Detection of REM sleep by heart rate

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It has been shown that there are two different kinds of sleeps that are REM (Rapid Eye Movement) sleep and non-REM sleep, respectively. People feel more comfortable when they could wake up in the REM sleep than in non-REM sleep. The purpose of this study was to develop a system that could awake people in a period of REM sleep. We used a heart rate (HR) to detect the period of REM sleep rather than using electroencephalogram (EEG), electrooculogram (EOG) and electromyogram (EMG) recordings which were conventionally used. Subjects had to put many electrodes on their face to record EEG, EOG and EMG signals, which makes them unpleasant. The measurement of the HR is simpler since the measurement requires only two electrodes. In the first experiment, we obtained the period of estimated REM sleep from variation of the HR and the period of actual REM sleep from EEG, EOG and EMG signals. The results showed that the periods of the estimated REM sleep and of the actual REM sleep were quite similar in 79 %. In the second experiment, we attempted to find whether subjects woke up comfortably when the system awaked them in the period of the E-REM sleep. The results showed that the eighty percent of subjects felt more comfortable when they woke up in REM sleep than in non-REM sleep. We conclude that our system could be a good system to assist people wake up in the period of the REM sleep.

***Key words**: REM, non-REM, a wake-up system, Heart rate, EEG EOG and EMG signals*

Introduction

It has been shown that there are two different kinds of sleeps that are REM (Rapid Eye Movement) sleep and non-REM sleep. These sleeps alternatively appear in the night (Fig.1). The periodical rhythm of the REM and the non-REM sleeps are called a sleep cycle. Several studies have shown that people feel more comfortable when they could wake up in the REM sleep than in non-REM sleep. It is, however, technically difficult to wake up in the REM sleep. It would require an automatic system to detect the REM and the non-REM sleeps. Here, we developed a system to automatically detect the REM sleep. The system is able to awake people in a period of the REM sleep so that people could wake up comfortably.

Conventionally, many studies used electroencephalogram (EEG), electrooculogram (EOG) and electromyogram (EMG) signals to detect the period of the REM sleep. The system needs subjects to put many electrodes on their face for the recordings. In this study, we used a heart rate (HR) instead of the EEG, EOG and EMG signals. The measurement of the HR is easier than the measurements of the EEG, EOG and EMG signals since it requires only two electrodes.

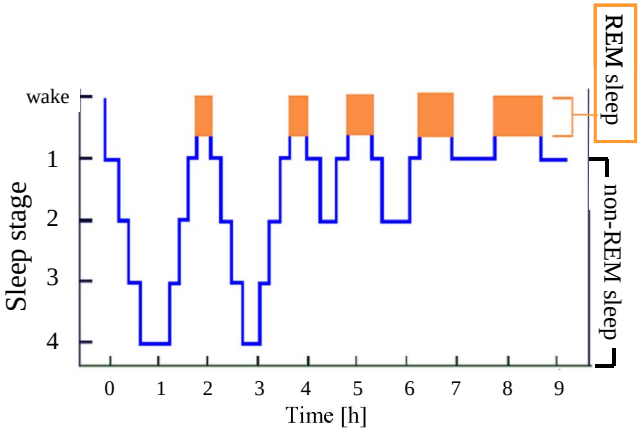


Fig.1. The period of the REM and non-REM sleeps alternatively appear in the night.

In our previous study, we reported that the heart rate could be a good index to detect the REM sleep. We measured a variation of the HR and used it to estimate REM or non-REM sleep. The aim of this study was to develop the wake-up system to detect the REM sleep. The system is able to awake people in the REM sleep so that people could wake up comfortably.

Methods

We conducted two experiments. In the first experiment, we evaluated that our system could detect the period of the REM sleep correctly. We called the period of the estimated REM sleep as E-REM in the following. We attempted to record the period of the actual REM sleep (A-REM) evaluated from the EEG, EOG and EMG signals according to international standard criteria (Rechtshaffen & Kales, 1968). In the second experiment, we attempted to find whether subjects waked up comfortably when the system awaked them in the period of the REM sleep.

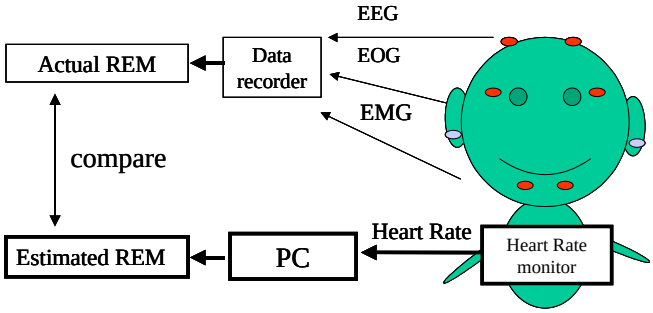


Fig.2. The schematic diagram of the experiment.

In the first experiment, we used 20 healthy adults (12 males, 8 females, age ranges from 21 to 25 years). Subjects were asked not to take any foods and drinks before the experiment that could affect their sleeps. In the first night we found that subjects had a tendency to be sleep-deprived. For example, the sleep cycle (appearance of the REM sleep) was different from those in latter days, which might be due to a difference in sleep environment (the first night effect). We analyzed data obtained in the second or latter days to avoid these effects.

Figure 2 shows a schematic diagram of the experiment. The electrocardiogram (ECG) signals were recorded on their chest and the HR was calculated from an R-R interval of ECG signals every 5 seconds to estimate the E-REM sleep and saved it on PC. We collected the EEG (C3-A2, C4-A1), EOG (O1-A1, O2-A1) and EMG signals at the same time to estimate the A-REM sleep according to the international standard criteria. Although the E-REM sleep was calculated in real time the A-RAM sleep was calculated after collecting the whole data over the night. We computed a ratio of concordance between the E-REM and the A-REM sleeps to evaluate the system quantitatively.

In the second experiment, we attempted to find whether subjects woke up comfortably when the system awaked them in the period of the E-REM sleep. The details of the HR recording were the same as those in the first experiment.

The system awaked subjects either in the E-REM or in the non-E-REM in two days. In the second day, for example, subjects woke up in the E-REM and in the third day woke up in the non-E-REM, *vice versa*. In the third day subjects had to answer the questionnaire right after they woke up to find how feel they had woken up in the third day in comparison with that in the second day. The subjects had to choose one of four level of the feeling that were “much better”, “better”, “worse” and “much worse”. Since the subjects did not know whether they woke up in either REM or non-REM sleep we can directly compare their feelings when woke up. We also attempted measure a time of wake-up in order to quantitatively estimate the subject’s feelings. We defined the time to wake up as a time when subject’s head was away from the pillow by analyzing a video-camera image.

We calculated a variation of the HR to detect the E-REM sleep. The details of an algorithm have been described elsewhere (reference of abstract: Koki. M. et al., 2005). Figure 3 showed a relationship between a variation of the HR and the E-REM sleep. First, we calculated the HR from the R-R interval of the ECG signals. In the previous study we found a variation of the HR well correlate with the sleep cycle (*e.g.* REM or non-REM sleep). The larger variation would occur in the REM sleep, while the smaller a variation was in the non-REM sleep. We calculated the variation of the HR every 3 minutes. In the preliminary experiment, we found a certain change of the variation as criteria for each subjects to discriminate the REM sleep from the non-REM sleep. The system could detect the REM sleep when the variation was larger than the criteria, otherwise it is in the non-REM sleep.

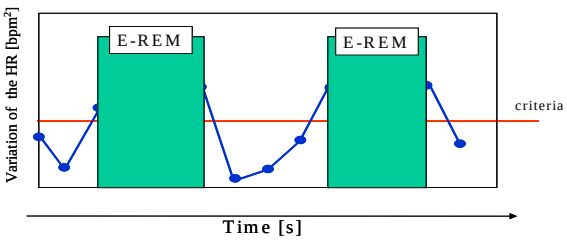
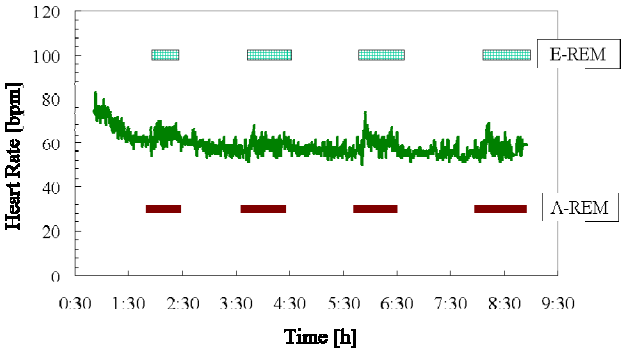


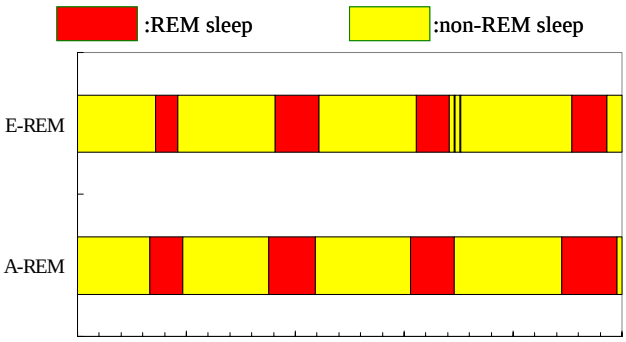
Fig.3. The relationship between a variation of the HR and the E-REM sleeps.

Results

Figure 4 (a) shows a relationship among the HR, E-REM and A-REM sleeps. The horizontal axis specified a time after the sleep and the vertical axis represents a HR. The dashed curve represents a HR, upper bars represent the E-REM sleeps and lower bars represent the A-REM sleeps. As shown in Figure 4 (b), the variation of the HR could reflect the period of the A-REM sleep. For all subjects the period of E-REM and A-REM sleeps were quite similar over the time measured. We calculated a ratio of the concordance for all subjects. They were more than 79 % for all subjects.



(a) The relationship among the HR, E-REM and A-REM sleeps.

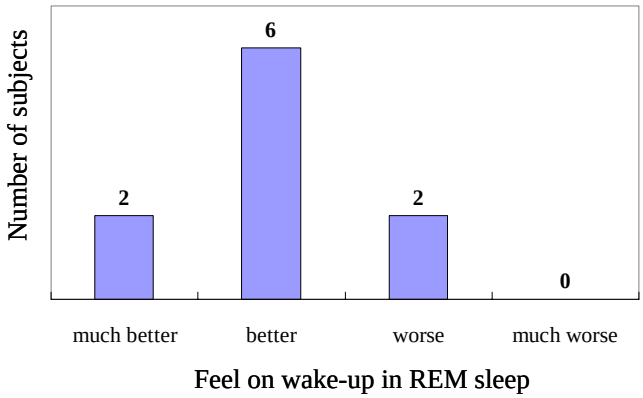


(b) The periods of the E-REM and A-REM. A ratio of the concordance was 88.8 % in this case.

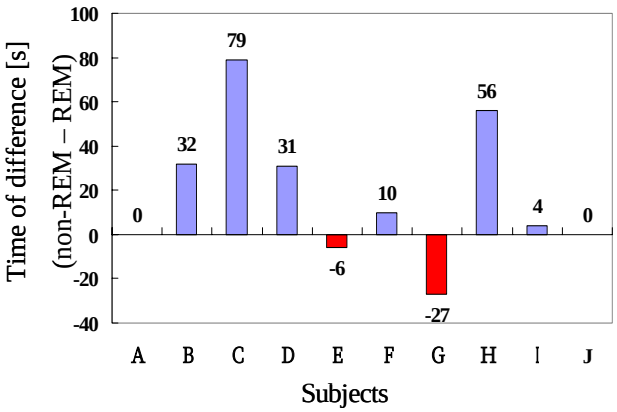
Fig.4. Result of the first experiment

In the second experiment, we collected data from subjects how feel when they woke up in the REM sleeps or in non-REM sleeps. The results showed that two of ten subjects felt much better when they woke in the REM sleep than in non-REM sleep, six subjects felt better and two felt worse in the REM sleep. The eighty percents of subjects felt more comfortable in the REM sleep than in non-REM sleep.

In six subjects among ten subjects, the time of wake-up when they woke up in the REM sleep was shorter than in non-REM sleep. For two subjects, since wake-up time was too short to analyze we removed them. These results support that our system could awake people in the REM sleep so that people wake up comfortably.



(a) Feeling of wake-up in REM when subjects woke up in the REM sleep than in non-REM sleep.



(b) The difference of in time for wake-up. Six of eight subjects woke up quicker in the REM sleep than in non-REM sleep

Fig.5. Result of the second experiment.

Conclusion

In this study, we developed the system to awake people in their REM sleep so that they could wake up comfortably. We have shown (1) that the periods of the REM sleep estimated by the system and that of the actual REM sleep were quite similar in 79 % and (2) that the

eighty percents of subjects felt more comfortable when they woke up in REM sleep than in non-REM sleep. We conclude that our system could be a good system to assist people wake up in the period of the REM sleep.

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