東海學報 48 卷(2009):01-12
中華民國九十八年十一月出版

Effects of polarity and working memory on users' performance and brain wave response

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Abstract

This study investigated the effect of display polarity and memory load on VDT performance and electroencephalogram (EEG) response. 18 college students of Tunghai University participated in this experiment as the subjects. The independent variables were the memory load and polarity. The results revealed that:

(1) Memory load significantly affected the finish time and error number. According to the task performance, both the finish time and the error number increased with increased characters remembered.

(2) Since the searching and recognizing task needed more attention, in this study we found the frontal θ rhythm (FP1 and FP2) has been noted to increase in strength as tasks require more focused attention.

(3) According to the EEG under different polarity (negative and positive), the power change of θ was stronger for positive contrast than negative one.

The results of this study have implications for using computer in memory and cognitive processing activities. In addition, the significant effect of display polarity and memory load on memory performance and EEG may assist in improving human-computer interaction.

Key Words: Display Characteristics, Polarity, Memory Load, EEG

1. Introduction

As science and technology progress, one of the consequences of the information age is that we increasingly rely on computers to acquire information and knowledge. Because of the expanded use of computers, especially e-document and e-book, electronic reading has become more popular today. Statistically, the scale of people who gets informed increased largely, but low-speedy reading and high-error possibly result in visual fatigue and incomprehension. Even though the VDT performance and visual fatigue of computer exhibit worse than real book, computers have still gradually replaced the real paper for acquiring knowledge. How to improve the VDT performance by enhancing the recognition of text or picture on the screen has become more and more important today. (Crushman, 1986)

In addition to human machine interfacing, working memory plays a role in operation performance. Medically, the brain is also called the central nervous system, which is the most important organ in the human body and responds to memory and cognition. The activity of a neuronal cell can be detected by neuroelectrophysiological and an EEG is a kind of brain-wave recorded spectrum. In the present study, EEG measurement (Table 1: The International 10-20 system of electrode placement) is employed for inspection of working memory. In this study, we will discuss the effects of memory load and display polarity on VDT performance and EEG response.

In this investigation, the main title is the effects of display characteristics and memory load on VDT performance. Further, it will be discussed in details about the influence of memory load and different polarities. Meanwhile, the distribution and modulation of EEG which is domestically rarely discussed would also be involved to the subjective inspection. (Shieh and chen, 2005)

2. Literature Review

2.1 Brain Wave

Recent theoretical and experiment work has focused on the role of brain oscillations in working memory and target differentiation; the distribution of the potential of brain cells has been particularly interesting. Medically, brain is called central nervous system, which is the most important organ in human body. The diverse functions of different regions of cortex can be indexed:

(1) Frontal lobe, which is located at forehead, responsible for sport coordination, considering determination, and problem solving.
(2) Parietal lobe, that is located at top of the head, responsible for tactile sensitivity.
(3) Occipital lobe, which is located at hindbrain, responsible for vision.
(4) Temporal lobe, which is located on bilateral sites of the head, responsible for auditory.

Brain wave can be approximately distinguished into four bands in frequency: beta (β) wave (12~32 Hz), alpha (α) wave (8~12 Hz), theta (θ) wave (4~8 Hz), delta (δ) (0.4~4 Hz).

2.2 EEG Data Acquirement and recording

Subjects wore a movement-proof electrode cap with 36 sintered Ag/AgCl electrodes to measure the electrical activities of brain. The EEG electrodes were placed according to the international 10-20 system with a unipolar reference at the right earlobe. The subject with EEG device is shown in figure 1.

The impedance between EEG electrodes and skin was kept to less than 5kΩ by injecting NaCl based conductive gel. Data were amplified and recorded by the Scan NuAmps Express system (Compumedics Ltd., VIC, Australia), a high-quality 40-channel digital EEG amplifier capable of 32-bit precision sampled at 1000 Hz. The EEG data were recorded with 16-bit quantization levels at a sampling rate of 500 Hz in this study. Data were preprocessed using a low-pass filter with a cut-off frequency of 50 Hz in order to remove the power line noise and other high-frequency noise. Similarly, a high-pass filter with a cut-off frequency at 0.5 Hz was applied to remove baseline drifts.

Table 1 The International 10-20 system of electrode placement

Electrode number		International code		Name
left	right	left	right	
1	2	FP1	FP2	Frontal pole
3	4	F3	F4	Frontal
5	6	C3	C4	Center
7	8	P3	P4	Parietal
9	10	O1	O2	Occipital
13	14	F7	F8	anterior Frontal
15	16	T3	T4	middle Temporal
17	18	T5	T6	posterior Temporal
19		Fz		midline Frontal
24		Pz		midline Parietal
20		Cz		midline Central
11	12	A1	A2	Auricular


Figure 1 The subject with EEG device

2.3 Studies of EEG

The sensitivity of the human EEG to changes in mental effort has been known since Hans Berger reported a decrease in the amplitude of the α rhythm of the EEG during mental arithmetic in 1929(Gundel and Wilson, 1992). The α rhythm tends to decrease in strength as tasks become more difficult (Gevins et al., 1997; Sterman et al., 1994). This inverse relationship between α amplitude and task difficulty has sometimes been interpreted as indicating that the α rhythm represents a form of cortical idling (Van Winsum et al., 1984). The dynamic nature of the cortical visuospatial attention processes during the line bisection test, which is sensitive to perceptual asymmetries (Cieck et al., 2007). Klimesch (1999) reported that α band activity was stronger during retention of supraspan compared to subspan memory lists.

In contrast, the frontal θ rhythm has been noted to increase in strength as tasks require more focused attention (e.g. Ishihari and Yoshii, 1972, Gevins et al., 1997, Miyata et al., 1990, Yamamoto and Matsuoka, 1990, Gundel and Wilson, 1992). According to the results of the thesis of Gevins (1993), there were several emphases induced:

(1) A frontal midline θ rhythm increased in strength with increased task difficulty.
(2) Slow (low-frequency, 8~10 Hz) α signal decreased in magnitude with increased task difficulty.
(3) Both the frontal θ rhythm and the slow α signal were largely insensitive to the type of information.
(4) With increased practice on the task, both the θ rhythm and the slow α signal increased in amplitude.
(5) Faster (high-frequency, 10~12 Hz) α signal, which was also attenuated in difficult tasks, showed less change in amplitude with practice, and was suppressed more when attending to spatial than verbal information.

Furthermore, the effort required to sustain attention to even superficial tasks tended to increase after extended periods of performance (Warm et al., 1996). This heightened effort might be responsible for the practice-related enhancement of frontal θ. In addition to its increase in amplitude in the more difficult task, frontal θ also increased with practice. This increase suggests that the subjects practiced the tasks over an extended period, and had to make an increased effort to maintain a task-related attention set.

2.4 Memory

The composition of memory system includes "memory storage" and "memory process". According to the sequence of stimulation, "memory storage" could be divided into sensory memory, short-term memory, and long-term memory. Memory process comprises four components --- attention, rehearsal, encode, and retrieve. Obviously, memorization plays a critical role in the progress of comprehension. Short-term memory is also called working memory (Gevins, 1993), which is produced by cognitive stimulations and sustains for a while after the stimulation ends. With limited capacity, short-term memory is in the range of 7±2 sense units, which are easily misplaced within 20~30s without rehearsal and encoding (Miller, 1956). However, with particular rehearsal and encoding, short-term memory would transform into long-term memory which sustains for a longer duration.

Memory system is divided into primary memory and secondary memory. (Waugh & Norman, 1965) Referring to the primary memory, the old message would be replaced with the new one if there is no rehearsal. Many psychologists, over a long period of study, believe that short-term memory is not only the passively stored message, but also an actively message-processing system. (Kintsch, 1977)

Dagnall et al. (2007) pointed out that the restriction of memory capacity will influence response time. Siegel, J.A. & Siegel, W. (1972) take absolute judgment for example to point out that subjects will begin to make judgment mistakes when the number of incentives exceeds 5 or 6 in single dimension, and the rate of mistakes will increase with the number of incentives. In addition, scholars point out that careless mistakes are related to working memory. Byrne & Bovair (1997) point out that some mistake emergence can be due to the overload of memory.

2.5 Polarity

Polarity is an important property of display. The contrast between targets and background can be separated into two sorts by luminance: positive contrast and negative contrast. Positive contrast means dark targets on a bright background; negative contrast means bright targets on a dark background. Some studies revealed that positive contrast was better than negative. Shieh and Lai (2008) indicated that positive contrast was rated higher for aesthetic appearance and legibility. The results from Saito et al. (1993) about diverse polarities of VDT reported that positive contrast was the better form of CRT display. Research about effects of polarity on VDT performance also showed similar results. (Snyder et al., 1990)

Even though some studies indicated that positive contrast was better than negative, Cushman (1986) expressed that positive contrast which led to a faster reading speed didn't lead to significantly better comprehension, moreover, the positive contrast led to a worse outcome of subjective visual fatigue. However, study of the effects of display polarity on VDT performance and operator's EEG response is lacking in the literature so far. There is a need to compare different polarity on VDT performance and operator's EEG response.

3. Methods and Materials

3.1 Subjects

Eighteen undergraduate students (9 male and 9 female) aged between 19 and 23 years(mean 22 years), volunteered to participate in this experiment. These subjects were screened to ensure visual acuity of at least 20/20 with or without glasses.

3.2 Experimental Design

Two independent variables were analyzed: memory loads and polarity. Polarity had two levels: positive and negative. Five levels of memory loads were employed: 3, 5, 7, 9, and 11 items (amount of Chinese characters). Both independent variables were within-subject factors. There were two independent variables and three dependent ones were included in this experiment:

◎ Independent variable

1. Memory loads--- 3, 5, 7, 9, and 11 of Chinese characters.
2. Polarity --- positive and negative.

◎ Dependent variable

1. Finish time --- the finish time of the task operating.
2. Error number --- the number of the errors occur during the task.
3. EEG --- recording the modulation of brain wave acquired from 9 electrodes: FP1, FP2, FZ, CZ, PZ, O1, O2, T5, and T6.

3.3 Apparatus

The experimental equipment used included an ACER Travel Mate C100 tablet PC Computer: the liquid crystal screen is 10.4 inches long, the resolution of TFT-LCD screen is 1024 x 768 pixels, 16 million colors, the touchpad is inside the board. The software is a self-developed computer program designed in Microsoft Visual Basic, which records Finish time (seconds) and Error number (times) automatically. The EEG was recorded and analyzed using NEUROSCAN developed by Neurosoft Inc. The optometer Vision tester is OPTEC 2000, the Digital Light Meter is TES1330. Microsoft Windows XP Tablet PC Edition is adopted as the operating system in the experiment.

3.4 Experimental Process

First, the participant as requested to closed his eyes for about 2 minutes in order to relax until his brain wave seemed to be stable. Second, the participant started to operate the task right after the assistant's permission. At the beginning of the task, the characters remembered would be presented on the screen, and the presenting time as varied according to the number of characters. The participant as instructed to memorize these characters, and then click the "start" button to start searching recognizing in the following text. After the searching and recognizing started, the participant was asked to find and click the characters remembered in the text as fast as he could. (Figure 2). The task was not finished until all the characters remembered were clicked out, unless the task limit time, 200s, was reached.

3.5 Research Method

The experiment of characters remembered was implemented in this research. Three dependent variables involved in this experiment were finish time, error number and EEG. All the statistics would be analyzed as ANOVA with the program SPSS.

Figure 2 Experimental text arrangement (in Chinese)

3.6 EEG instrumentation and recording

The EEG was recorded from FP1, FP2, Fz, Cz, Pz, T5 and T6 according to international 10–20 system.

EEG processing and preliminary analyses were performed with the NEUROSCAN 4.3.1 software package. Adaptive filtering methods were employed to minimize eye movement contamination of the EEG. The data were then visually inspected, and data segments containing residual eye movements and blinks, instrumental noise, and movement artifacts were eliminated from subsequent analyses.

4. Results

4.1 Analysis of Memory performance

The discussion of the results was about the effects of the memory load and polarity on the VDT performance and visual fatigue. On the one hand, the memory performance depended on "finish time" and "error number"; In addition, the electroencephalogram (EEG) was also discussed.

4.1.1 Finish Time

Finish time is one of the indicators of operation performance, and could be analyzed if it was influenced by the independent variables. Table 2 indicated that: (1) polarity didn't apparently affect the finish time. (2) The effects of the memory load on finish time reached a level of significance. ($F(4，170)= 32.72$； $P< 0.05$).

Table 2 ANOVA for finish time

Source	SS	d.f.	MS	F-value	P-value
Polarity	1499.97	1	1499.97	0.78	0.38
Memory Load	251047.53	4	62761.88	32.72	0.001**
Error	333719.93	174	1917.93		
Sum	586267.43	179			

**: P< 0.01

4.1.2 Error Number

Besides finish time, error number was recorded during the experiment. Table 3 indicates that: (1) the effects of polarity on error number did not reach a significant level. (2) The amount of characters apparently affected the error number. ($F(4，170)= 6.72$；$P< 0.05$).

Table 3 ANOVA of error number

Source	SS	d.f.	MS	F-value	P-value
Polarity	0.45	1	0.45	0.69	0.41
Memory Load	17.42	4	4.36	6.72	0.001**
Error	112.86	174	0.65		
Sum	130.73	179			

**: P< 0.01

4.1.3 Brief Summary

Integrating the two above-mentioned performances, and according to the memory performance and polarity, Figure 3 and Figure 4 were drawn as follows. The trend of average finish time and error number of each task, which showed that the average finish time increased from 94.33s (3 characters) to 190.57s (11 characters). This result revealed that working time increased with the amount of characters remembered. Furthermore, the average error number increased from 0.06 errors (3 characters) to 0.83 errors (11 characters), and this result suggested that the error number also increased with the number of characters remembered.

The trend of average finish time and error number for each polarity. The average finish time for positive contrast (148.81s) was longer than negative one (143.04s), but the average error number for negative (0.51 errors) contrast was larger than for positive (0.41 errors). This effect might result from the fact that most of the displays are for positive contrast, which led to situation unaccommodated for negative contrast.

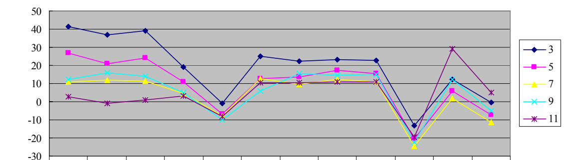
4.2 Analysis of EEG

Only θ band were analyzed in this research. Recent studies of EEG indicated that the modulation of θ band was regarded as the measuring factor of mental workload, attention, and active memory. Therefore, θ band was often specially discussed in studies of EEG.

4.2.1 Power Change Analysis

(1) Power Change of θ rhythm under various memory load

According to the recent studies, the θ wave increased in power as the mental workload and attention increased. Table 4 indicates that the modulations of the θ wave at FP1 and FP2 are larger in power than T5 and T6. Figure 3 showed the trend of the mean power change (%) of θ signal of memory load at each electrode. This outcome meant that memorization apparently elicited a stronger θ rhythm at FP1. ANOVA in Table 5 shows that the effects of the memory load on FP2-θ reached a level of significance ($p<0.05$).



	FP1	FP2	Average	FZ	CZ	PZ	O1	O2	Average	T5	T6	Average
3	41.56	36.86	39.21	18.89	-0.88	25.15	22.3	23.14	22.72	-13.18	12.44	-0.37
5	26.85	21.08	23.965	10.88	-7	12.67	13.83	17.48	15.655	-20.37	5.79	-7.29
7	10.83	11.89	11.36	4.66	-7.92	12.55	9.32	12.17	10.745	-24.61	1.88	-11.365
9	12.44	16.11	14.275	4.88	-9.93	6.12	15.58	14.42	15	-22.2	12.08	-5.06
11	2.86	-1.03	0.915	3.22	-8.26	10.25	10.4	11.03	10.715	-19.41	29.13	4.86

Figure 3 The trend of the mean power change (%) of

Table 4 The mean θ power change (%) at each electrode site under various memory loads

Electrode\ Memory Load		3	5	7	9	11
Frontal pole	FP1	41.56	26.85	10.83	12.44	2.86
	FP2	36.86	21.08	11.89	16.11	-1.03
	Average	**39.21**	**23.965**	**11.36**	**14.275**	**0.915**
midline Frontal	FZ	18.89	10.88	4.66	4.88	3.22
midline Central	CZ	-0.88	-7	-7.92	-9.93	-8.26
midline Parietal	PZ	25.15	12.67	12.55	6.12	10.25
Occipital	O1	22.3	13.83	9.32	15.58	10.4
	O2	23.14	17.48	12.17	14.42	11.03
	Average	**22.72**	**15.655**	**10.745**	**15**	**10.715**
posterior Temporal	T5	-13.18	-20.37	-24.61	-22.2	-19.41
	T6	12.44	5.79	1.88	12.08	29.13
	Average	**-0.37**	**-7.29**	**-11.365**	**-5.06**	**4.86**

Table 5 ANOVA for FP2 θ Power Change

Source	SS	d.f.	MS	F-value	P-value
Memory Load	2.75	4	0.69	2.40	0.05
Polarity	0.01	1	0.01	0.02	0.88
Error	49.77	174	0.29		
Sum	52.52	179			

*:P< 0.05

4.2.2 Power Change of θ rhythm of different polarities

Table 6 is the power changes of the θ rhythm under different polarities at all electrodes. It also showed that the positive-θ were marginally stronger than the negative-θ. The power changes of θ at O1 and O2 were relatively stronger than at T5 and T6. Figure 4 also showed the trend of the mean θ power change (%) of different polarities at each electrode O1 and O2. Although it didn't reach a level of significance, these results suggested that polarity might be slightly correlative with the occipital lobe which responded to vision.

Table 6 The mean θ power change (%) of different polarities at each electrode

Electrode / Polarity		Positive	Negative
	FP1	20.20	17.62
Frontal pole	FP2	17.61	16.36
	Average	**18.90**	**16.99**
midline Frontal	FZ	9.01	8.00
midline Central	CZ	-3.93	-9.66
midline Parietal	PZ	16.16	10.53
	O1	15.16	13.42
Occipital	O2	16.45	14.85
	Average	**15.80**	**14.13**
	T5	-19.68	-20.23
posterior Temporal	T6	14.64	9.89
	Average	**-2.52**	**-5.17**

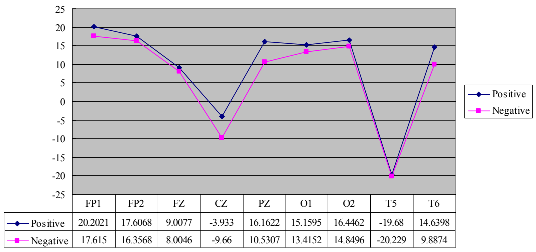


Figure 4 The trend of the mean θ power change (%) of different polarities at each electrode

5. Discussions and Suggestions

Effects of display polarity and memory load on VDT performance and EEG are principally discussed in this research. Followings are the respective discussions.

5.1 Memory Load

Finish time, error number, and the EEG reached significant differences. The results revealed that the finish time increased with memory load increased. Thus, the memory load apparently affected finish time and error number. Subjects rashly made mistakes and wasted too much time when the memory load exceeded the capacity range of short-term memory (7±2 sense units). This situation suggested that the number of units which are going to be remembered and recognized should be carefully considered in further job design involved in short-term memory.

5.2 Polarity

Although the effects were not significant, the VDT performances such as finish time for the negative contrast was better than the positive one while the error number showed an opposite result.

In the study of the effects of polarity of the CRT on operation performance (Snyder et al., 1990), the VDT performance for positive contrast was better than for negative when subjects worked on searching and reading. Nevertheless, in another study about display polarity (Chan et al., 2008), the analysis indicated that negative contrast performed better on ordinary screens because the subjects were less sensitive to screen flicker for negative than positive.

This investigation revealed similar results to the old studies, that are neither positive contrast nor negative led to an absolutely better performance than the other.

5.3 EEG response

The modulation of θ signal reached a level of significance at certain electrodes. The experiment of EEG indicated:

The increases in power changes of θ at FP1 and FP2 were stronger than at O1 and O2, and showed a progressive attenuation from forebrain to hindbrain. Since the searching and recognizing task needed more attention, in this study we found the frontal θ rhythm (FP1 and FP2) has been noted to increase in strength as tasks require more focused attention. Such an increase in power change of θ reached a level of significance at FP2. These statements showed the same results as the studies about the increase in power change of θ with mental workload and attention. (e.g. Gevins et al., 1997; Gunedl & Wilson, 1992)

The experiment polarity indicated: (1) the increases in power change of θ at O1 and O2 were stronger than at T5 and T6, and showed a high correlation between polarity and occipital which responds to vision. (2) Generally, the power change of θ was stronger for positive contrast than negative.

According to the modulation of θ waves, the experiment on memorization indicated that the subjects performed relatively better and paid more attention when the number of characters remembered was 7.

ACKNOWLEDGEMENTS

The authors wish to thank Prof. David Newquist for the English correction of the manuscript.

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螢幕極性與工作記憶對電腦使用者作業績效與腦波反應的影響

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摘要

本研究在探討極性與工作記憶對使用者績效與腦波反應的影響。受試者為 18 位東海大學的學生。實驗自變數為記憶個數與極性。研究結果顯示：

(1) 記憶個數對於完成時間與錯誤次數有顯著影響。在績效的表現上，記憶個數越多者，完成時間越長且錯誤次數愈多。
(2) 搜尋與認知作業需要更多的注意力。本研究指出，隨著任務需要更多的注意力，前額 θ 波(FP1、FP2)功率變化會隨之增加。
(3) 在腦波活動上發現，不同極性(陽性與陰性)下，陰極之 θ 波活動強度增加小於陽極。

本研究顯示電腦極性與記憶個數在人類記憶績效與腦波反應的結果，在改善人機互動上，效果顯著。本研究結果將可應用於使用電腦時的人類記憶與認知過程之設計。

關鍵詞：螢幕特性、極性、記憶個數、腦波(EEG)