

**Frontal midline theta rhythm and eyeblinking
activity during a VDT task and a video game:
useful tools for psychophysiology in ergonomics.**

FUMIO YAMADA, Ph.D.

**Laboratory of Psychophysiology, Osaka Prefectural College of Nursing, Japan
3-7-30, Habikino, Habikino, Osaka 586 Japan**

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The necessity of psychophysiological research in ergonomics has gradually been recognized in Japan. In this article, frontal midline theta rhythm (Fm-theta) and eyeblinking are recommended as tools in this field, especially for assessing workers' attention concentration, mental work load, fatigue, and interest during VDT work at the workplace and playing video games at home. In experiment 1, Fm-theta and eyeblink rates were measured in 10 Japanese abacus experts (Gr.-E) and 10 normal students (Gr.-C) during a visual search task with VDT. Memory load affected all measures. The amount of Fm-theta appeared more in Gr.-E than Gr.-C, but blink rate was lower in Gr.-E than in Gr.-C. As abacus experts have such highly developed skills in concentration, the result indicates that the amount of Fm-theta would be a good index of attention concentration of VDT workers. The second experiment was done with 10 school-aged children as subjects during three visual tasks, i.e., video game, mental test, and animation. Amounts of Fm-theta and the degree of blink inhibition were maximum while playing video game, which all subjects reported they most preferred, and minimum while watching animation, which 8 subjects reported to be most boring. An interesting task would seem to provoke Fm-theta and inhibit eyeblink activity. From these two experiments, Fm-theta and eyeblink rate would appear to be good indices of attention concentration and task pleasantness of a mental task using VDT.

1. Introduction

Psychological factors affecting workers' performance, such as attention concentration, visibility, fatigue, mental workload, stress, and comfortableness, have been discussed in the field of Ergonomics and Human Engineering. A large number of studies have found many critical laws using behavioral index or subjective measures such as reaction time, correct ratio, or subjective scales. But a recent tendency in ergonomic research is to choose more objective measures to assess workers' mental condition or workplace design in Japanese industry. For example, when a researcher's task is to assess workers' mental work load during a given task, it is recommended to measure not only a subjective check list but also heart rate and blood pressure. In this article, the utility and validity of Fm-theta rhythm and eyeblink activity as indices of psychological factors affecting workers' performance would seem to be clarified from our set of experiments.

The first useful psychophysiological measure in ergonomics is an Fm-theta rhythm observed on a scalp EEG. As is well known to many EEG researchers, Fm-theta is the name of the

psychologically significant EEG rhythm discovered by a Japanese researcher, Tsutomu Ishihara, in the 1960s (Yoshii, Ishihara, & Tani, 1964; Ishihara & Yoshii, 1972). The Fm-theta has a frequency band from 6 to 7 Hz and has a large amplitude from 30 to 100 micro volts. The name 'Fm-theta' came from the dominant area and the frequency. The maximum amplitude is always recorded from the frontal midline, typically at Fz electrode position of international 10/20 system. Formerly thought to be abnormal by international EEG researchers, Fm-theta is recognized in recent years as one of the normal EEG patterns (Yamaguchi, 1980).

It is interesting that Fm-theta appears during a continuous mental task with eyes opened, but not during a rest period with eyes closed. The standard mental tasks used to provoke Fm-theta is a continuous mental arithmetic task. In this task, subjects are instructed to add two single digits printed on a sheet and to write down the sum between the digits, and to do the next addition in the same manner until they hear the call 'Stop!' as fast as possible for 5 min. or more. It is known also that Fm-theta appears only when the subject focuses on performing the task without thinking of anything other than the task. Such a mental state is called 'attention concentration' or 'absorbedness'.

Additionally, it is known that Fm-theta is affected by anxiety states and personality traits. For example, a high-anxiety situation inhibits the appearance of Fm-theta during the task (Mizuki, Tanaka, & Inanaga, 1982), and extroverts or less anxious persons provoke more Fm-theta than introverts or anxious persons (Niwa, Yamaguchi, Hino, & Tsujimoto, 1975). Anxious states or anxious personalities are thought to facilitate the distractive effects on attention concentration. So Japanese researchers on Fm-theta commonly consider this EEG-rhythm to be an index of attention concentration.

The second useful psychophysiological index is eyeblinking. Eyeblinking in relation to psychological factors has been studied for about 70 years. The initial researchers, the British physiologists Ponder and Kennedy (1928), established many findings concerning eyeblinking activity. Their comprehensive works on the relationship between human eyeblink activity and mental states have been cited frequently in psychophysiological articles on blinking. Their notion is that blink frequency or blink rate may be an index of strain or tension. In particular within these 10 years, more systematic investigations on the relationship between spontaneous eyeblinking and mental states have been conducted by many psychophysiologicalists in the USA and Japan (for example Stern et al., 1984; Tada, Yamada, & Fukuda, 1991). Most of the research has focused on the relationship between spontaneous eyeblinking and some psychological factors, i.e., attention and human information processing (Fukuda & Matsunaga, 1983), interest (Tada, 1986, Tsuda & Suzuki, 1990), and mental workload and fatigue (Stern et al., 1994; Omori et al., 1997).

In this article, Fm-theta and spontaneous blinking are recommended as a new assessment tool for human factors, i.e., workers mental workload and pleasantness of working environment from the standpoint of psychophysiology in ergonomics. In order to show the utility and validity of these two measures, two experiments done for different purposes will be reported.

In the first experiment, it is demonstrated that these two measures would be a good index of mental work load and attention concentration. In the second experiment, it is demonstrated that these two measures would also be a measure of interest in subjects or pleasantness of workplace.

2. Experiment 1: VDT task

2.1. Purpose

The purpose of the first experiment was to examine the effect of memory load upon the eyeblink rate and amount of Fm-theta during a continuous visual search task using VDT (visual display terminal). An additional purpose of this experiment was to evaluate the effect of skill in attention concentration on eyeblink activity and duration of Fm-theta using as subjects Japanese abacus experts, whose ability of attention concentration is thought to be extremely high. Memory load factor was controlled by systematically varying the memory set size.

2.2. Methods

Subjects were 10 undergraduates (Gr.-C:5 males and 5 females) and 10 Japanese abacus experts (Gr.-E:2 males and 8 females), with normal vision, whose mean age was 20.0 (16-28) years old. They were paid 5,000 yen for their participation. The skill of calculation with and without abacus in Gr.-E was evaluated as top rank in the All Japan Abacus Match held in the same year.

Blinking was recorded by an electrode hookup method (Yamada et al, 1979:1980). Two Ag-AgCl miniature electrodes were placed on a subject's forehead and on the cheek bone with the electrode collar filled with paste. Vertical EOGs were amplified and recorded with DC and AC with Time Constant of 3.0s. Horizontal EOG was also monitored to detect eye movements. Eyeblinks were detected by the DC and AC recordings of vertical EOG. Horizontal EOG was also monitored in order to exclude the eye movement artifact from the vertical EOG trace. Only the fast deflections of vertical EOG trace with an amplitude over 50 microvolts were identified as blinking. Numbers of blinks during the total time of each trial were assessed for statistical analysis. EEGs were recorded with 12 Ag-AgCl electrodes affixed to the subject's scalp at Fp1, Fp2, F7, Fz, F8, C3, C4, T5, Pz, T6, O1 and O2 and referenced to the linked ear electrodes. Fm-theta rhythm was defined as frequency window of 5.5-7.5 Hz and properties of scalp distribution with naked eyes. That is, Fm-theta was detected only if the amplitude of theta rhythms was dominant at the frontal areas, mainly at Fz, Fp1, or Fp2 electrode positions. Percentage of Fm-theta duration during each task was calculated as total Fm-theta duration divided by task duration. ECG and respiration were monitored during the experiment.

After the electrode attachment, subjects were instructed to rest for a few minutes with their eyes on the CRT display. During this period, subjects were not aware of the following tasks. After 3 minutes of this rest period, subjects were given the experimental instruction with two exercise trials. After a short rest period, subjects were given 9 trials sequentially without any rest. Just before each trial, a set of target letters to be memorized were presented for 5 sec on the CRT display. Then the stimulus set of 400 alphabetic letters, 40 by 10 matrix, were presented on the CRT display as shown in Figure 1. The subjects' task was to move their eyes from left to right on each line and top to bottom across lines without moving their heads. Their task was to identify and count non-vocally the target letters in the stimulus set as quickly as possible. The mental load factor was controlled by manipulating the memory set, i.e., concurrently search for 1,2, or 4 different letters. Each condition was repeated 3 times after 3 by 3 Latin Square.



Figure 1 The stimulus set, 40 by 10 consisting of 400 alphabetical letters, display on a CRT in Experiment 1.

2.3. Results

2.3.1. Performance (Search Time): Figure 2 (a) shows mean task performance for abacus experts and control groups as a function of memory set size.

The mean search time, the time from the onset of the matrix display to the end of visual search, increased as a function of memory set size. ANOVA indicated that only the memory set size was significant ($F(2,36)=72.495, p<.001$). Other main factors and any interaction effects were not significant.

2.3.2. Fm-theta: Figure 2 (b) shows mean Fm-theta appearance time in percent during the task for abacus experts and control groups as a function of memory set size..

In the expert group, Fm-theta was found in all subjects, but in only 7 out of 10 subjects in the control group. Group (2) by condition (3) 2-way ANOVA indicated that both main effects were significant; Group ($F(1,18)=7.476, p<.05$) and condition ($F(2,36)=13.681, p<.001$). This result indicates that Japanese abacus experts show greater amounts of Fm-theta during the visual search tasks and that amounts of Fm-theta increase as a function of memory set size.

2.3.3. Blink rate: Figure 3 shows that the mean eyeblink rate during the task decreased from the pre-task rest period. Such a continuous visual task might require the subjects to inhibit blinking. The task required subjects to inhibit blinking at the same level throughout the trial. Just after the end of the trial, blinks occurred in bursts as if to compensate for the preceding blink inhibition. This result is compatible with earlier studies with VDT tasks (Yamada, 1989).

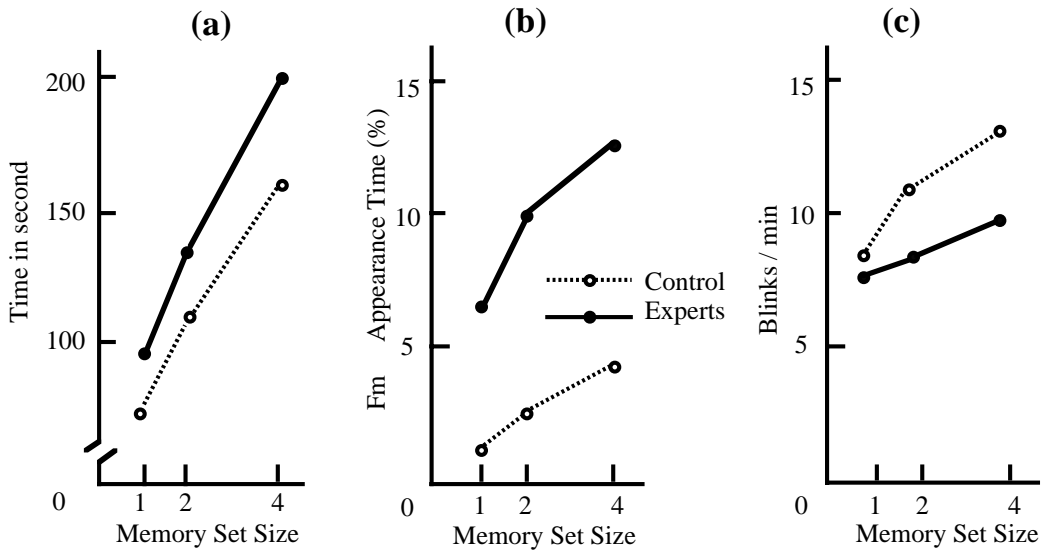


Figure 2 Means of search time (a), Fm-theta appearance time in percent (b), and eyeblink rate (c) for abacus experts (n=10) and control (n=10) groups as a function of memory set size in Experiment 1.

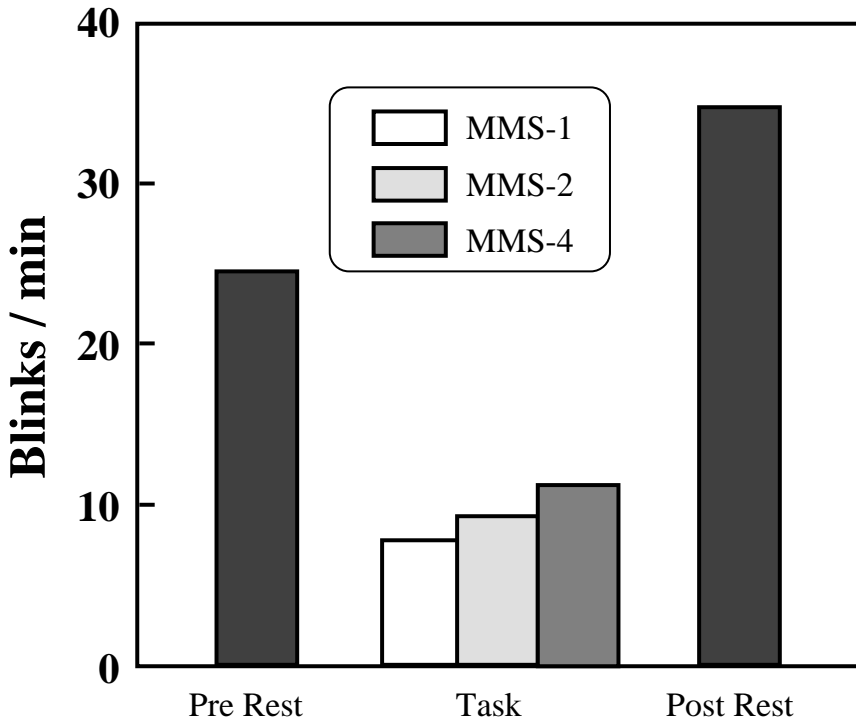


Figure 3 Mean eyeblink rate in pre-rest, during the VDT task, and in post-rest period in Experiment 1.

Figure 2 (c) shows mean blink rate during the task for abacus experts and control groups as a function of memory set size. Two way ANOVA indicated that only the memory set size effect was significant ($F(2,36) = 12.241, p < .001$). Eyeblink rate during the task increased linearly as a function of the memory set size. This result indicates that the task demand inhibited blink activity during the visual search task throughout the experiment, and that the higher memory load interfered with the inhibition of spontaneous eyeblink.

2.4. Discussion

From this experiment, it is found that eyeblink rate decreased and Fm-theta appeared just after the initiation of the continuous visual search tasks. This result can be explained by the effect of task demand.

During the task, both blink rate and amount of Fm-theta sensitively increased as a function of memory set size. Increases in mental work load by manipulating memory set size would require subjects to allocate more processing resource into the processing within a working memory. Large amount of Fm-theta might indicate the amount of attention resource spent for the given task.

In general, visual task required subjects to inhibit blinking for high efficiency of information processing at the input stage involuntarily (Stern et al., 1994). But as the memory load increases, the rate of processing or the amount of processing density would be accelerated. As spontaneous blink is initiated just after the end of information processing (Fukuda & Matsunaga, 1983), increases in number of processing demand would provoke blink in bursts in a high memory load condition.

If the amount of Fm-theta is an index of the degree of attention concentration, the results of Japanese abacus experts show that they could allocate their attention resource into the task performance more than control group subjects could.

3. Experiment 2: Video game task

3.1. Purpose

The purpose of the second experiment was to estimate how the blink rate and Fm-theta rhythm reflect the children's state of interest during different kinds of visual tasks.

3.2 Methods

Subjects were ten volunteer school children, 4 boys and 6 girls, aged from 8 to 12 years. They were paid 5,000 yen for their cooperation.

Subjects performed three different visual tasks, playing a video game, watching an animation, and being tested in the Color Conflict Stroop Test. In the video game task, they played Nintendo's 'Super-Mario 3' for 20 min. or more as they liked. In the animation task, they watched a VTR titled Snoopy & Charlie Brown for 22 min. We used Color Conflict Stroop Test Sheets published by Hiroshima University in the last task. These tasks were run in a random order.

Blinking and EEGs were recorded in the same manner as in the first experiment. We also monitored subjects' behavior, i.e., facial expression and some movements including eye movements, by a high speed video camera, set in a doll 1.2m ahead of the subjects. This picture and polygraphic images taken by another camera were composed in the same frame and recorded on a VTR with each frame stamped with sequential numbers. Blinking was detected as a fast deflection of vertical EOG

trace by naked eyes. When it was difficult to decide whether it was a real blink or not, we checked pictures recorded on VTR. Blink rate during each task was calculated as number of blinks divided by task duration.

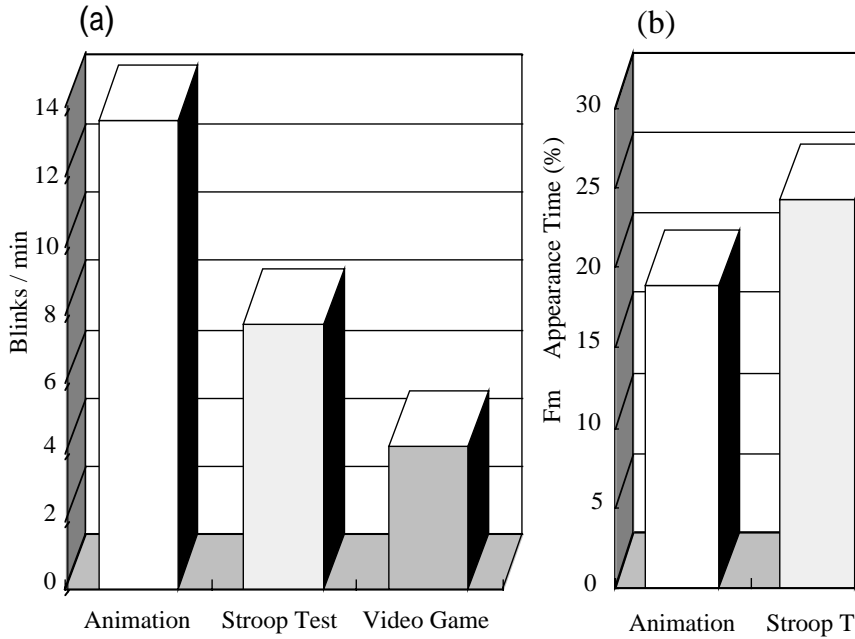
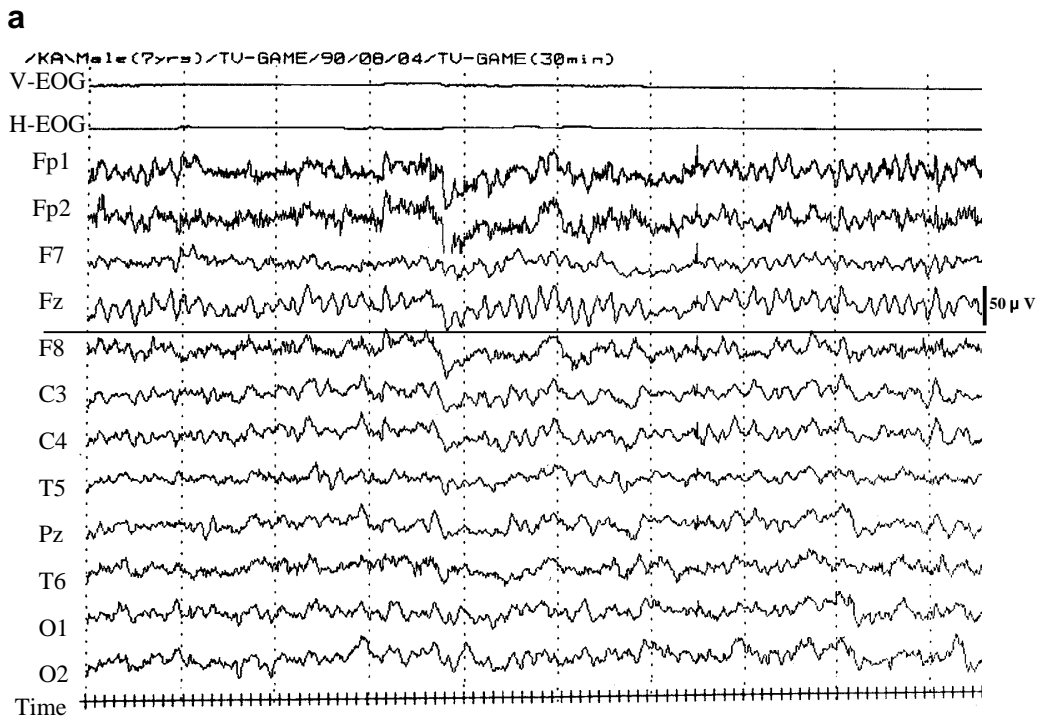


Figure 4 Mean Fm-theta appearance time in percent (a) and eyeblink rate (b) during three different visual tasks in Experiment 2.



Additionally, tape recorded EEGs were analyzed by digital computer (NEC San'ei Co. Ltd. Model 7T17) in order to get the topographical mapping of scalp EEG. The original processing program was made with Signal BASIC No. 5. In this analysis, topographical mapping was made in the following manner. Initially, 12-channel EEGs were sampled for 10.28 s with a sampling clock of 10

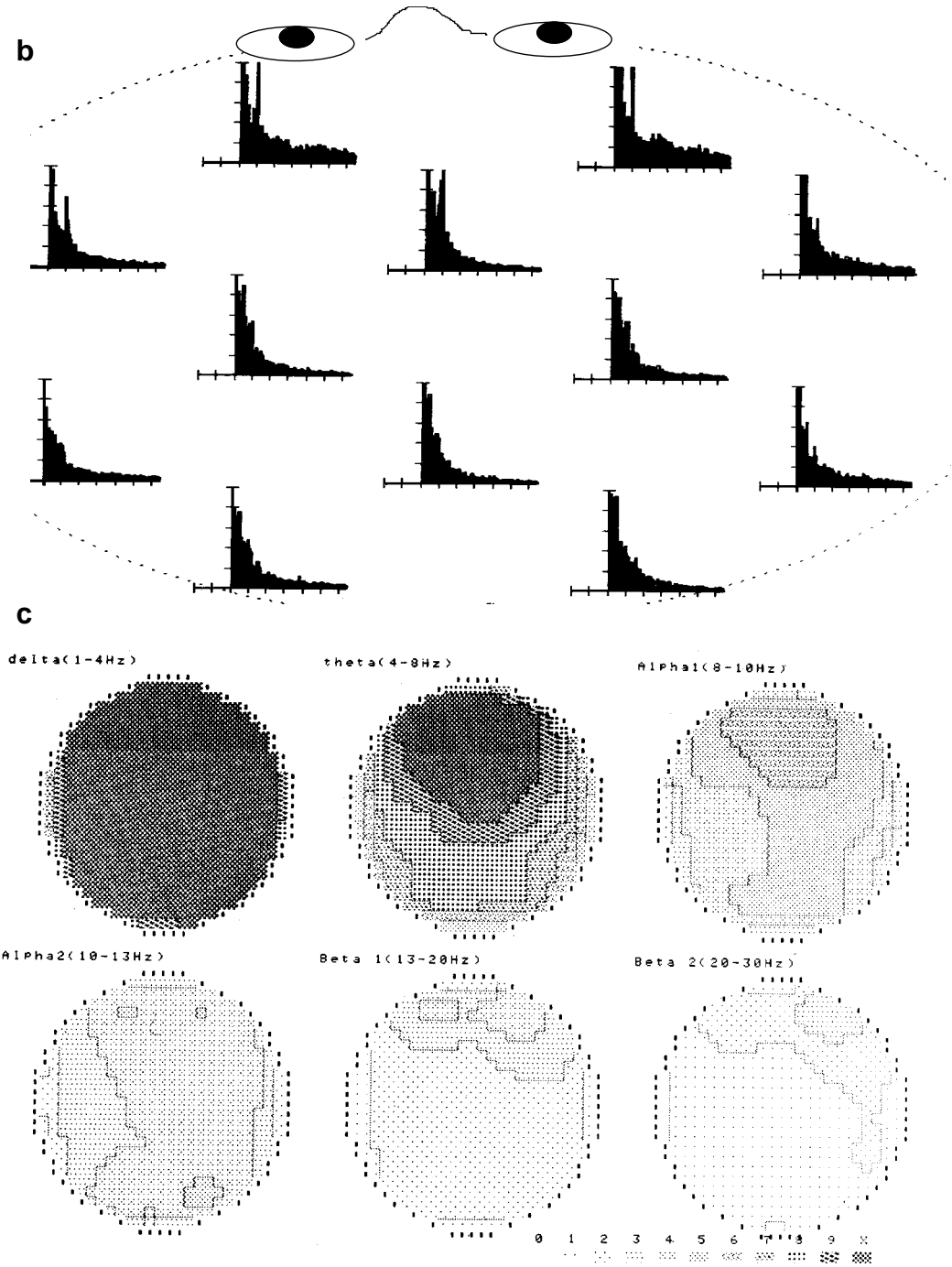


Figure 5(a) A typical Fm-theta appearing on an EEG trace during video game from a 7-year-old boy in Experiment 2. Fz trace is underlined to show Fm-theta in μ V (b) FFT power histogram of EEG; (c) EEG topographical Mapping of EEG.

ms. The A/D converted data were divided into 10 periods, each of which has sequential 128 points. The latter 28 points on each epoch were overlapped on the next period. For each epoch, data were subtracted by the average value and processed by the cosine taper for each channel. Then FFT analysis was done on these 10 periods separately. The mean power spectrum was calculated by summing across these 10 power spectrums and divided by 10 for each channel. In this manner, 12 channel power spectrums were given on one processing epoch. The mean power in each frequency band, delta(-2.8 Hz), theta (3.0-7.8 Hz), alpha-1 (8.0-9.8 Hz), alpha-2 (10.0-12.8 Hz), beta-1 (13.0-19.8 Hz), and beta-2 (20.0 Hz-) were calculated for each channel. The topogram for each frequency band was drawn by the linear interpolation method.

3.3. Results and Discussion

After the experiment, all subjects reported that they were most interested in the video game. Eight out of ten subjects said watching the animation was the most boring among the three tasks.

3.3.1. Behavior: Subjects were monitored and recorded by our video system during three tasks. In all cases, subjects' behaviors were as follows.

- (1) *Animation*: While watching the animation, children watched the CRT display silently for initial 3-4 min. But after that they seemed to become bored, i.e., their movement of body and eyes gradually increased.
- (2) *Stroop test*: While being tested with Color Stroop test, they seemed to be interested in the task. They actively vocalized each letter or color circle making their best efforts.
- (3) *Video game*: While playing the video game, subjects seemed to be very interested in playing. Subjects' blinking was inhibited just after the initiation of the game stage with their eyes fixated on the CRT display. When the given game stage ended, blink occurred in bursts.

3.3.2. Blink rate: As shown in Figure 4a, blink rate decreased during tasks, and its effect was most intense in the video game and poorest in the animation task. The effect of task on mean blink rate was significant ($F(2,18)=19.90$, $p<.001$). The differences in blink rates between pairs were all significant.

3.3.3. Fm-theta : On the contrary, Fm-theta appeared richest in the video game and poorest in the animation task as shown in Figure 4b. Analysis of variance showed that task main effect was significant ($F(2,18)=6.26$ $p<.01$). Paired t-tests showed all differences were significant.

Figure 5a shows the EEG trace in which Fm-theta rhythms appeared, typically on Fz , Fp1, and Fp2 electrode positions. In this case, frequency was about 7.0 Hz and amplitude was about 50 micro Volts. Figure 5b shows the power histogram of FFT analysis for twelve electrode positions. Maximum power was found within theta band (5.5-7.5 Hz) in frontal areas. Figure 5c shows the topographic mapping of EEG of Figures 5a and 5b. In each mapping, high density shows high power values within the frequency bands. It can be seen that theta band, upper middle trace, has a focus on Fz area.

It is suggested that inhibition of blink rate and enhancement of Fm-theta would be fine indices of children's interest during visual tasks.

4. General discussion

Summarizing reported results and several other studies done in my laboratory to assess workers' strain during visual tasks measuring both Fm-theta and spontaneous eyeblinking, the following four consistent outcomes are found.

- (1) *Task Demand*: Initially, when subjects start the VDT task, Fm-theta appears and eyeblink activity is suppressed in comparison with the pre-task rest period.
- (2) *Memory Load*: Second, both the duration of Fm-theta and eyeblink rate increase as a function of memory load during the VDT task.
- (3) *Fatigue*: Third, when subjects feel fatigue of their visual organs or eye strain, the appearance of Fm-theta is suppressed and eyeblink rate increases. In this case, a typical blinking pattern called 'blink bursts' (frequent eyeblinking in bursts) is observed.
- (4) *Interest*: Finally, an interesting visual task, such as a video game, induces the intense inhibition of eyeblinking and facilitates the appearance of Fm-theta.

In these circumstances, we can suspect that the inhibition of eyeblinking may be an index of task demand during the visual task, degree of mental work load, and states of interest. It is also noted that Fm-theta may be an index of degree of attention concentration and of state of interest. We conclude that both Fm-theta and spontaneous eyeblinking are expected to be good psychophysiological measures in evaluating the working environment and the quality of work, as suggested by our previous experiment of visual search task (Omori, *et al.* 1996).

A recent concern is to develop low-priced, small-sized, and user-friendly equipment that can automatically detect both Fm-theta and eyeblinking simultaneously. We have already established the basic specifications of the equipment, intelligent sensor-amplifier terminal and WINDOWS program run on PCs (Yamada, 1996). Using this equipment and fine software run on PCs, psychological factors affecting workers performance and pleasantness of the workspace or work environment could be assessed by a psychophysiological method easily.

Beyond my proposal, it is expected that more useful and accurate psychophysiological index of mental workload, fatigue, stress, attention concentration will be found by researchers concerned with psychophysiology in ergonomics.

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References

- FUKUDA, K., & MATSUNAGA, K. 1983 Changes in blink rate during signal discrimination tasks. *Japanese Psychological Research*, 25, 140-146.

- ISHIHARA, T., & YOSHII, N. 1972, Multivariate analytic study of EEG and mental activity in juvenile delinquents. *Electroencephalography and Clinical Neurophysiology*, 33, 71-80.
- MIZUKI, Y., TANAKA, M., & INANAGA, K. 1982, Effects of centrally acting drugs on the frontal midline theta activity. *Electroencephalography and Clinical Neurophysiology*, 54, 28.
- NIWA, K., YAMAGUCHI, HINO, K., & TSUJIMOTO, T., 1975, Frontal theta burst and personality trait. *Rinsho-Nouha (Clinical EEG)*, 17, 661-668. (In Japanese)
- OMORI, Y., MIYATA, Y., & YAMADA, F. 1996, The effects of visibility and memory load on blink rate during visual search task. K. Shirakura, S. Tsutsui, & I. Saito (Eds.), *Current Biofeedback Research in Japan 1995-1996*, Japanese Society of Biofeedback Biofeedback Research, Tokyo, 1-6.
- PONDER, E., & KENNEDY, W. P. 1928, On the act of blinking. *Quarterly Journal of Experimental Physiology*, 18, 89-110.
- STERN, J.A., WALRATH, L.C., & GOLDSTEIN, R. 1984, The endogenous eyeblink. *Psychophysiology*, 21, 22-33.
- TADA, H. 1986, Eyeblink rates as a function of the interest value of video stimuli. *Tohoku Psychologica Folia*, 45, 107-113.
- TADA, H., YAMADA, F., & FUKUDA, K. 1991, *Psychology of Blinking*. Kitaoji-Shobou, Kyoto (In Japanese).
- TSUDA, K., & SUZUKI, N. 1990, Effects of subjective interest on eyeblink rate and occurrences of body movements: Experimental control of interest by sample-prewriting method. *Japanese Journal of Physiological Psychology and Psychophysiology*, 8, 31-37. (In Japanese with English abstract)
- YAMADA, F. 1996, Development of the personal computer assisted stress management instruction system. *Proceedings of the International Conference on Stress Management Education*, Waseda University, Tokyo, 2-6.
- YAMADA, F., YAMASAKI, K., & MIYATA, Y. 1979, Lead-stimulation effects on human startle eyeblink recorded by an electrode hookup. *Japanese Psychological Research*, 21, 174-180.
- YAMADA, F., YAMASAKI, K., NAKAYAMA, M., & MIYATA, Y. 1980, Distribution of eyeblink amplitude recorded by an electrode hookup: Re-examination. *Perceptual and Motor Skills*, 51, 1283-1287.
- YAMADA, F., & YAMAZAKI, M. 1995, Effect of Fm biofeedback on anxiety. T. Kikuchi, H. Sakauma, I. Saito, & K. Tsuboi (Eds.), *Biobehavioral Self-Regulation: Eastern and Western Perspectives*, Springer, Japan, 203-208.
- YAMAGUCHI, Y. 1981, Frontal midline theta activity. In N. Yamaguchi & K. Fujisawa (eds.), *Recent Advances in EEG and EMG Data Processing*. Elsevier, North-Holland Biomedical Press, 391-396.
- YOSHII, N., ISHIIHARA, T., & TANI, K. 1964, Juvenile delinquents and their abnormal EEGs (2) continuous theta waves. *Folia Psychiatrica et Neurologica Japonica*, 18, 389-395.