Experimental Results of Measuring Human Fatigue by Utilizing Uttered Voice Processing

Kakuichi Shiomi
Electronic Navigation Research Institute
Tokyo 182-0012, Japan
(e-mail: shiomi@enri.go.jp)

Kiyoshi Sato
Railway Technical Research Institute
Tokyo 185-8540, Japan
(e-mail: kiyosato@rtri.or.jp)

Mitsugu Sawa
Railway Technical Research Institute
Tokyo 185-8540, Japan
(e-mail: sawa@rtri.or.jp)

Naoki Mizukami
Railway Technical Research Institute
Tokyo 185-8540, Japan
(e-mail: mizu@rtri.or.jp)

Ayako Suzuki
Railway Technical Research Institute
Tokyo 185-8540, Japan
(e-mail: ayako@rtri.or.jp)

***Abstract*—It is possible to measure human cerebral activity by utilizing a new chaotic method for analyzing the spoken voice. In experiments, we measured the Flicker Frequency and voice-derived Cerebral Exponents of subjects at 12-minutes intervals during a ten-hour railway driving simulation exercise. The results confirm that our analysis method is able to measure human central nervous system activity levels, as is possible using the Flicker Tester, from speech. We believe that it will be possible to evaluate the mental and physical condition of critical workers in real-time in their working environments by monitoring only their speech. We also believe that workspace safety will be much improved by the introduction of the new chaotic voice analyzer.**

***Keywords*—chaos, fatigue, voice processing, Cerebral Exponent, SiCECA**

I. Introduction

In 1998, one of the authors discovered that the chaotic characteristics of uttered voice change according to the psychosomatic condition of a speaker [1, 2]. Since this discovery, the authors have been working to develop a fatigue and drowsiness predictor for automobile drivers and airplane pilots. In 2005 the authors carried out experiments to confirm the performance of the signal processing software of the prediction system, and confirmed by fatigue measurement experiments that the chaotic characteristics of uttered voice change as fatigue and drowsiness increase. In one case in which an experimental subject driving a train simulator fell asleep in the simulator cab after about ten hours of driving, the exponent calculated from his uttered voice indicated that his cerebral activity was very low before he lost consciousness.

Our system will enable us to enter a new paradigm of human stress management.

II. Chaos of Uttered Voice

It is known that the human voice has chaotic characteristics, but apart from for voice synthesis there has been very little research into the characteristics of voice. One reason is that the chaos of uttered voice is far more complex than the chaos of heart electrical activity and is very difficult to analyze; in particular, current chaos theory assumes that the dynamics of the system that generates a time-varying signal is unchanging and stable during over the period of generation. However, the dynamics of the system of human speech is not quite stable, and in everyday Japanese speech eight or more vowels may be uttered each second.

III. Fatigue Measurement Experiment

A fatigue measurement experiment was carried out using a train operation simulator at the Railroad Technical Research Institute (Tokyo, Japan) from Aug. 1 to Sep. 29 2005.

A. Subjects

The participants in this experiment were eleven male university students and postgraduates of physical education at Tokyo Gakugei University, and one assistant professor. All subjects were informed of the purpose and procedures of the experiment beforehand. Effective data were obtained from ten of the subjects.

B. Timetable of experiment

Figure 1 shows the timetable of the fatigue measurement experiment. Subjects were first administered three days of simulator training. The fatigue measurement test itself consisted of sets of 12-minute train driving exercises carried out over two days. First, subjects performed a train driving exercises during the morning, followed by four hours of physical exercise to induce fatigue and sleepiness in the afternoon, then 11 hours of driving exercises from 6 p.m. until 5 a.m. the next morning with two breaks during the period, sleep from 6 a.m. to noon, and then a final train driving session. The physical exercise consisted on walking up and down stairs shouldering a weight of 20 kg.

C. Apparatus

To obtain spoken voice for assessing fatigue level, subjects were required to read aloud text printed on cards. Each card contained an excerpt from a Japanese folk story and could be read in about ten seconds. Between train driving exercises, subjects read aloud from three cards and their voices were recorded. The Critical Flicker Frequency (CFF) obtained by the Hashimoto flicker tester was also measured at the same time for reference. CFF is a measurement that indicates the level of wakefulness, and was used under the hypothesis that it is strongly correlated with the level of activity of the part of the cerebral neocortex which we are attempting to measure from voice.

During the driving exercises, subjects were required to make a verbal call-out “Heisoku Shinko!” (“proceed into the next block”) on confirming a signal before entering each track section, and these call-outs were also recorded. There were 18 call-outs per exercise, but subjects sometimes forgot the call-out.

Voice signals from the card reading and call-outs were recorded in the simulator cab by a headset microphone (AKG C420-II/III) and a PCM recorder (Roland EDIROL R-4) at sampling frequency of 48.0 kHz with 24 bits/sample.

IV. Experimental Results

The experimental results from ten subjects (subject numbers 1, 2, 3, 4, 5, 7, 8, 9, 10, 11, and 12) are presented

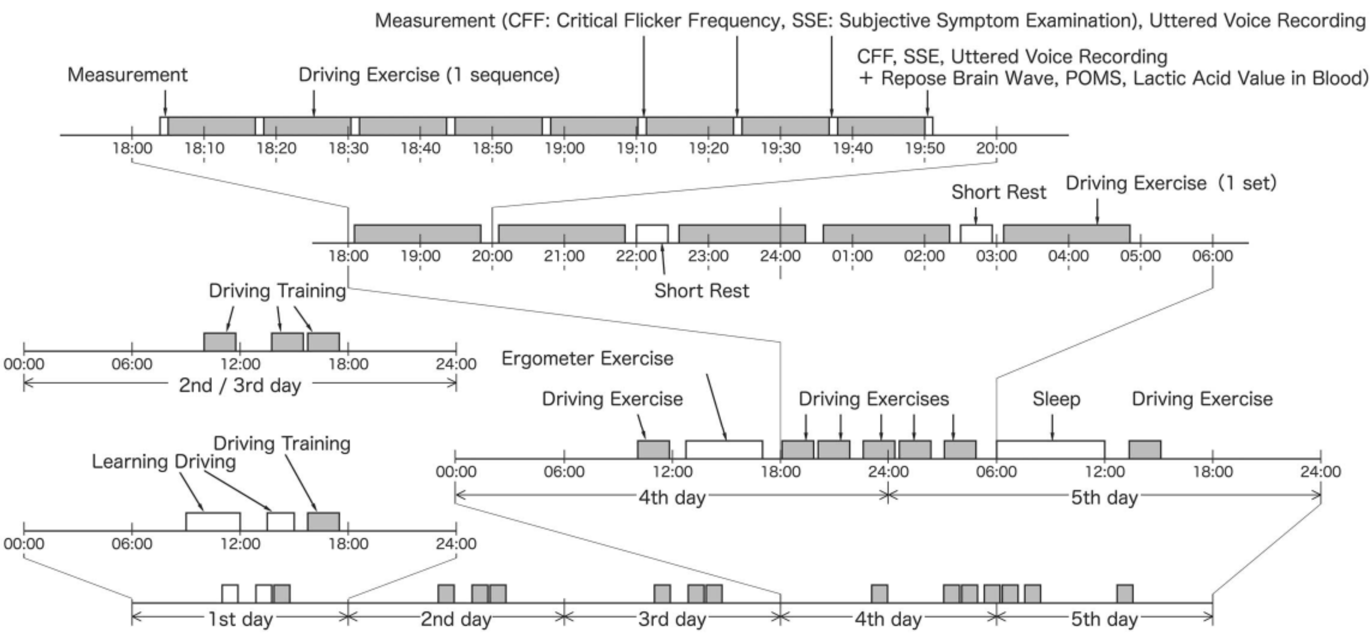

Fig.1 Timetable of fatigue measurement experiment.

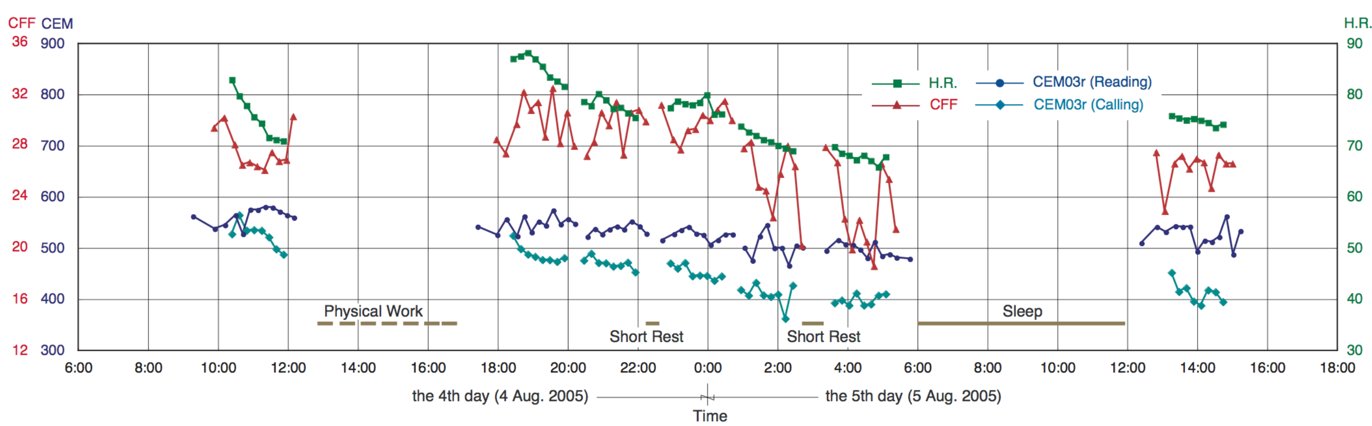

Fig.2 Results of subject 1.

below.

Since the age of subject number 6 (an assistant professor) was significantly different from the other subjects, his results are excluded. The result obtained from subject 7 is also excluded since he could not complete the whole test due to poor health.

In the following figures, "CEM03r" is the value calculated by our chaotic voice analysis method, and CFF is the critical flicker frequency (CFF) value from the Hashimoto flicker tester.

Figure 2 shows the result of subject 1. A decreasing tendency both in reading-CEM values (CEM values calculated from card-reading voice) and calling-CEM values (CEM values calculated from call-out voice) can be seen in the continuous work period from 6 p.m. to 6 a.m. the following morning. A decrease of CFF values (wakefulness level) was also observed after 1 a.m..

Figure 3 shows the result of subject 2. In this case, there were no notable trends in the reading-CEM, calling-CEM and CFF, and it is thought that this subject might be tough enough to complete all continuous work.

Figure 4 shows the result obtained from subject 3. Here, reading-CEM and CFF show similar trends, and the cross-correlation coefficient between the pattern of change of reading-CEM and CFF is more than 0.6 under the data size of

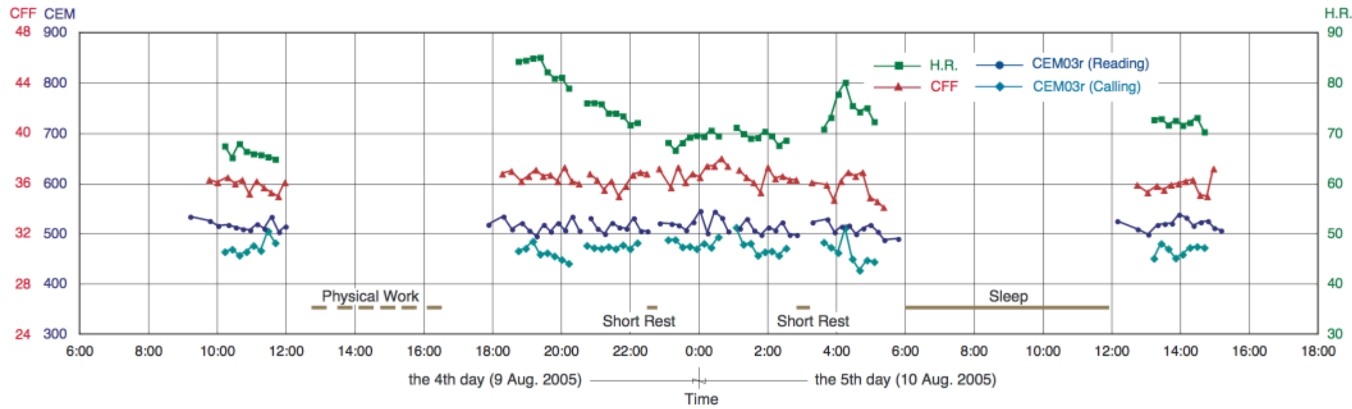

Fig.3 Results of subject 2.

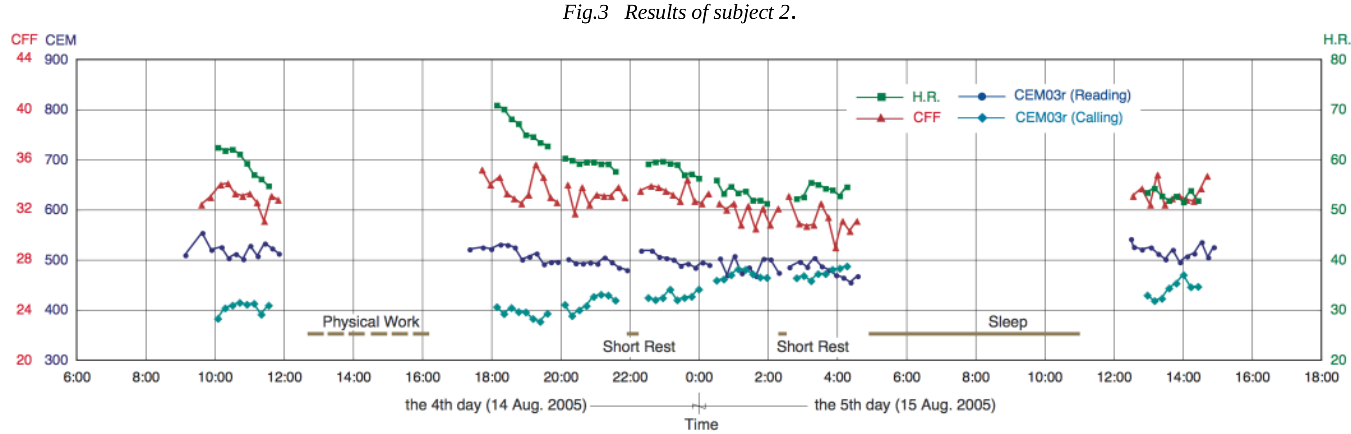

Fig.4 Results of subject 3.

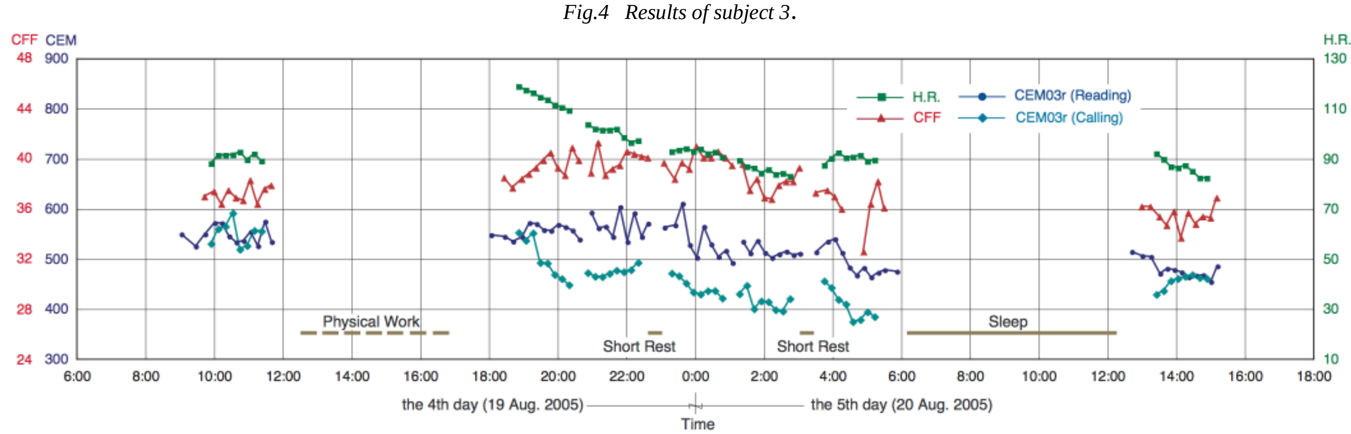

Fig.5 Results of subject 4.

49. On the other hand, calling-CEM increases with the passage of time. It can be thought that the subject was relaxed and could easily handle the work at the start of the continuous work period, and it might be not difficult for him to stop the train at a station correctly, but eventually he found it harder to maintain performance after long period. An increasing tendency in calling-CEM were also observed for subjects 9 (shown in Fig. 8) and 10 (Fig. 9),.

Figure 5 shows the result of subject 4, who was the most tired of the subjects. He had been exhausted and missed a station to stop at about 4:20 a.m. in the morning. He also fell asleep during one CFF measurement, so his CFF data at this time was missing. In this case, it can be seen that the subject worked hard at the start of the continuous work period, and it is also observed that after each short rest period his calling-CEM values decreased rapidly and the reading-CEM values decreased in staircase pattern.

Figures 6–11 show the results obtained from the other subjects. Subject 11 is an amateur mountain climber. He was the only subject who showed an increasing tendency in reading-CEM values. The authors think that the level of calling-CEM was smaller than that of reading-CEM when the simulator, not a real train, failed to make the subject feel the necessary tension to maintain operational safety.

The change in heart pulse rate of the subjects should be

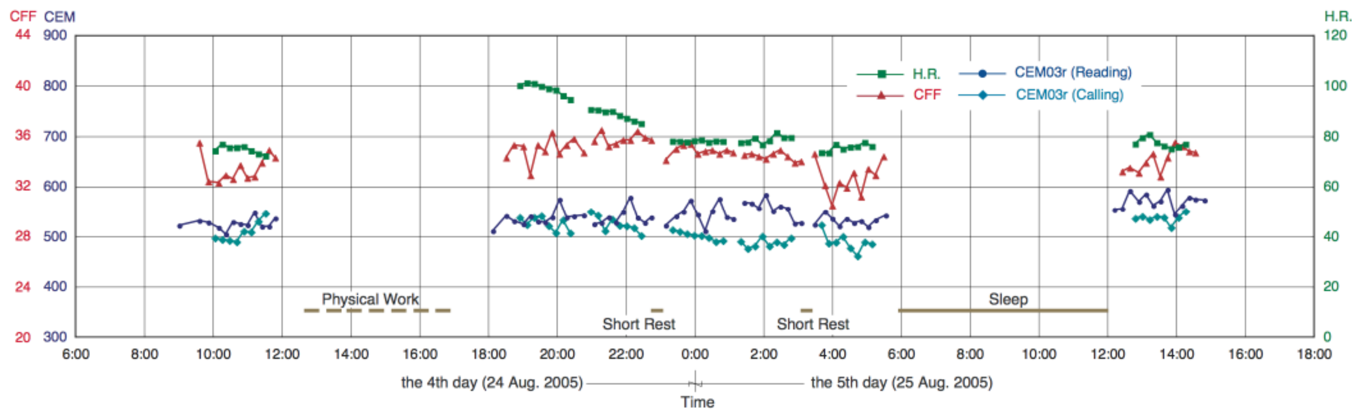

Fig.6 Results of subject 5.

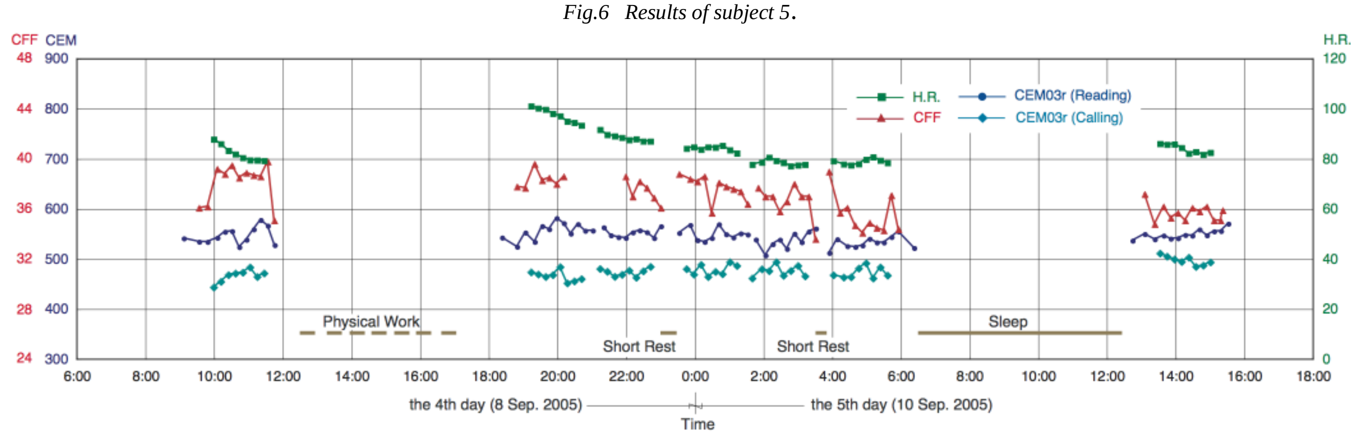

Fig.7 Results of subject 8.

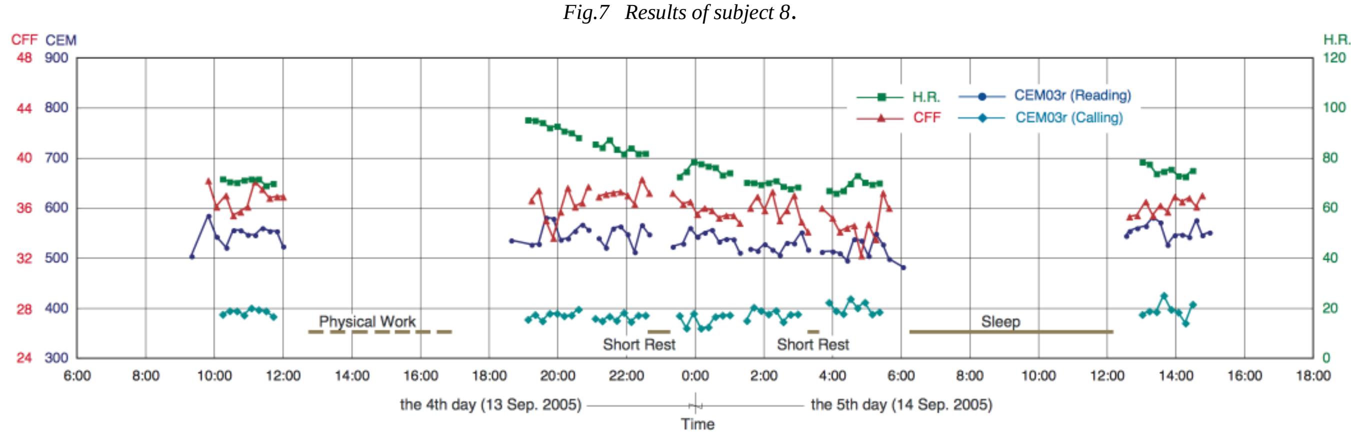

Fig.8 Results of subject 9.

thought of as dependent on circadian rhythm.

V. Short Conclusion

It is possible to a detect state of overwork by processing a person's uttered voice. Because there is little individual variation in the index calculated value from uttered voice, prior calibration is not necessary.

Acknowledgement

All recorded voice data in this experiment will be provided to researchers who would like to process the data themselves, at the cost of copying the data to CD-R or DVD media.

The system of uttered voice chaotic analysis used in this experiment has been granted the following patents in the U.S.A.: US 6,876,964 (Oct. 19, 2005), US 7,321,842 (Jan. 22, 2008) and US 7,363,226 (Apr. 22, 2008).

References

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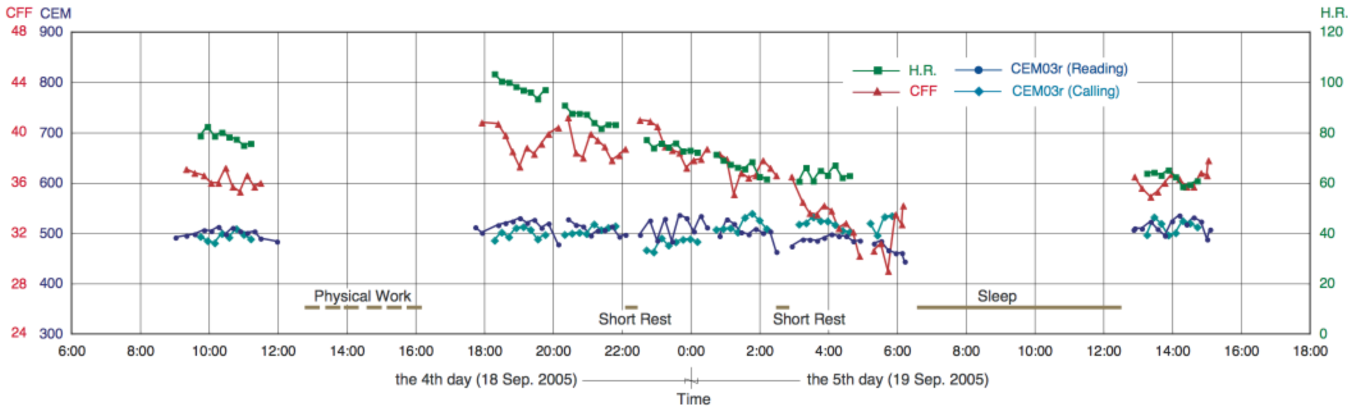

Fig.9 Results of subject 10.

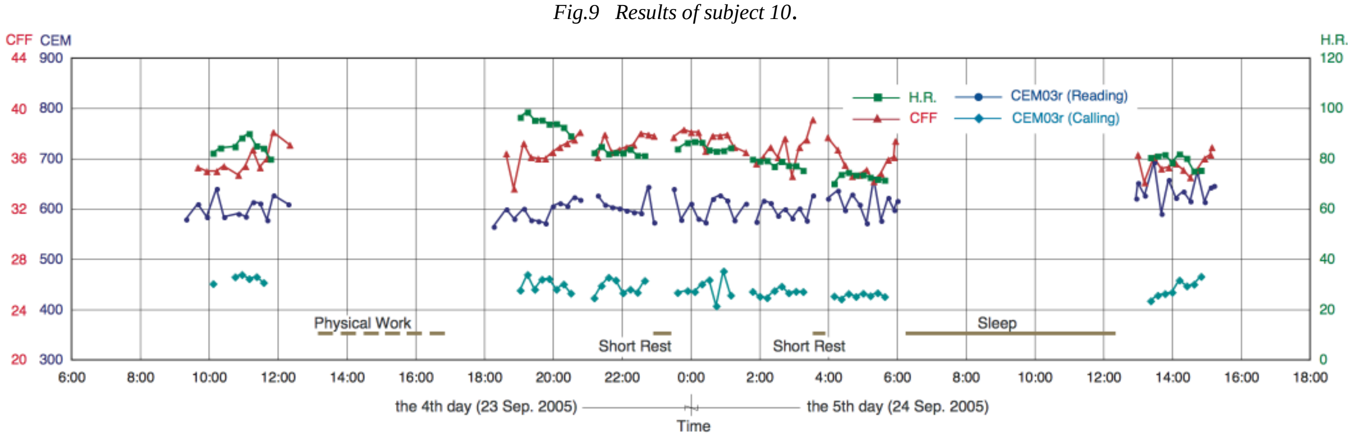

Fig.10 Results of subject 11.

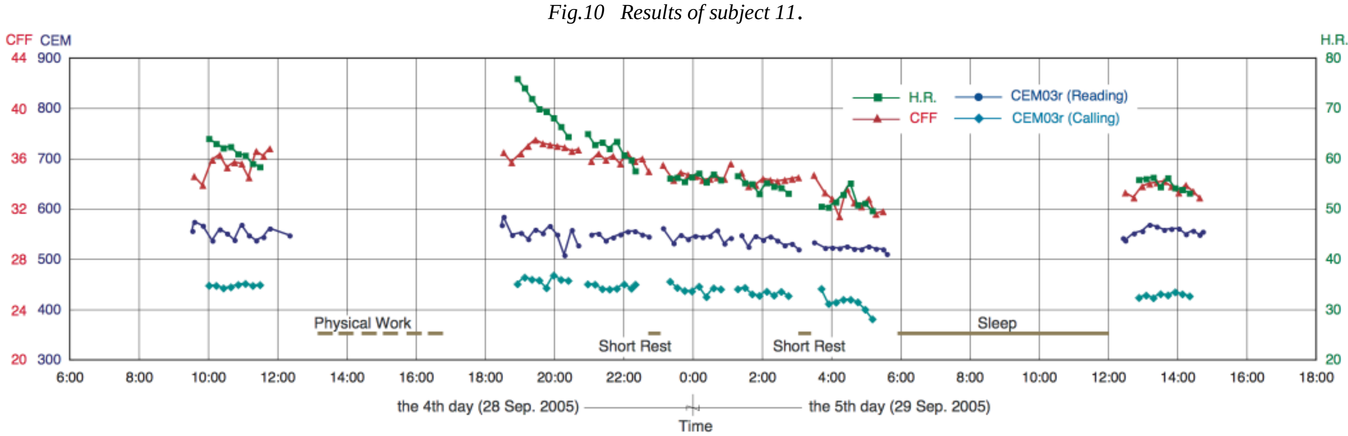

Fig.11 Results of subject 12.