Abbreviation

**NBSD:** nighttime basic sleep duration

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