Topographic EEG Study of Visual Display Terminal (VDT) Performance with Special Reference to Frontal Midline Theta Waves

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Summary: Operators of visual display terminals (VDT) often complain of physical, as well as psychological stress. Under certain circumstances, increased psychological stress among VDT operators is seen to create serious problems in their occupations, yet few studies have dealt directly with this problem. It is not clear how this should be measured and evaluated. We report the results of experiments where psychological stress was induced during VDT tasks such as visual search and computer mouse operations. The relationship between spatio-temporal analysis of EEG activity and productivity of VDT work was investigated. The subjects were divided into three age groups: young adults (18-22 years old), middle-aged (38-42 years old) and the elderly (58 years and over). Characteristic EEG changes occurred during VDT tasks. These consisted of frontal midline theta waves with maximum amplitude at Fz. Statistically significant relationships were found between duration of working, EEG electrode location on the head, as well as correlations between work speed and variation of theta waves. It was concluded that some factors relating to the severity of a mental task and the distribution of cortical EEG potentials are closely related. When long lasting theta waves appear in the EEG, a rest period should be considered, before the subjects complain of fatigue. An effective method to optimally determine the duration of work and rest periods can be designed using the EEG.

Key words: Topographic EEG; VDT task; Psychological stress; Spatio-temporal analysis; Frontal midline theta waves; Analysis of variance.

Introduction

Many electronic devices play an important role in today's office or factory. Due to its flexibility, the visual display terminal (VDT) is a prominent and essential component. It is composed of a cathode ray tube display (CRT), which is similar to a television display, combined with a keyboard. One can operate computers using the VDT to obtain responses and messages, or to review a patient's condition with bedside monitoring systems. The VDT has changed old style electrical tasks into modern mechanized and computerized work. Operators of VDT complain of physical stress and pain, as well as psychological stress. In some situations such psychological stress can cause serious operational problems. Of the few studies which have dealt directly with this problem, for example, Smith et al. (1981), most have been based on subjective responses derived from questionnaires. Only a few investigators (Haider et al. 1981; Floru et al. 1985; Osaka 1983) have attempted to obtain objective measures of psychological stress using physiological parameters. In the present study the EEG and its distribution of is scalp was used to derive potentials on the VDT operator's scalp was used to derive objective indices of psychological stress. Other physiological measurements included ECG and respiration. However, these parameters are not very suitable for measurement of VDT performance because their variation is very small (Kato et al. 1974, Tanaka et al. 1990). Appropriate methods should measure the variation of physiological states accurately. The relationship between EEG activity and VDT performance was investigated using quantitative analysis of the EEG. The accuracy of performing VDT tasks was also studied.

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(Accepted for publication: May 24, 1990).
Acknowledgments: This investigation was supported by a special grant from the Minister of Labor of Japan for studies on Industrial Ecological Sciences. The authors would like to thank Mr. H. Togami, Analytical Laboratory of Human Information, University of Occupational and Environmental Health for his computer program for experimental mouse operation.
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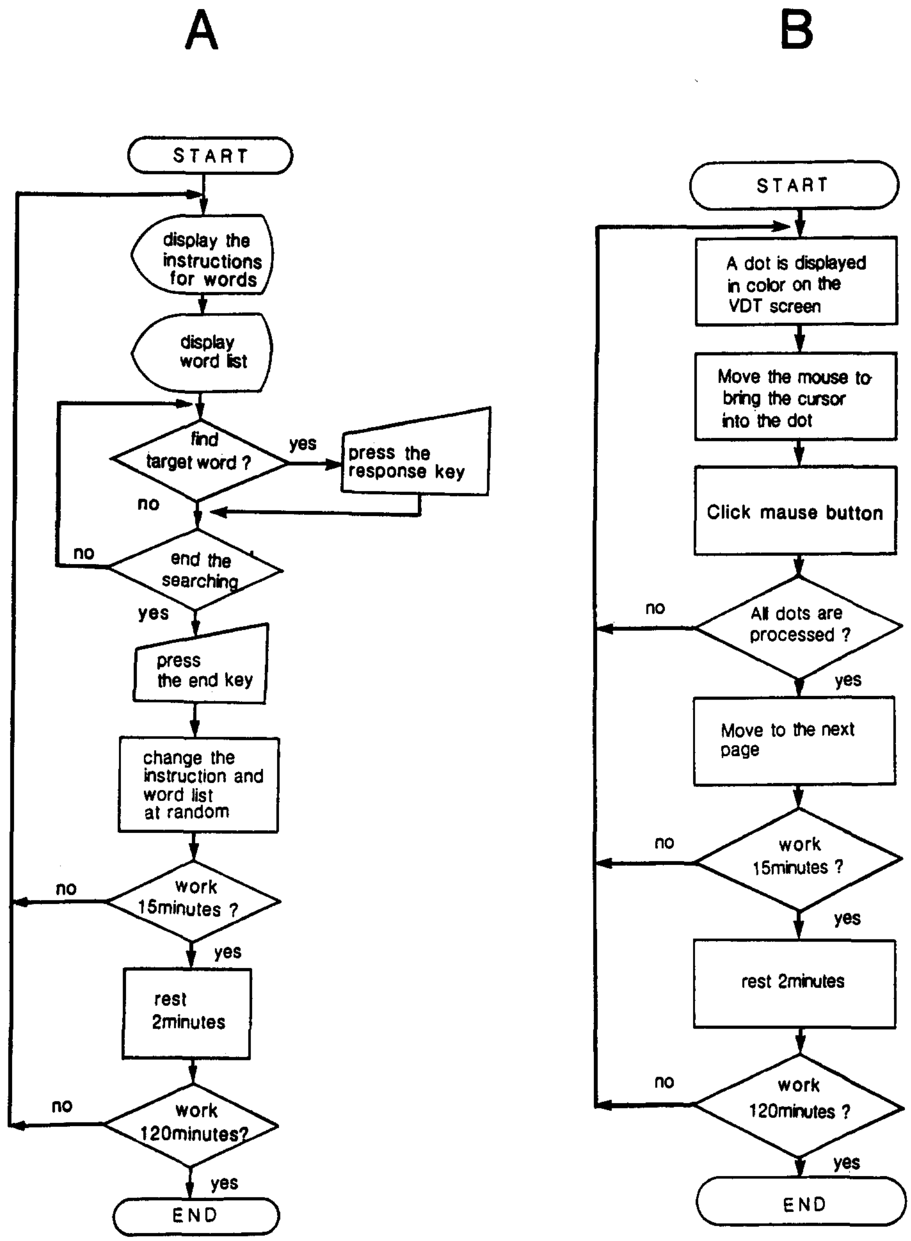

Figure 1: Flow chart of the experimental design of the visual search (A) and mouse test (B).

Methods

Visual search test

The experimental design of this visual search test is illustrated in Figure 1A. The instructions for the task were first displayed for 5 sec. The name of a group was given; for example, the names of countries, flowers, animals, etc. Ten groups were prepared. After this, a list of words to be searched by the subject was displayed. The list was made up of 60 objects and names of various kinds and some indications, called target words, were hidden in the list. Each word was made up of four or five Japanese katakana characters. When the subject found the target, he pressed the response button and continued to search for other targets. After completing his search, he depressed a second button, changing the target and word list at random. Subjects were instructed to perform this task at their best speed. When the search has been completed, the off switch was pressed, thus starting a new test. Each stage was 15 minutes, after which the subject rested with eyes closed for 2 minutes. The entire task was carried out in 8 stages. Thus the total test time was 120 minutes.

During the period of EEG measurement, the subject's eyes were closed. As control the eyes-closed EEG of each

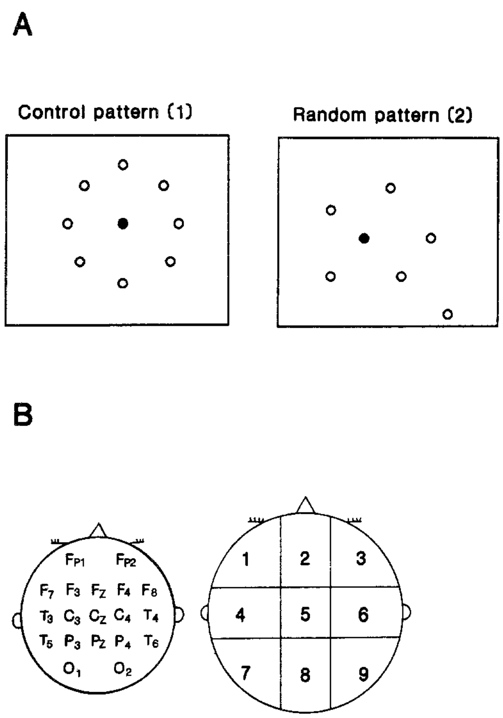

Figure 2: **(A)** The template patterns of control (l) and random pattern (2) in the mouse test. **(B)** Location of the electrodes and edited blocks. Left : Location of electrodes of the 10-20 system. Right : Edited parts (location) of EEG with block number.

subject was measured for 5 minutes before the experiment, under identical conditions.

A paper work test was developed as a cross-reference experiment. Each target and list of names were typed on size A4 paper, using the same targets list of words as on the VDT test. The experiment was carried out using such paper lists instead of VDT. Such work is referred to as hardcopy.

Mouse operation test

The experimental design of this test is illustrated in Figure lB. This is a pointing procedure for selection of a particular location on the CRT screen. The template with one colored dot (the "target location") was first displayed. The subject then points to the colored dot on the CRT as rapidly as possible by moving the mouse, and then press the mouse button. This changed the template, with a new random target location. After again completing the pointing procedure, the subject was required to begin working with another set of templates. The total task was 120 minutes, including measurement of the EEG, which was done every 15 minutes for two minutes with the eyes closed. The experimental schedule was the same as the visual search test. The template alternates between the 2 patterns (1 and 2 in Figure 2A).

Measurement of EEG

Data was recorded from 16 electrodes applied to the scalp according to the international 10-20 system (Jasper 1958). The following electrode sites were used: Fpl, Fp2, F3, F4, C3, C4, P3, P4, F7, F8, T5, T6, Fz, Pz, Ol and O2. The indifferent electrodes were applied to both earlobes. Spectral analysis was then performed using an EEG scanner (model ATAC 3700 Nihon-Koden Co., Ltd. Tokyo) which calculated the spectral amplitude at frequencies from 0.5 to 30 Hz in 0.2 Hz steps.

After this procedure, the electrodes of the 10-20 system are rearranged on a two-dimensional grid plane, and interpolated by a two-variable sampling function on the potentials between grid points (Ueno et al. 1975). The electrode potentials at T3, T4, Fpz and Cz were calculated as follows:

T3 = (F7+C3+T5)/3
T4 = (F8+C4+T6)/3
Fpz = (Fp1+Fz+Fp2)/3
Cz = (Fz+C3+Pz+C4)/4
Oz = (O1 + Pz + O2) /3.

In order to clarify the variation of EEG localization, a division of scalp locations into nine blocks was made. The means for each block (Figure 2B) are indicated as follows:

Block #1= (Fp1+F7+F3)/3
Block #2= (Fpz+Fz)/2
Block #3= (Fp2+F4+F8)/3
Block #4= (T3+C3)/2
Block #5= Cz
Block #6= (C4+T4)/2
Block #7= (T5+P3+O1)/3
Block #8= (Pz+Oz)/2
Block #9= (P4+T6+O2)/3

After this procedure, the differences between the EEG data measured in each region after each session and the EEG control measured before the task was taken. These differences were averaged and used in subsequent analyses. Frequency bands of 3.4-7.8 Hz and 8-10 Hz were selected for comparison with recording time, cortical location and age.

In the visual search task, a three way layout analysis of variance was performed. Firstly, we calculated analytical data as expressed by Equation (1) as follows;

Xijkl = Yijkl - Y0jk1 (1)

where

Y : measured data

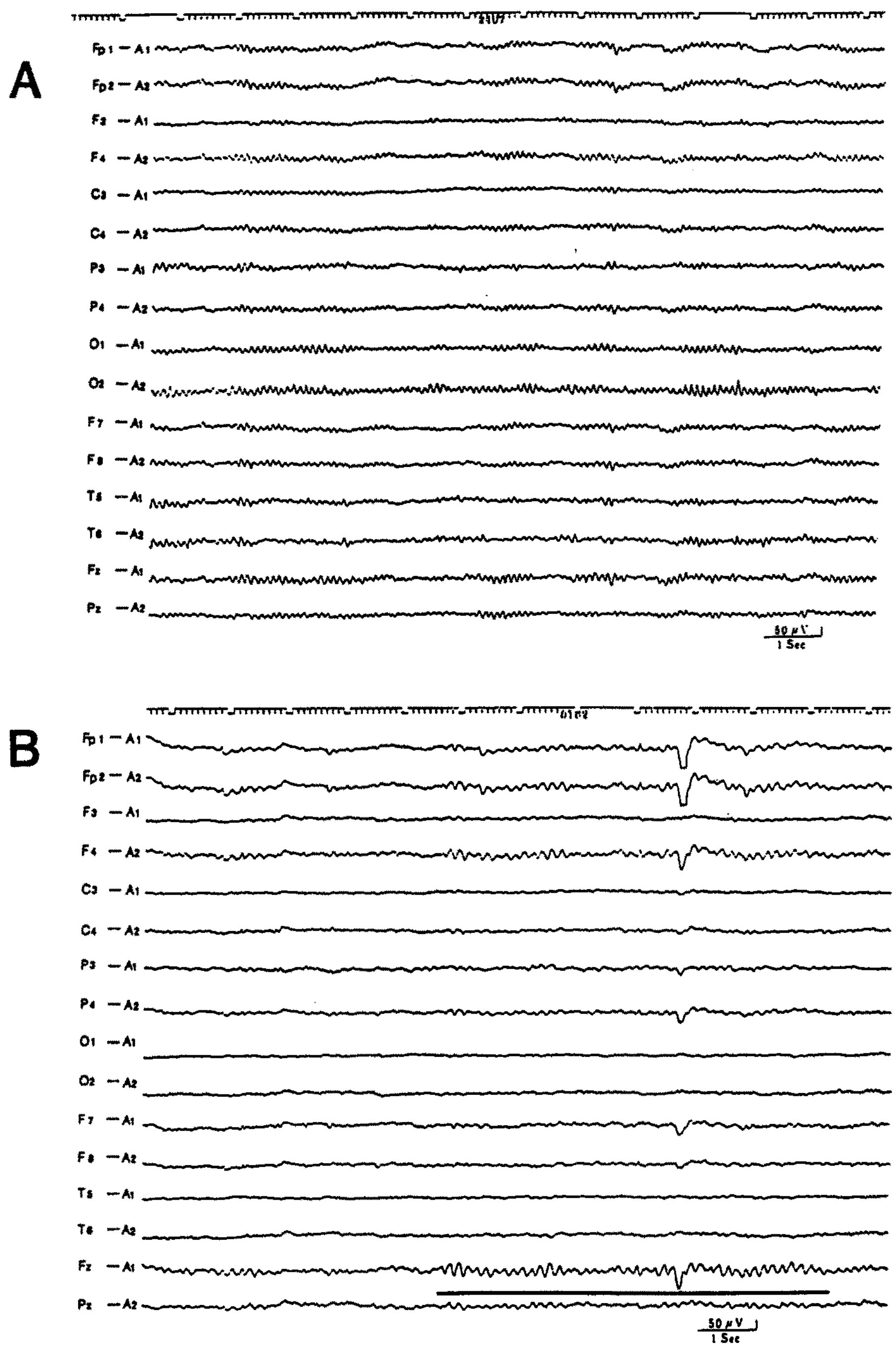

Figure 3: EEG effects obtained during the visual search task. **(A)** EEG in the pre-test period. Note 10 Hz moderate voltage, rhythmc alpha waves predominantly in occipital region at the time of closing of the eyes. **(B)** Characteristic theta waves (underlined in black) can be seen predominantly in the frontal midline region with a maximum amplitude at Fz with the eyes open.

X : analytical data

i : time of measurement (i=0, .. . ,8)

i=0 denotes the control measured before the tasks, i=1-8 is task stage.

j : scalp region (block number)

k : age group, k=1 indicates young, k=2 indicates middle and k=3 indicates old.

l : subject number (l=1 to 5)

In the mouse task, a two way layout was performed. The analytical data was calculated as follows;

Xijk = Yjik - Y0jk(2)

where

Y : measured data

X : analytical data

i : time of measurement (i=0, .. . ,8)

i=0 denotes the control measured before the task, i=1-8 is task stage.

j : region of measurement (j=1 to 9)

k : iteration (number of subjects)(k=1 to 6)

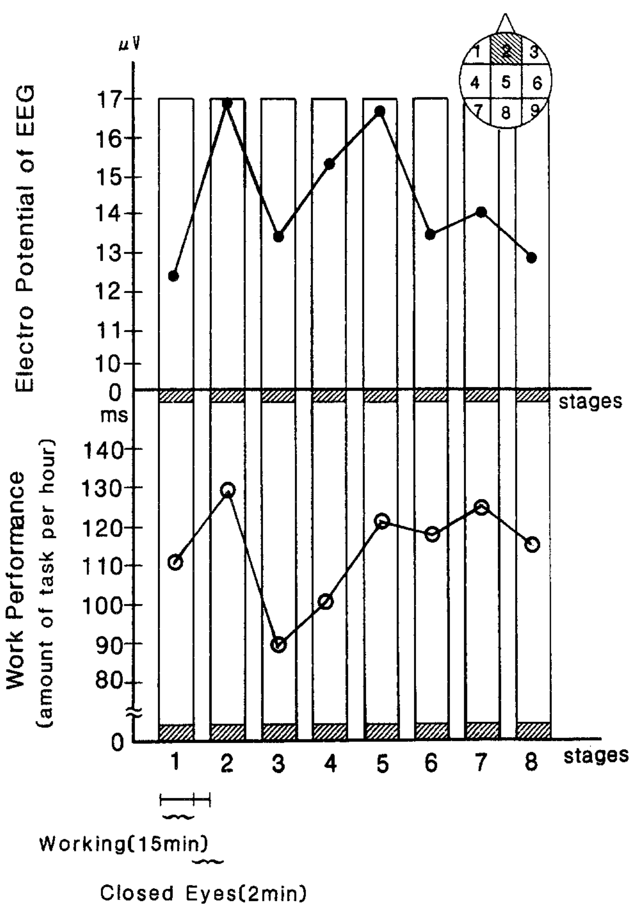

Figure 4: EEG changes during VDT work (Experiment 1). The work speed and variation of EEG potentials (3.6-7.8 Hz, part #2) were derived from the difference between the control and experimental data of each stage.

The mean and standard deviation (S.D.) were calculated from the data of 9 blocks at each point. The values obtained were the mean ± S.D. and mean ± 2 S.D. A two or three way analysis of variance were applied using two wave bands of EEG data (alpha and theta) for statistical analysis of the results.

Subjects

Volunteers were selected from a local office by a questionnaire which included subjects' health situation and health history. They were included if there was no evidence of health problems, on no medication, had no headaches and so on.

The subjects were divided into three age groups of 5 each for the visual search test: young adults (18-22 years old), middle-aged (38-42 years) and elderly (58 years and over). Six young subjects performed the mouse test.

Results

Experiment I

The EEG showed characteristic patterns of theta waves during the visual search test (Figure 3). These developed paroxysmally in relatively brief bursts supplanting the normal background or dominantly in the frontal region intermixing with it. They were predominantly in the frontal midline region with a maximum amplitude at Fz. This subject was a 21-year-old female college student. She did not blink for about 20 to 30 seconds during one page of the search task. EEGs were taken totally twice, in the first 3-5 minutes and in the 12-15 minutes during 15 minutes. Therefore, the total work-performance was done eight times and EEG recordings were taken 16 times. The pre-task EEG was taken as control and the difference of each subsequent measurement from the pre-task value was calculated. The theta band results are shown in the upper graph of Figure 4. The changes in the work performance of the subject are shown in the lower graph. As performance improved, the theta wave potential increased and as the performance declined, the theta wave potential decreased. The first appearance in the theta wave potential may be taken to indicate the increase in concentration on the task.

The EEG data were then analyzed using the three way analysis of variance (Table 1). Factor A is due to duration of working time, factor B due to the effect of location on the head, and factor C the effect of age. There was a

Table 1: The results of analysis of variance in the visual search test. **(A)** the effect of working time. **(B)** the effect of the blocks of the head. **(C)** the effect of the difference in age groups. E: error. T: Total sum of squares. S.S. = Sum of squares. D.F. = Degrees of Freedom. M.S. = Mean Square. F = F-test. * PI ** P *** PI

Theta wave

Main Effects	S.S.	D.F.	M.S.	F
A	564.58	8	70.57	3.44***
B	3, 456.11	8	432.01	21.08***
C	2, 108.69	2	1, 054.34	51.44***
A X B	63.41	64	0.99	0.05
A X C	502.23	16	31.39	1.53*
B X C	400.95	16	25.09	1.22
A X B X C	238.17	128	1.86	0.09
E	19, 921.80	972	20.50	
T	27, 255.90	1, 214		

Alpha wave

Main Effects	S.S	D.F.	M.S.	F
A	1, 567.13	8	195.89	2.04**
B	11, 864.70	8	1, 483.09	15.46***
C	2, 895.06	2	1, 447.53	15.09***
A X B	244.94	64	3.83	0.04
A X C	2, 350.00	16	146.88	1.53*
B X C	683.00	16	42.69	0.44
A X B X C	440.44	128	3.44	0.04
E	93, 250.10	972	95.94	
T	113, 295.00	1, 214		

significant interaction of the two factors A and C in each wave band. However, there were no differences in the cross-reference experiments (hard copy work).

The mean $\pm$1 S.D. and 2 S.D. were calculated from the 9 blocks of the data at each stage.

Figures 5A, 5B and 5C illustrate the distribution of changes of theta wave activity and work performance. Figure 5A represents young adult group, Figure 5B the middle-aged group and Figure 5C the elderly group.

In analysing performance data, two indices were sought, that is, the error rate (ER) and the work speed (WS) for every 15 minutes. ER and WS were defined as

$$ER = EN / TN$$

$$WS = CN / TT \times 3600,$$

where EN is the number of errors in unit time, TN is the total number of tasks, TT is the total time of the whole work, and CN is the number of whole work. WS was transformed into work speed by the hour. The work performance (WP) of the subject was calculated by

$$WP = WS \times (1 - ER).$$

This index becomes equal to the work speed when the error rate is zero and becomes zero when the error rate is 100% regardless of work speed. We defined this index as the productivity of the experimental work. Using the above mentioned measurement method, performances for each subject were investigated.

The pre-task EEG potential was taken as control and

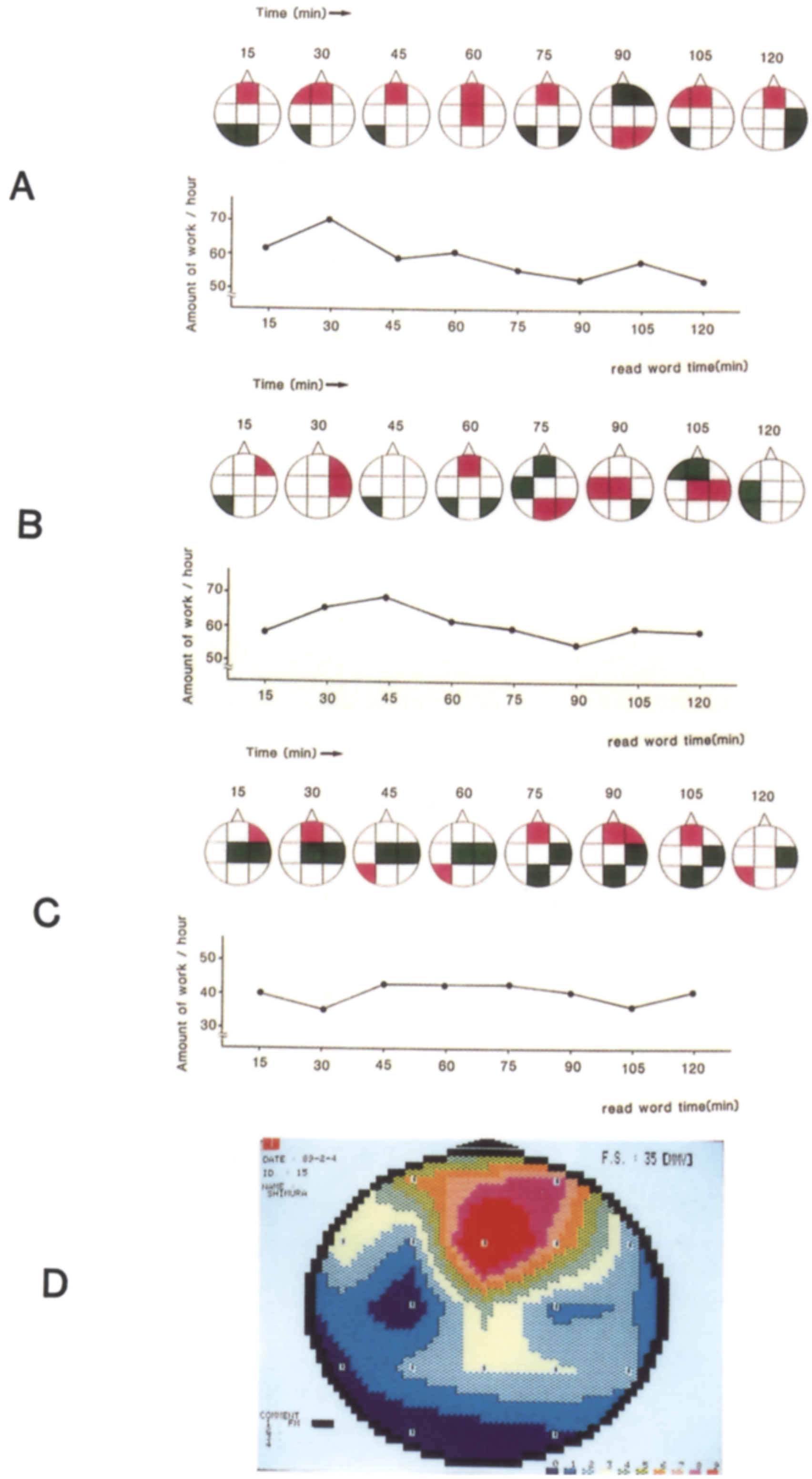

Figure 5: The variatrion of EEG and work speed in VDT work. **(A)**. Theta waves in young adults; **(B)**. in middle-aged subjects; **(C)** in elderly. Calculated value: red color: mean + 2 S.D.; pink color: mean + S.D.; blue color: mean - S.D.; dark color: mean - 2 S.D. **(D)**. The topographic display of the EEG theta band is shown. Scaling of colors show from 0 to 9 by 3.5uV/step, maximum amplitude at 55uV in red.

the difference of each subsequent measurement from the pre-task value calculated and the mean values for each subject group were obtained. These mean values are shown in Figure 5A, 5B, 5C. The change in the performance of the subject is shown in the lower half of each graph.

As illustrated in Figure 5A, during the first 15 minutes the amount of work per hour was 62 trials. In the next 15-30 minutes, it increased to 72 trials. These results are due to the initial effect and to the fact that the subject may have become accustomed to the work with consequent increased work performance. During the next thirty to forty-five minutes, the performance decreased to about 60, which means that with decreasing work performance there were increased errors. Until 75 minutes, work performance was maintained at the same level which means that performance was stable. And at about 75-90 minutes, there was a decrease in performance. This means that there was not only a decrease in the performance speed, but that there were many errors and decreased work performances. In the comparison of error rates, that is 30% at 45-75 minutes, and later, 43% at about 90 minutes, increasing work performance may be due to the end effect of the work. The appearance of theta waves was most dominantly located at the frontal midline region (Figure 5D), from the beginning of performance to seventy five minutes. At this time work performance was stable. In addition, sixty minutes later, these theta waves were revealed as extending more to the parietal region. Ninety minutes later, at the time of decreasing work performance (that is, errors increased) there was a decrease in theta activity. This may be due to tiredness. At 90 to 105 minutes, increased theta waves was associated with an increase in work performance. This is a characteristic finding in this group. This variation was not found in the middle-aged young group as shown in Figure 5B. According to the results of the group as shown In Figure 5B. According to the results of the questionnaire survey, this middle-aged group answered that they had worked at their own pace. Figure 5C illustrates the large variation of theta waves in the frontal and midline areas of the elderly group. In the elderly group, performance first increased, and then stayed at the upper level, with a large variation of theta waves. In the elderly group, theta waves in the frontal midline region due to working were constant. There were no typical variations in the cross-reference experiments.

Experiment II

In this case of a 19 year-old female, rhythmic 6.5 Hz theta waves were located at Fz maximally with a duration of a few seconds. At the same time, the alpha waves were completely blocked by opening the eyes for the pointing procedures (Figure 6A).

The two way layout analysis of variance during mouse operation using the EEG power spectrum are shown in Table 2. It shows that the relationship between duration of working time and the electrode location on the head was statistically significant.

Figure 6B illustrates work speed (mouse movement time) and variation of the EEG potential (3.6-7.8 Hz, block #2) which was derived from the difference between the control period and each test stage. It is seen that the decreasing mouse movement time indicates increasing work speed. This means increased familiarity and increased concentration on the task.

The relationship between the duration of working time and electrode location on the head was statistically significant. Theta waves similar to those during the visual search test began predominantly in the frontocentral midline region at the middle of the operation procedure.

Figure 7 illustrates the negative correlation between work speed and variations in the frontal midline theta wave activity. A linear relationship between the theta duration and mouse response time as a function of the task was established. This denotes that with short mouse response time, the duration of appearance of the frontal midline theta waves increases. In addition, when the mouse response time was high, subjects complained of fatigue. On the other hand, the variance in alpha waves increased predominantly in the occipital region in the latter half of the task, while frontal midline theta waves appeared over a relatively long period of time.

Discussion

There is a characteristic pattern of 5-6 Hz rhythmic theta wave activity in the frontal midline region during VDT performance. Similar patterns were noted in the visual search test and the mouse procedure. With these results in mind, we considered whether the variation of theta waves indicated the presence of psychological stress. Schacter (1977) has reviewed and analyzed the correlation between EEG theta activity and psychological phenomena. However no topographic studies have been done on this subject. Using the spatio-temporal display of the EEG, the following results were obtained in the visual search test: (1) In young adults, performance decreased as the amplitude variation in the EEG in the frontal midline region increased; in the middle-aged group, there were no such correlations; in the elderly group, performance increased to some degree and continued as theta wave activity increased. (2) There were no such characteristic theta waves during performance

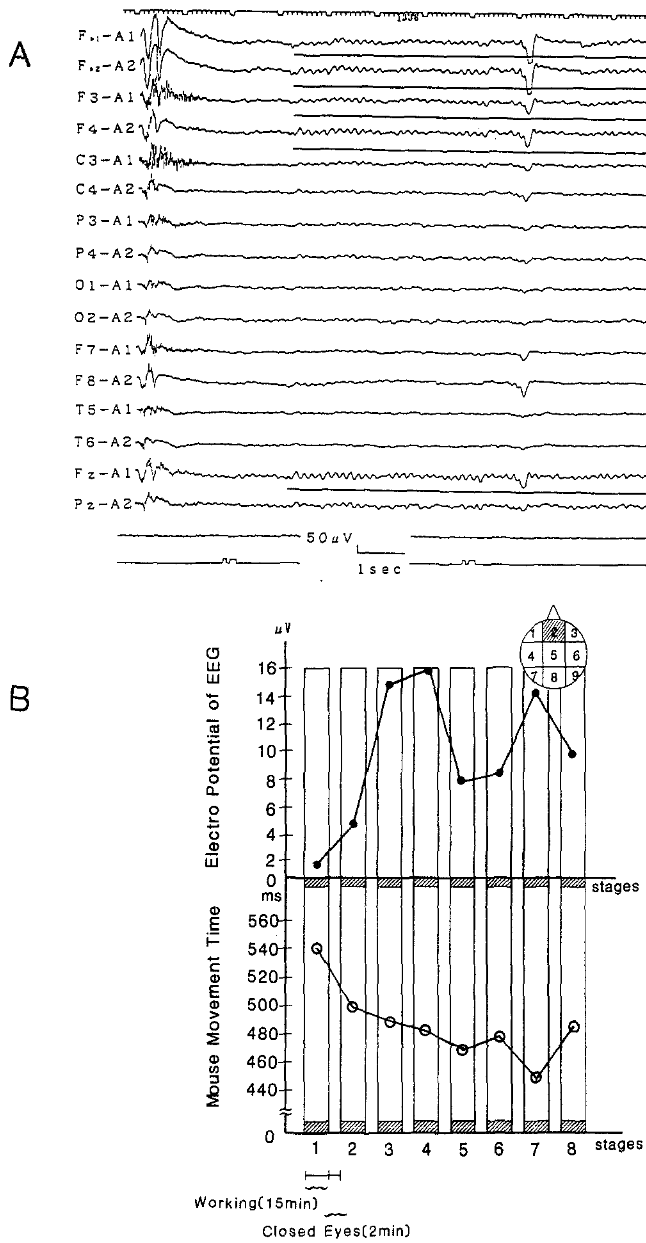

Figure 6: The original EEG in experiment II. **(A)** The original EEG in experiment II. Characteristic theta waves (underlined in black) can be seen predominantly in the frontal midline region with a maximum amplitude at Fz with the eyes open. **(B)**. EEG changes during VDT work. The work speed and variation of the frontal EEG potential (theta waves, part #2) derived from the difference between the control and each stage.

of the paper task. As a result of these findings it appears that characteristic theta waves are valuable measures of work load.

Frontal midline theta was recorded during a stressful mental task with mouse operation. In this task the subject had to keep looking at the CRT continuously, a more arduous mental task than the visual search test.

The theta waves observed in the VDT test were located with a maximum amplitude at Fz, with a frequency of 6-7 Hz and over one second in duration. This EEG pattern is similar to that described previously (Yasoshima et al. 1967; Ishihara and Yoshii 1972; Yamaguchi 1981; Hayashi et al. 1987). Such slow wave changes are affected by altered physiological states. On the other hand, Westmoreland and Klass (1986) showed that of 36 patients with midline theta rhythm, 28 had a seizure disorder, while the other 8 had various neurological conditions unassociated with epilepsy.

Although its origin is uncertain, midline theta rhythm appears to represent a nonspecific EEG pattern that can occur in a mixed group of patients with various neurologic diagnoses. Midline theta wave activity may

Table 2: The results of analysis of variance in the mouse test. A: the effect of working time. B: the effect of block number on the head. E: error. T: total sum of squares. F: F-test.

Theta wave

	S.S.	D.F.	M.S.	F
A	4484.3	15	299.0	3.27***
B	2951.2	8	368.9	4.03***
A X B	4241.1	120	35.3	0.39
E	65930.3	720	91.6	
T	77606.8	863		

Alpha

	S.S.	D.F.	M.S.	F
A	122469.0	15	8164.6	33.38***
B	6927.4	8	865.9	3.54***
A X B	10343.5	120	86.2	0.35
E	176128.0	720	244.6	
T	315868.0	863		*** P < 0.01

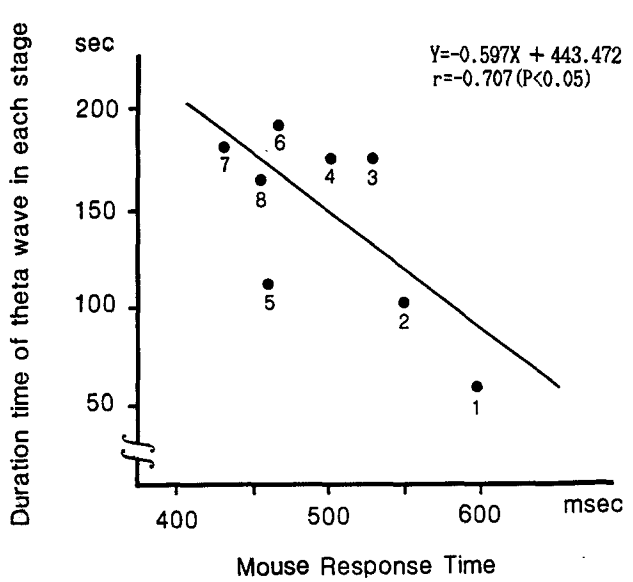

Figure 7: Negative correlation between work speed and duration of EEG theta wave potentials. The mean data of trials 1 through 8 are plotted. The regression line generated, r and p values are shown. X: Moving time of mouse. Y: Duration time of theta wave. r = Coefficient of correlation.

thus represent a nonspecific variant of theta activity that is present in a heterogeneous group of epileptic patients (Westmoreland and Klass 1986). It can also be observed in the normal EEG, or it may be related to certain mental activities (Yamaguchi 1981), or to emotional activities induced by helium under high pressure (Okuda et al. 1985).

Schacter (1977) reviewed the subject of EEG theta waves and their relationship to psychological phenomena. He emphasized that there are at least three attentional components which need to be considered: 1) alertness, 2)selectivity, and 3) conscious effort.

EEG theta activity occurred in a variety of mental states including: hypnagogic state in drowsiness, REM sleep, sleep deprivation, problem solving, perceptual processing, and learning and memory during several cognitive processes of alert persons, hypnotized persons, during meditation, as well as during autogenic training, also known as passive concentration on verbal suggestions, affective phenomena, and particularly emotional states.

Topographic EEG studies have not been systematically carried out during these various states. As a result, the distribution of theta rhythm in the scalp EEG has not been well described in the literature. Recent advances in topographic mapping of the EEG will contribute to an understanding of the differential distribution of theta waves in these diverse mental processes (Matsuoka et al. 1985; Yamamoto et al. 1985).

Yasoshima et al. (1967) and Hayashi et al. (1987) have clarified the appearance of frontal midline theta rhythm during sleep and its relationship to various mental activities. These investigators confirmed that frontal midline theta occurred not only during mental tasks in the waking state, but also during night time sleep where it was most frequently associated during stage REM and less frequently during stage 1 of sleep. The presence of frontal midline theta activity bursts was occasionally seen during stage II and rarely during stage III and never during stage IV. In particular, the greatest increase in theta activity, even over wakefulness, was during stage REM. These investigators also evaluated different reports on awakening from stage 1 and REM and the relationship to frontal midline theta activity. Frontal midline theta activities recorded during the present VDT experiments were similar to the described.

Conclusions

Frontal midline theta waves represent a characteristic EEG pattern during VDT tasks involving a high degree of mental concentration. There is a close relationship between the mental task and the distribution of these EEG potentials.

When long lasting theta waves appear, a rest period should be considered before the subjects become fatigued and complain of the work burden. An effective method to decide the length of work and rest could be designed based upon the characteristic EEG findings observed.

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