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Biofeedback of Eye Movements for Sleep

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SUMMARY We examined the effects of biofeedback of saccadic eye movements (saccades) on sleep onset. EEGs and EOGs of 20 subjects closing eyes were measured. When the saccade exceeded a given level, a pip tone was feedbacked to 10 subjects in F-group (FG). They were asked to refrain from moving their eyes, when a pip tone was sounded. The other 10 subjects were in yoked control group (YG). The number of saccades in FG decreased gradually. The average sleep onset time to stage 1 for FG was 12 min and YG was 16 min. All subjects in FG went to sleep. Although nine subjects in YG went to sleep, there were larger inter-individual differences in the number of saccades.

Key words: biofeedback, EEG, eye movement, saccade, sleep

INTRODUCTION

Raskin, Johnson and Rondesvedt[1] reported that the relaxation training by the frontal EMG biofeedback would be useful for patients of insomnia. Budzynsky[2] and Bell[3] reported that the biofeedback of the theta wave of EEG would improve sleep.

We learned from the experiences that some subjects went to sleep during an experiment, when they were asked not to move eyes in the eye closing situation. When people worry about something in bed, many images run through in the head. They complain about difficulty in sleeping.

Sugano and Inanaga[4] suggested that the mental stress and anxiety creating by worrying increased the frequency of saccadic eye movements (saccades). Therefore, sleep onset might be hastened by restraining saccades by means of biofeedback. In this experiment, we examined the effects of biofeedback of saccades on sleep onset.

METHOD

Subjects:

Subjects were 20 normal students (10 males and 10 females) aged 19 to 23 years old, who had no experience of a biofeedback experiment. They were divided into two groups, the feedback group (FG) and the yoked control group (YG). Each subject in FG had a partner in YG.

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Biofeedback of Saccadic Eye Movements:

Fig. 1 shows the block-diagram of the biofeedback system of saccades. Eye movements were recorded by means of electrooculography (EOG). A pair of Ag-AgCl electrodes was placed at the outer canthi of two eyes for horizontal movements.

Another pair was placed above and below the right eye for vertical movements. EOGs were amplified with bio-amplifiers at a low frequency time constant of 0.1 s and a high frequency cut off at 100 Hz. The horizontal(x) and vertical(y) EOGs were fed to inputs of a vector module (Teledyne-Philbrick, 4352) to obtain the absolute value of the saccades (v); $v = \sqrt{x^2+y^2}$.

Fig. 2 shows an example of wave forms EOGs. The potentials from the output were fed to a pulse generator. Whenever the output of the module exceeded given levels (17-25 μV), a trigger pulse was transmitted to a sound generator to feedback a tone pip. The latitude varied with different saccade sizes of individual subjects. The tone pip (1000 Hz, 33 dB SL) was sounded in the left ear through a headphone. When subjects went to sleep, slow eye movements appeared. Tones were produced only by saccades. No tones were triggered by the slow eye movement.

Procedure:

After electrode placement, each subject was seated on a reclining seat in a sound proof shielded room. Before the experiment, the saccade size was measured for calibration. After the feedback level according to the saccade size was decided on, each subject was instructed on the experiment. The 10 subjects in the feedback-group (FG) were instructed that when their eyes moved, a pip tone would be sounded.

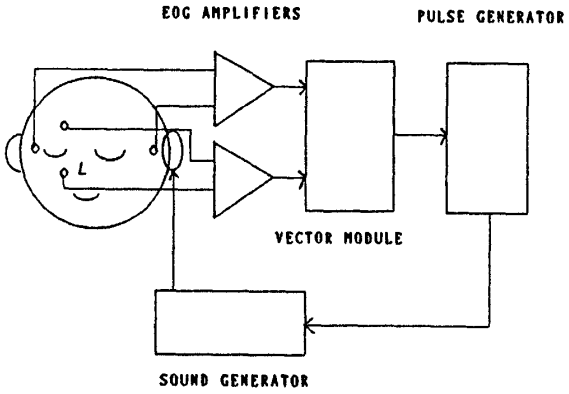

Fig. 1. Block diagram of biofeedback system.

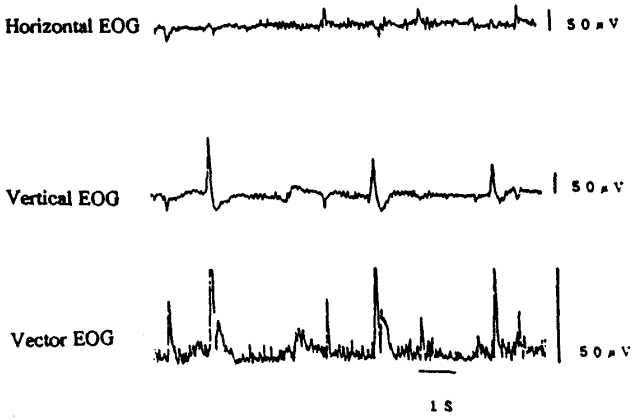

Fig.2. Wave forms of EOGs. From top, horizontal EOGs (x), vertical EOGs (y) and vector EOG (v)= $\sqrt{x^2+y^2}$

They were asked to relax and to refrain moving their eyes. The tone pips which the subjects in FG produced during the experiment were recorded on magnetic tape and transmitted to the partners in the yoked control group (YG). Therefore, each subject in YG received the same number of tones as the partner in FG. The starting times of the experiment were 10 a.m., 1 p.m. and 4 p.m..

The starting times were matched between FG and YG. The 10 subjects in YG were instructed to listen to the tone pips and relax.

Subjects in both groups closed their eyes during the experiment which lasted for 45 min.

Recording:

EEG was recorded from C3 referred to linked ears. The ground lead was attached to the forehead. The horizontal and the vertical EOGs were recorded as mentioned above.

The horizontal EOG was amplified in parallel by two amplifiers with low frequency time constant of 0.1 s and 2.0 s. The output of the amplifier of 0.1 s was used for the biofeedback signal. The other amplifier of 2.0 s was used for the detection of slow eye movements appearing at early stages of sleep.

EEG, EOGs and the pulse synchronized with the tone pip were recorded on magnetic tape and on paper. Sleep stages were determined by visual observation every section of 30 s.

RESULTS AND DISCUSSION

Fig. 3 shows an example of a female subject (JF) in FG. Graphs from the top indicate the sleep stage, frequencies of the pulse synchronized with saccades and frequencies of slow eye movements (SEM).

The number on the horizontal axis indicates the section number. One section represents 30 s. Therefore, section 10 indicates 5 min.

The frequency of the pulse, representing the rate of saccades, gradually decreased.

Meanwhile, slow eye movements began to appear after around 7 min (at the 15th section) and then increased. After 10 min from the beginning of the trial (the 20th section), the subject went to sleep. After stage 1 continued for about 18 min, her sleep

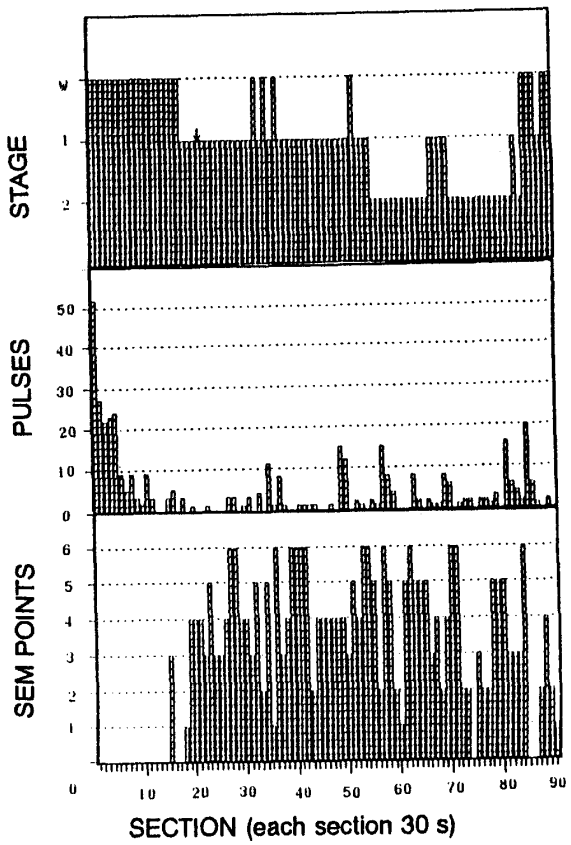

Fig.3. An example of data for a subject in FG. From the top, sleep stage, frequencies of pulse synchronized with saccades and frequencies of slow eye movements. The number on the horizontal axis indicates the section (each section; 30 s).

changed to stage 2.

Subjects in FG went into sleep stage 1 in an average of 12 min. On the other hand, the average sleep onset time of YG was 16 min, although there was no significant difference between two groups.

Fig. 4 shows mean frequencies of saccades in both groups. In order to analyse processes of effects of biofeedback, intervals from the beginning of trials to sleep onset were arranged. The frequencies of saccades, characteristically in FG, decreased gradually until sleep onset. Two subjects in FG showed rather high arousal immediately after the beginning of the trial, as they were trying to focusing on the relationship between eye movements and the tones in stead of relaxing.

However, all subjects in FG went to sleep. The tone pip itself did not have any effect in disturbing sleep. In YG, there were large inter-individual differences in the number of saccades. One of the subjects in YG did not go to sleep.

We obtained the possibility of sleep improvement with biofeedback of eye movements. In the present experiment, all subjects were normal students who had no problems with sleeping. Subjects in YG went to sleep shortly after subjects in FG did, therefore there was no significant difference between the two groups.

After the experiment, some subjects in FG reported difficulty in stopping the tone pips in the beginning of the trial. Perhaps a pre-training would be required preceding the trial.

In a recent study of biofeedback of saccades[5], we found that sleep onset occurred faster when saccades were restrained than when saccades were increased intentionally. The method of instruction should be improved for better training.

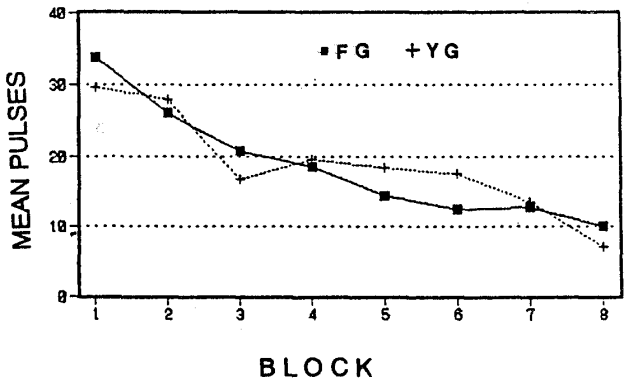

Fig.4. Mean frequencies of pulse in FG and YG before sleep onset. The interval from the beginning of the trial to the sleep onset was divided into eight blocks for each subject.

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