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Body Movement Analysis during Sleep for Children with ADHD Using Video Image Processing

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Abstract— **In recent years, the amount of children with sleep disorders that cause arousal during sleep or light sleep is increasing. Attention-deficit hyperactivity disorder (ADHD) is a cause of this sleep disorder; children with ADHD have frequent body movement during sleep. Therefore, we investigated the body movement during sleep of children with and without ADHD using video imaging. We analysed large gross body movements (GM) that occur and obtained the GM rate and the rest duration. There were differences between the body movements of children with ADHD and normally developed children. The children with ADHD moved frequently, so their rest duration was shorter than that of the normally developed children. Additionally, the rate of gross body movement indicated a significant difference in REM sleep ($p < 0.05$). In the future, we will develop a new device that can easily diagnose children with ADHD, using video image processing.**

I. Introduction

Sleep is important for children to develop normally and to maintain brain and body functionally. However, children affected by the sleep disorders that cause arousal during sleep or light sleep is increasing. Attention deficit/hyperactivity disorder (ADHD) is a cause of sleep disorder; children with ADHD have frequent body movement during sleep. Attention deficit and hyperactivity during daylight are coursed by light sleep and it is difficult to quantitatively evaluate body movement during sleep because of their sensitivities (1). However, it is difficult to detect ADHD in young children and secondary disabilities can be brought on by ADHD. Therefore, it is important to detect and treat ADHD at an early stage. There is strong relationship between sleep quality and body movement during sleep. We investigated the difference in body movement during sleep of children with and without ADHD using video image processing for a method that is both non-invasive and non-contact.

A. ADHD

Children with ADHD often develop secondary disabilities such as learning deficiencies, Asperger's syndrome, and high-functioning autism. In children with ADHD, the causes of learning deficiencies may be an attention deficit and/or hyperactivity. However, children with ADHD can outgrow attention deficiency and hyperactivity as their symptoms wane with time.

It is known that the cause of ADHD is a deficit in noradrenaline secretion, dopamine secretion, and blood flow in the frontal lobe. Even though children can outgrow the features of ADHD, the abnormalities remain in the brain. Therefore, it is necessary to remedy ADHD in children with easily detectable features.

II. Methods

We used video image processing to investigate body movement and polysomnography PSG to measure the sleep stage at a given time. In PSG, an electrocardiogram (ECG), electro oculo gram (EOG), electro encephalo gram (EEG), and chin electro myo gram (chinEMG) were measured at 30 s intervals. From the body movement and sleep stage data, we quantitatively evaluate the subject's sleep quality. The sleep depth is broadly divided into REM sleep and non-REM sleep, which is divided into four stages that become deeper as the sleep stage progresses from stage 1 to stage 4. The basics of the sleep stages are shown in Table 1. Children aged 3−6 yr are investigated. Subjects are divided into two groups; normally developed children (Control, N = 11) and children with ADHD (ADHD, N=5). The children in the ADHD group were diagnosed with ADHD before this experiment.

A. Body movements

The body movements during sleep are divided into three states by Fukumoto el al. (2): twitch movements, localised movements, and gross body movements (GMs). We focused on the GMs and used them for the analysis. GMs are body movements that are large in nature and continue for more than 2s, such as turning over in the bed. It is easy to divide into ADHD and sleep apnoea, restless legs syndrome using GMs because of different feature of ADHD and sleep apnoea, restless legs syndrome.

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TABLE I. BASICS OF- SLEEP STAGES

Sleep stage	EEG	Movement of EOG	ChinEMG
Wake	A wave: periodic	REMs	High amplitude
REM	Disappearance of wenny wave	REMs	Lowest on record
Stage 1	α wave: More than 50%	SEMs	Less than during wake
Stage 2	α wave: unbeheld δ wave: less than 20%		
Stage 3	δ wave: 20~50%		
Stage 4	δ wave: more than 20%		

B. *Outline of video analysis*

The video analysis was carried out using different processing techniques. The concentration value of each pixel in a video image changes with the movements of the subject, enabling the evaluation of body movements by monitoring the changes in the pixels. The size of the video image was 340 (width) × 240 (height) pixels. After a video image was read successively, a region of interest (ROI) was specified for high-speed processing. Following ROI processing, the video image was converted into a grey scale, and changes in grey values between frames were detected using image difference processing.

In difference image processing, the centre coordinate shows a decrease and increase in its concentration value before and after the movement, respectively. Thus, we first determined the pixels that show an increase or a decrease in their concentration values. We then calculated the average coordinate positions (px, py) of all the pixels that show an increase in their concentration values and the average coordinate positions (nx, ny) of all the pixels that show a decrease in their concentration values. Finally, we obtained the rate of GMs (RGBM) and the rest duration from this data. The RGBM is the ratio of GMs to the total time of sleep in each sleep stage. The rest duration is the time at rest after subtracting the time of body movements from the total time asleep in each sleep stage.

After image processing, we removed all body movements smaller than GMs, video noise, and reflected nurse from the video using visual analysis.

Finally, we obtained the RGBM and the rest duration. The RGBM is defined as follows:

$$\text{RGBM [\%]} = t_m / t_s * 100, \quad (1)$$

where t_m is the time of body movement in each sleep stage and t_s is the total time of sleep in each sleep stage. The RGBM is the ratio of GMs to the total time of sleep in each sleep stage. Fig 1 shows an outline of the rest duration.

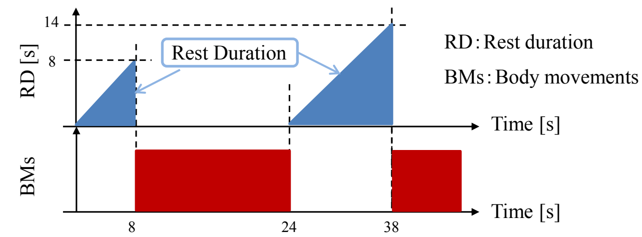

Figure 1. Sleep stage measured by PSG

III. RESULTS

The sleep stages of normally developed children that were measured by PSG is shown in Fig 2 and the same for children with ADHD is shown in Fig 3. From Fig 2 and Fig 3, children with ADHD remained in stage 1 longer than normally developed children; this suggests the sleep of children with ADHD is shallower. Children with ADHD remained in stage 2 for a shorter amount of time than the normally developed children. For the other stages, there was not a large difference between the children with ADHD and the normally developed children. There was significant difference between the two groups for stage 1 ($p < 0.05$).

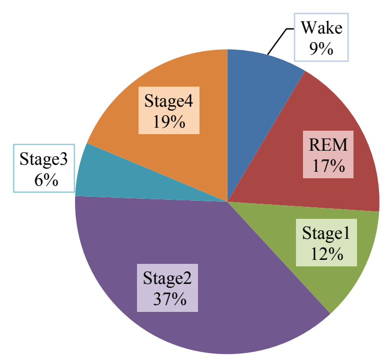

Figure 2. Sleep stage of normally developed children measured by PSG

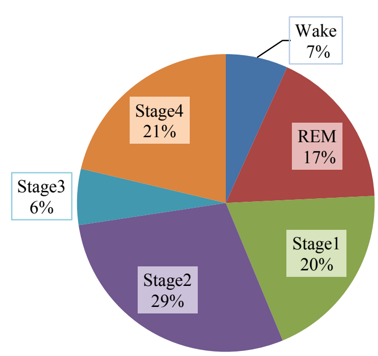

Figure 3. Sleep stage of children with ADHD measured by PSG

A histogram of normally developed children with respect to the rest duration is showed in Fig 4 and the same for children with ADHD is shown in Fig 5. The rest duration is divided by each 30 s intervals; a rest duration of fewer than 30 s was too short to include in the analysis. Fig 4 and Fig 5, rate of GMs for children with ADHD with rest durations less than 120 s was higher than that for the normally developed children. Additionally, the rate of GMs for children with ADHD with rest durations over 301 s is less than that for normally developed children.

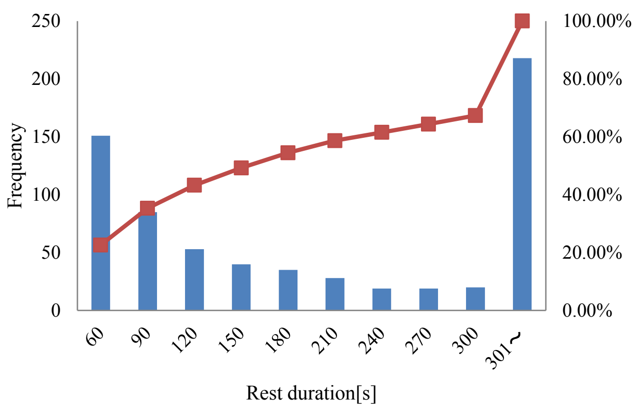

Figure 4. Histogram of normally developed children with respect to rest duration

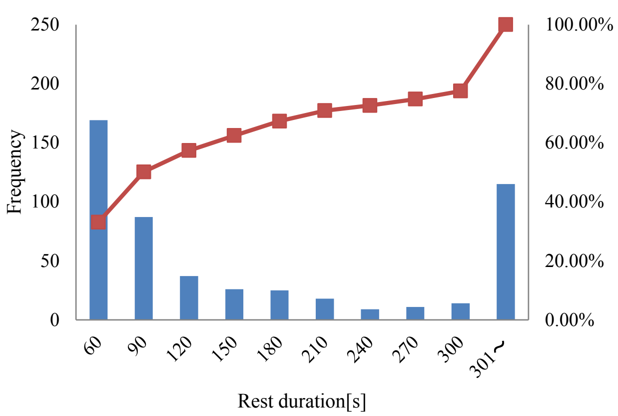

Figure 5. Histogram of children with ADHD with respect to rest duration

The average RGBM for each sleep stage is shown in Fig 6 and the individual RGBM is showed in Fig 7; a normally developed child and a child with ADHD of REM sleep, stage 1, stage 2, stage 3, stage 4, and the total. The RGBM of children with ADHD is higher than the RGBM for the normally developed children. In stage 1, there was no difference between children with ADHD and normally developed children. However, there was a significant difference between the two groups for REM sleep ($p < 0.05$). From Fig 7, body movements are also frequency in children with ADHD.

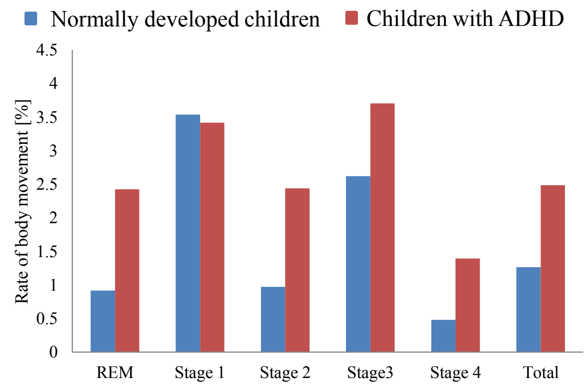

Figure 6. Average rate of gross body movement in each sleep stage

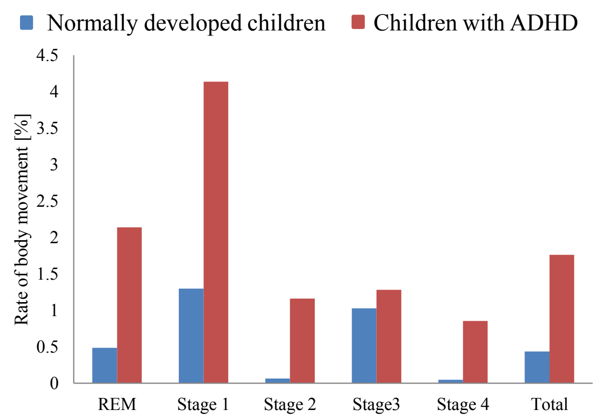

Figure 7. Individual rate of gross body movement in each sleep stage

IV. Discussion

Compared with normally developed children, the sleep of children with ADHD is shallower and the rate of body movement is higher during sleep. From the histogram of the rest duration, having rest duration of over 301 s for children with ADHD is less common than for normally developed children. There was difference in frequency between the 90 s and 150 s rest durations because children with ADHD are more unstable than normally developed children during sleep. Therefore, rest duration can divide children with ADHD and normally developed children. When analyzing each sleep stage, the body movement of children with ADHD is higher than the body movement for normally developed children during REM sleep, stage 2, stage 3, stage 4, and the total. The occupancy sleep of stage 1 in normally developed children is less than that in children with ADHD, so there is a negligible difference in this stage between children with and without ADHD.

The subjects were sleeping in an unaccustomed place and wore PSG equipment, so sensitive children with ADHD did not acclimate well to the experimental surroundings. Therefore, the body movements are higher for children with ADHD than for normally developed children. Deficits of noradrenaline secretion and dopamine secretion are the underlying reasons that body movements are more frequent in children with ADHD.

V. CONCLUSION

We investigated a comparison of body movements during sleep of children with and without ADHD using video imaging. The sleep of children with ADHD is shallower than normally developed children. There was remarkable difference between rest durations of children with ADHD and of normally developed children, so the rest duration analysis can be an ADHD diagnosis criterion. When the movements are compared during each sleep stage, the children with ADHD have a higher frequency of movement. In the future, we will develop a new device that can easily diagnose children with ADHD using video image processing; it will also investigate the difference of the body movement cycle between children with ADHD and normally developed children. Additionally, we will subject the data to a cyclic alternating pattern analysis, which is a novel analysis method of PSG data and use actigraphy (3). When compared in term of GMs with actigraphy and video analysis, video analysis can measure GMS quantitatively, however actigraphy only attached to the arm so actigraphy can measure body movement easily.

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