

Effects of Nighttime Sleep Characteristics on Function of Attention Network in Young Children.

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It is well known that the characteristics of nighttime sleep is strongly linked to cognitive abilities in daytime. However, studies investigating the influence of poor-sleep characteristics on pre-adolescent children's cognitive abilities are relatively few. The present study aimed at investigating the influence of night-time sleep characteristics on pre-adolescent children's cognitive abilities by utilizing objective indicators. To achieve this goal, we analyzed the relation between attentional control ability measured by standardized behavioral task and nighttime sleep characteristics quantified by actigraph measurement. The results revealed a significant correlation between ability of executive attention and total sleep time, i.e. total length of uninterrupted sleep. To be more specific, focal attention of children with long total sleep time was more easily distracted by goal-irrelevant information than that of children with short total sleep time, which indicates that sub-component of attentional control subserved by prefrontal cortex is particularly susceptible to sleep characteristics. The implication of this findings are discussed in the context of previous studies on the relation between children's nighttime sleep characteristics and their cognitive functions.

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1. Introduction

Degradation of sleep-characteristics is pervasive problem not only among adults but among pre-adolescent children. It is well known that the characteristics of nighttime sleep is strongly linked to cognitive abilities in daytime. Majority of previous studies on this issue have investigated the influence of sleep-deprivation on cognitive functioning in adult subjects. These studies show that total sleep deprivation drastically impairs adults' performance in cognitive tasks especially when these cognitive tasks require sustained attention and executive function^{1,2}, both of which are supposed to be subserved by the dorsolateral prefrontal cortex³. Similarly, recent studies revealed that sleep-deprivation significantly increases the activity of the amygdala, which indicates that

poor sleep-characteristics not only degrades the cognitive functioning but makes people more emotionally unstable^{4,5}.

Compared to the abundance of researches on adults subjects, studies investigating the influence of poor-sleep characteristics on pre-adolescent children's cognitive abilities are relatively few. A significant portion of this line of research was motivated by clinical observations by Dahl (1996)⁶, who suggested that children suffering from poor sleep characteristics tend to show behavior problem and ADHD (Attention-Deficit/Hyperactivity Disorder) like symptoms. The link between the characteristics of nighttime-sleep and children's behavior problems has been partially confirmed by the later empirical studies. However, the reliability of these results are somewhat limited because these studies largely relied on subjective evaluations and questionnaires⁷⁻¹¹. For example,

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measurement of children's cognitive abilities is often substituted by their academic performance. However, academic performance is influenced by wide-ranging factors such as achievement motivation. Moreover, the relation between academic performance and each type of cognitive abilities is not necessarily clear. The use of self- or parent-administered questionnaire for the purpose of measuring nighttime sleep is even more problematic, because subjective evaluation of nighttime sleep is notoriously unreliable.

The primary aim of the present study is to investigate the influence of night-time sleep characteristics on pre-adolescent children's cognitive abilities by utilizing more objective indicators. To achieve this goal, we analyzed the relation between attentional control ability measured by standardized behavioral task and nighttime sleep characteristics quantified by actigraph measurement.

Actigraph is small wearable device, which counts the number of discrete bodily movements minute-by-minute. Importantly, reliable algorithms have been developed to determine wake-sleep state on the basis of actigraph data. The assessment of activity by actigraph is supposed to be more precise and objective than that using sleep diary, which possibly leads to more reliable observations.

According to Posner and Pettersen (1990)¹², human attentional control system is comprised of three sub-components, each of which is dedicated to the control of arousal, attentional orientation and executive attention. To measure the influence of nighttime sleep characteristics on each of the three sub-components of attentional control system, subjects' attentional control ability was assessed by Attention Network Test (ANT) developed by Posner and his colleagues^{13,14}. Advantage of ANT is that this task measures the function of these sub-components independently with relatively small number of trials, which characteristics is especially beneficial for the study of young children. ANT has been applied to various populations such as healthy children¹³, patients with schizophrenia¹⁵ and ADHD¹⁶, and the neural activations in performing ANT has been clarified by fMRI^{14,17} and ERP measurements¹⁸.

2. Method

2.1 Participants

A total of eighteen healthy children (eight boys and ten girls, $M = 81.8$ months old, $SD = 5.3$) participated in the present study. They had no known medical conditions including developmental disorders and mental retardation at the point of participation. Informed consent was obtained

from the parents after the procedures were fully explained to them. The experimental procedure was approved by ethical committee in Graduate school of Biomedical Sciences in Nagasaki University.

2.2 Procedure

Measurement of nighttime sleep and assessment of attentional control ability by ANT were conducted for every participant. In actigraph recording, bodily movements of the participants was measured by actigraph for four consecutive nights. Participants' attentional control ability was assessed by ANT within one week after the last night of actigraph measurement. The measurement of attentional control ability was always conducted within the time-of-day from 12:00-14:00, and lasted about 20 minutes. The details of actigraph measurement and ANT are described below.

2.2.1 Actigraph Measurement

Activity pattern of the participants were measured in participants' homes. Before the start of recording, the experimenter delivered actigraphs (Ambulatory Monitoring, Ardsley, NY), a sleep diary and questionnaire sheet, and gave both the participants and their parents instructions about how to use these instruments. More than 5 days after the start of recording, the experimenter contacted the mother and visited her again to collect the instruments.

The participants wore an actigraph on the wrist of their non-dominant hand. We stressed that participants should not deviate from their everyday routines. Actigraphs were used in the zero-crossing mode and sampled the number of zero crossings with one minute intervals. Movement data were stored continuously in the memory of the actigraphs along with a time stamp. We asked parents to keep a sleep diary in order to obtain supplementary data useful in the analysis of actigraph data such as the start and stop of actigraph recording.

2.2.2 ANT

The stimuli were generated on a 19 inch color monitor, which was viewed binocularly from a distance of 75 cm. The schematic representation of the time-course of stimulus presentation is shown in Figure 1. On any given trial, a fixation cross is presented at the center of screen. 500 ms after the appearance of fixation cross, a row of five cartoon fishes, each of which subtended 3.0 cm in width and 2.0 cm in height, was presented either above or below the fixation cross. The vertical distance between fixation cross and the row of fishes was about 3.5 cm. The space between two

adjacent fishes was 0.5 cm, which made the horizontal length of the row 17.0 cm.

In half of the trials (Congruent Condition), all the five fishes were pointing in the same direction, while in the remaining half of the trials (Incongruent Condition), the central target fish was pointing in the reverse direction from the other four fishes. In three fourth of the trials, a pink-colored asterisk was flashed just before the appearance of the row of fishes. The location where the asterisk flashed was at the center of the screen (Center Cue Condition), the location where the row of the fish appeared (Congruent Cue Condition), or the location opposite to where the fish appeared (Incongruent Cue Condition). Each of Congruency (Congruent-Incongruent) \times Cue Location (No Cue-Center Cue-Congruent Cue-Incongruent Cue) = 8 conditions were 16 times throughout experiment.

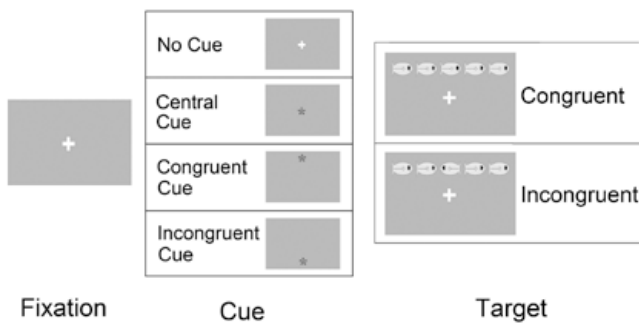


Figure 1. Schematic representation of time-course of stimulus presentation in each condition of ANT.

The participants were instructed to answer the direction of central target fish by pressing hand-held button as soon as possible. They were also told that the location of asterisk and the pointing direction of the other four fishes are not at all predictive of the pointing direction of the central fish.

2.3 Data Analysis

2.3.1 Actigraph Data

After collecting the actigraphs, the data were downloaded to a PC. The background data obtained from questionnaires were stored as electronic files. Before further analysis, the data from the periods before the start and after the stop of recording as identified by sleep diaries were omitted from the analysis. On the basis of these data, three sleep parameters, which characterizes the characteristics of nighttime sleep, were quantified. The definition of each sleep parameter is as follows.

Total Sleep Time (TST) : Length of sleep uninterrupted

by arousal.

Length of Arousal during Sleep (LAS): Total length of wakefulness after participants got to sleep in the night and until got up in the next morning.

Number of Arousal during Sleep (NAS): The frequency with which nighttime sleep was interrupted by arousal.

2.3.2 ANT Data

The outliers were discarded from each participant's RT (Reaction Time) by removing the RTs that were either above or below 2.5 SDs from the mean in each condition¹⁹. On the basis of individual reaction time data, we computed three parameters (ANT scores), Arousal Score, Conflicting Score, Orienting Score, characterizing the function of each sub-component of attentional control system.

Alerting Score was computed by subtracting mean RT in the Central Cue condition from that in the No Cue condition. Presentation of central cue is supposed to enhance the participant's arousal state and shorten RT in the Central Cue condition. Thus, participants with superior ability of arousal state control show *larger* Alerting Score.

Conflicting Score is the indicator of executive attention function computed by subtracting RT in the Congruent condition from that in the Incongruent condition. In the Incongruent condition, direction information of the peripheral distractor fishes interfere with the direction discrimination of the central target fish. Participant with superior ability of executive attention can filter out the interference from distractor fishes, which shortens the reaction time in the Incongruent condition. Thus, participants with superior ability of executive attention are supposed to show *smaller* Conflicting Score.

Lastly, Orienting Score is computed by subtracting RT in the Congruent Cue condition from the Incongruent Cue condition. Presentation of asterisk automatically attracts visuo-spatial attention to the location where it appears. Thus, in order for the participants to focus their attention on the target fish, additional operation of shifting attentional-focus from asterisk to the location of target fish is required in the Incongruent Cue condition. Participants with superior ability of attention orienting require less time to shift their attentional focus in the Incongruent Cue condition, which makes their Orienting Score *smaller*.

3. Results

The participants have dutifully complied with the procedures of actigraph measurement, and completed ANT

without difficulty. Therefore, the data from all the eighteen participants were submitted for further analyses.

The inter-participant means of each sleep parameter are summarized in Table 1 together with standard deviations. To examine the relation between sleep parameters and ANT scores, Pearson' correlation coefficients were calculated for every pair of sleep parameters and ANT scores. The correlation coefficients are summarized in Table 2.

This analysis revealed that TST correlated significantly with Conflicting Score, $r(16) = 0.79, p < .05$. The scatterplot between total sleep time and Conflicting Score is depicted in Figure 2. No other significant correlations were obtained, r^2 values $< .25, p$ values $> .10$.

Table 1. Inter-participant mean of sleep parameters. In the parentheses are standard deviations.

TST	LAS	NAS
546.6 (31.4)	18.5 (21.7)	4.3 (3.3)

TST: Total Sleep Time (in min), LAS: Length of Arousal during Sleep (in min), NAS: Number of Arousal during Sleep.

Table 2. The correlation coefficients between ANT scores and sleep parameters.

	Alerting Score	Orienting Score	Conflicting Score
TST	0.22	0.311	0.78*
LAS	0.36	-0.11	0.08
NAS	0.31	-0.11	0.04

TST: Total Sleep Time, LAS: Length of Arousal during Sleep, NAS: Number of Arousal during Sleep. * $p < .05$.

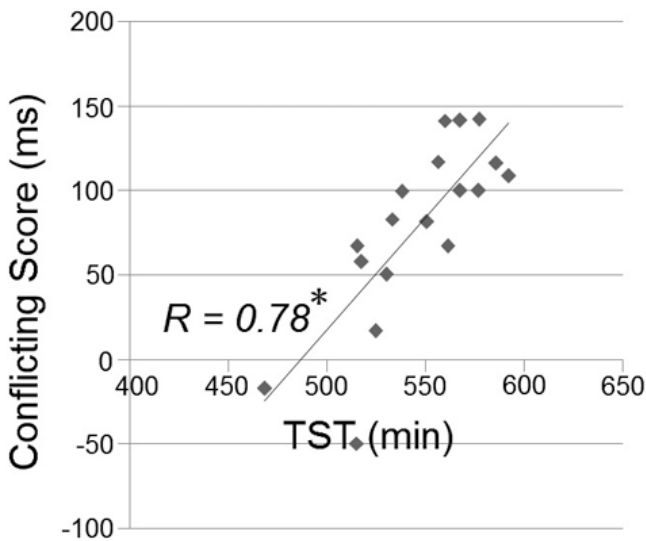


Figure 2. Scatterplot between TST and Conflicting Score.

In order to further clarify the source of the significant correlation between Conflicting Score and TST, the relation between TST and RTs in the Congruent and Incongruent conditions were analyzed. In this analysis, the participant were split into two groups (Long and Short TST Group) by the inter-participant median of TST as criterion. The demographic distribution, sleep parameters and ANT scores in these groups are summarized in Table 3. Proportion of the number of girls did not differ across groups, $Z = 0.94, p > .10$. Long TST group showed significantly longer TST than Short TST group, $t(16) = 5.45, p < .01$, as expected. There were no significant differences between groups in Age, $t(16) = 0.13, p > .10$, LAS, $t(16) = 0.36, p > .10$, and NAS, $t(16) = 0.19, p > .10$. As for group differences in ANT scores, Alerting Score did not differ between TST groups, $t(16) = 0.21, p > .10$. The Long TST group tended to show larger Orienting Score than Short TST group, $t(16) = 2.07, p < .06$, but the difference failed to reach significance. Conflicting Score was significantly larger in Long TST group than in Short TST group, $t(16) = 3.62, p < .01$.

Table 3. Inter-participant mean of demographic data, sleep parameters and ANT scores in Short and Long TST groups. In the parenthesis are standard deviations.

	Group	
	Short	Long
Age (in months)	83.4 (4.6)	80.2 (6.6)
Number of Girls	6	4
TST (min)	521.6 (23.1)	571.6 (12.2)
LAS (min)	16.5 (10.9)	20.5 (29.6)
NAS (min)	4.1 (2.6)	4.5 (3.9)
Alerting Score (ms)	23.3 (62.4)	30.6 (74.0)
Orienting Score (ms)	39.8 (81.9)	141.1 [#] (111.7)
Conflicting Score (ms)	43.3 (49.9)	114.8** (24.8)

TST: Total Sleep Time, LAS: Length of Arousal during Sleep, NAS: Number of Arousal during Sleep. ** $p < .01, ^{\#}p < .10$ for the difference between groups.

The RT data were entered into two-way analysis of variance (ANOVA) with within-participant factor of Congruency (2) and between-participant factor of Group (2). The inter-participant mean of RT in each of Group (2) x Congruency (2) = 4 conditions are depicted in Figure 3. The main effect of Group failed to reach significance, $F(1, 16) = 1.81, p > .10$, but there was a significant main effect of Congruency, $F(1, 16) = 71.03, p < .01$. Importantly, these main effects were qualified by a significant interaction between Group and Congruency, $F(1, 16) = 14.63, p < .05$.

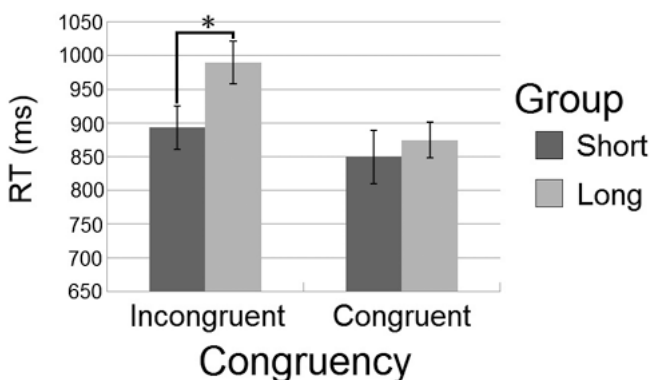


Figure 3. The inter-participant mean of RT in each of Group (2) x Congruency (2) = 4 conditions. * $p < .05$ for the simple main effect of Group.

The simple main effect analysis revealed that RTs in the Long TST group was significantly longer than those in the Short TST group, $F(1, 32) = 4.35, p < .05$, in the Incongruent condition, but no such trend was found in the Congruent condition, $F(1, 32) = 0.31, p > .10$. The simple main effect of Congruency reached significance in both the Short, $F(1, 16) = 10.59, p < .01$, and Long TST groups, $F(1, 16) = 75.06, p < .01$.

4. Discussion

The primary aim of the present study is to investigate the influence of night-time sleep characteristics on pre-adolescent children's cognitive abilities by utilizing objective indicators. More specifically, we monitored children's nighttime sleep by actigraph, and quantified their characteristics by computing sleep parameters. The participants' attentional ability is measured by standardized ANT^{13,14}. The results revealed a significant positive correlation between Conflicting Score and TST. Furthermore, participants with longer TST showed significantly larger RT than those with shorter TST in the Incongruent condition but not in the Congruent condition.

According to an influential model of neural network of attentional control, each component of attentional control¹², i.e. alerting, orienting and executive attention, is subserved by partially overlapping, but dissociable neural regions. Later studies have shown that control of arousal state is mediated by right fronto-parietal regions²⁰, and attention orienting is subserved by temporo-parietal junction²¹. Executive attention, which is reflected in Conflicting Score, is supposed to be more strongly associated with prefrontal regions such as dorsolateral prefrontal and anterior cingulate cortex¹⁷. On the basis of these studies, the present finding that only Conflicting Score was susceptible to characteristics of nighttime sleep seems to indicate that goal-directed executive control of attention is most vulnerable to characteristics of nighttime sleep. This interpretation concurs with a large number of neuroimaging studies showing that prefrontal function is strongly influenced by sleep deprivation^{2,3}. On the other hand, Orienting Score in long TST group tended to be larger than that in short TST group, which indicates the possibility that children with long TST exhibit deficiency in attention orienting as well as executive attention. Although the difference between groups failed to reach significance, this might be attributable to weak power of statistics. Considering these, it is quite possible that night time sleep characteristics exert their influences on attentional network outside frontal regions.

One may find it strange that children with long TST showed larger Conflicting Score, which indicates that selective attention of children with long TST is more easily distracted by goal-irrelevant information than that of children with short TST. This seems to contradict previous findings that children with longer nighttime sleep suffers less from inattention and impulsivity⁷⁻¹¹.

The cause for this discrepancy is not clear at this point. However, we have several tentative explanations for this point. First, larger interference from distractors in children with long TST might be the result of relatively positive mood induced by good characteristics of nighttime sleep. In traditional "moving spot-light theory" of attention, the function of visuo-spatial attention is likened to a spot-light²². That is, an object within the breadth of spot-light of attention, "the attentional spot-light", is prioritized in visual processing, and vice versa. When one has larger attentional spotlight, larger amount of goal-irrelevant information gets within the range of attentional spotlight, which makes him/her more vulnerable to interferences from goal-irrelevant information and consequently enlarges Conflicting Score. Importantly, recent study by Rowe, Hirsh, and Anderson (2007)²³ has shown that induction of positive mood widens

the breadth of attentional spotlight. On the basis of this, it seems possible that larger Conflicting Score might have been observed as a by-product of positive mood in children with long TST.

The second hypothesis is that there is optimal length of nighttime sleep for this age of children, which indicates that the relation between conflicting score and TST is V-shaped. To be more specific, the Conflicting Score hits the bottom at the certain length of TST, and increases as the distance between actual TST and the optimal value of TST gets larger. On the basis of this model, it may be because the participants' TSTs were longer than the optimal TST that positive correlation between Conflicting Score and TST was obtained in the present study. In fact, the mean TST of participants in the present study is about 40-70 minutes longer than the sleep length of children with the same chronological age reported in large-scale studies using polysomnography^{24,25} and actigraph²⁶. Another implication of this hypothesis is that negative correlation might be observed between TST and Conflicting Score, if we recruit children, whose TSTs are shorter than the hypothetical optimal TST. This hypothesis seems appealing because it can resolve the contradiction between the present and the previous findings. However, it apparently lacks empirical basis, and as such the future study should include larger sample of children to verify the validity of this hypothesis.

The interpretations of the present findings are limited by the following shortcomings. First, we did not measure children's cognitive functions other than attentional control. Behavioral data such as RT is end-product of large numbers of cognitive operations, and as such it is hard to pinpoint the stage at which the characteristics of nighttime sleep exerts its influences using only one type of behavioral task. Thus, it is an important step in the future study to include larger battery of behavioral tasks, and hopefully concurrent measurement brain activations, in order to clarify the mechanism through which the nighttime sleep characteristics influences children's executive attention.

Secondly, the present findings are correlational, which leaves it unanswered whether there actually was causal link between sleep characteristics and attentional control ability. Although restriction^{27,28}, let alone total deprivation, of nighttime sleep for children should be conducted very carefully for both ethical reason and safety concerns, such approach could potentially be quite helpful not in examining the causal effect of nighttime sleep characteristics but in determining whether cognitive functions of young children can benefit from active intervention to sleep hygiene.

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