PAPER

An Evaluation of the Physiological Effects of CRT Displays on Computer Users

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SUMMARY An experiment was conducted to measure and compare the physiological effects of three types of CRT on users. We proposed a new strategy for measuring the user's level of relaxation. In this strategy, called "Task Break Monitoring (TBM)," the subjects took a break with eyes closed after each interaction with the computer. During each break, electroencephalogram (EEG), especially alpha 1 waves, electrocardiogram (ECG) and galvanic skin resistance (GSR) were monitored and recorded. The results show that the type of CRT display which emits far-infrared rays modulated by a FIR-fan induce less fatigue in users while they are working and reduce the recovery time after the task was completed. We believe "TBM" to be an important innovation in human computer research and development because the after effects of computer use have an obvious bearing on recovery time, user endurance and psychological attitude to the technology in general etc.

key words: *alpha 1 wave, level of relaxation, level of fatigue, task break monitoring (TBM), far-infrared-ray-fan (FIR-fan)*

1. Introduction

The level of fatigue induced in users by CRTs strongly affects the recovery process, the endurance and psychological attitude of users. Psychological attitude here refers to emotional and behavioral characteristics of users during and after interaction. These in turn strongly influence productivity [1], therefore a variety of new input/output products have been developed in an attempt to reduce fatigue and to make users more productive. Cathode Ray Tubes (CRT) which emit modified far-infrared rays are good examples. Far-infrared rays are used, for example in the medical field, because it has been shown that they stimulate the metabolism and blood circulation [2], [3]. However, the effects of these types of CRT display on user fatigue levels had not previously been scientifically evaluated and compared with commonly available CRT displays.

This paper presents an empirical evaluation of the effects of different types of CRT displays on user fatigue levels during interactions and on user relaxation levels immediately after a interactions. Here we define relaxation as a state of relief from tension or strain resulting from interaction with a computer. We use EEG, the ratio of LF/HF and GSR indices to evaluate and express it quantitatively in task break monitoring. So far, some research has subjectively evaluated user responses to changes in, for example, CRT chrominance and luminance levels. However, subjective user satisfaction does not distinguish between psychological factors and measurable physiological effects and responses. The use of technology to measure physiological responses promises a more accurate evaluation of user fatigue/relaxation levels and psychological responses. One important index is the electroencephalogram (EEG), especially variations in alpha wave activity which may be used as an indicator of the user's level of relaxation [4], [5]. While much research has focused on heart rate variations (HRV) [6], [7], not much research has focused on alpha wave responses. One reason is that beta waves are present when users are doing tasks but alpha waves are present when users have finished their tasks and they are relaxing their minds with their eyes closed [8]*. We developed an evaluation method based on the computer users' EEG responses which allows us to measure their state after a task. In this experiment we monitored the user's EEG with an ECG monitor both during and immediately after the completion of each task i.e. during a break after each interaction with the computer. Thus, we were able to observe alpha waves clearly during the break. Moreover, we added ECG and galvanic skin resistance (GSR) monitoring to check and confirm our findings.

This paper makes two main contributions. First, it offers a quantitative evaluation, especially of alpha waves, which shows that the best CRT display is one with the far-infrared rays modulated and directed toward the user by a "FIR-fan, or electric fan." This device sinusoidally modulates the intensity of far-infrared rays to a more effective level (1 Hz) for absorption into the human body. Secondly, this paper introduces a new evaluation strategy called "Task Break Monitoring (TBM)." TBM consists of EEG, ECG and GSR

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*It is reported that alpha waves appear in the frontal lobe during mental arithmetic tasks as a result of deeply focused concentration and imagination [9].

monitoring of subjects during a break immediately after the task. During TBM the subjects relax with eyes closed. This enables us to observe and monitor the appearance of alpha waves which are not present during the interactions but which are an important index of user relaxation levels and the rate of recovery after interactions.

2. CRT Display Types

Three types of CRT display (A, B and C) were used in the experiment. They were each connected to a Power Macintosh PC 6300/120.

The A type CRT display is a normal display which is commonly sold in the market.

The B type CRT display is a new bio-television monitor which increases the radiation of the far-infrared rays (wavelength $5\,\mu$m–$15\,\mu$m, radiation temperature about 36°C which is equal to the temperature of electromagnetic waves) emitted from the cathode ray tube (CRT) (Figs. 1, 2). The back and front surfaces of the cathode ray tube are coated on the outside with ceramic material (aluminum trioxide, Al_2O_3) which strongly radiates the far-infrared rays through the side of the tube by generating thermal energy when the monitor is operating. The South Korean Materials Examination Research Academy has observed a far-infrared radiation rate of 93% or more when the black body is assumed to be 100%. Far-infrared rays are readily absorbed by humans, especially through the eyes and skin. It is known that far-infrared rays in this range have the effect of encouraging the human body and mental faculties to relax [10], [11], as in many physical therapies used in medical fields.

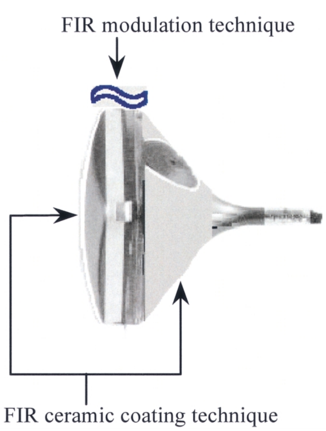

Fig. 1 The structure of a "Fresh Bio CRT."

In the type C CRT display, the surface of the cathode ray tube is also coated with aluminum trioxide (Al_2O_3), and an "FIR fan, or electric fan," consisting of a motor and a circuit, is installed in the front of the display cabinet (Fig. 3). The "FIR fan" modulates the far-infrared rays at a frequency of about 1 Hz. This sinusoidal emission of FIR corresponds to the vibration of "Qi" as observed in traditional Chinese therapies [12], [13]. Therefore we expected the low frequency modulation and sinusoidal emission of FIR to be more effective than continuous emissions of FIR at a constant level.

3. Method

3.1 Participants

Twenty-two subjects (15 male, 7 female) were tested in the experiment. They were from 24–40 years old. All subjects are graduate students and use computers. 17

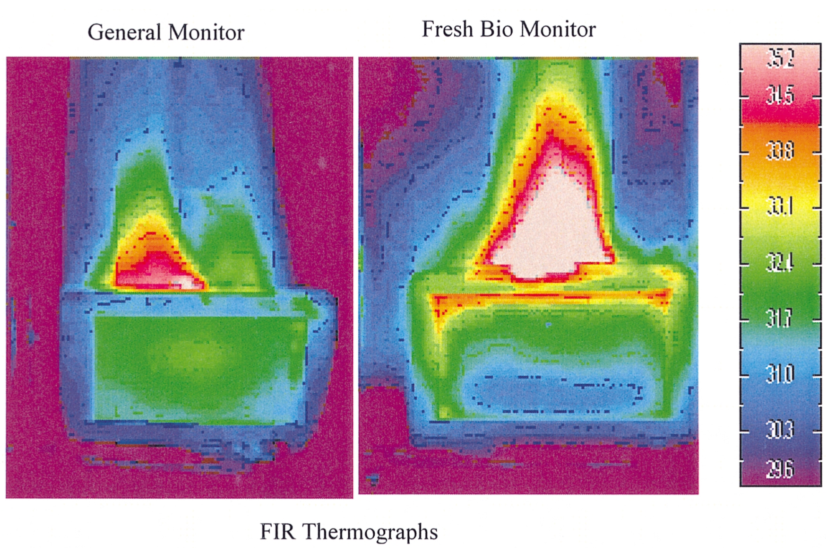

Fig. 2 Far-infrared ray emission images for a general CRT display and an FIR enhanced CRT display. Right side picture shows more bio-friendly far-infrared rays being emitted from the new type of monitor.

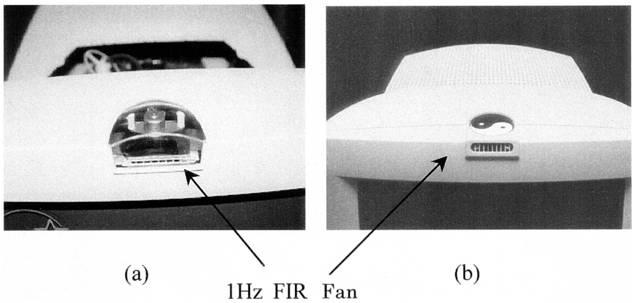

Fig. 3 1 Hz FIR modulator fan. (a) shows the "fan" assembly with no cover. (b) shows it with a cover.

subjects regularly used mouse-type-pointing devices.

3.2 Apparatus

The hardware used in this experiment was: an EEG monitor (SYNAFIT 5000, NEC Medical Systems Corp.), a Galvanic Skin Resistance sensor (GSR100A module, MP100, BIOPAC systems Corp.), an electrocardiogram (Bio-view G (2G52), MP100, NEC medical systems Corp.) and a personal computer (Power Macintosh 7600/200).

The software was as follows: Topography (ATALAS, Kissei Corp.), an electroencephalogram (EEG) analytic program used for bit map reading, and ECG and GSR analytic program (AcqKnowledge3.3.2, BIOPAC system Corp.)

3.3 Design and Procedure

Before the experiment we performed tests on five college students to confirm our design and to observe trends in the data. We then decided on the following steps.

Two types of simple task were designed: (i) typing an article with a word processor, and (ii) drawing a picture with Claris software.

The experiment was explained to the subjects before beginning the test session. Since users feel fatigue and stress when they have worked with computers for a long time, we paid attention to the recovery process during the break after each test session. We called this "Task Break Monitoring (TBM)."

Each subject was asked to follow these steps using each type of display.

(1) Close your eyes and keep your mind in a relaxed state for three minutes.

(2) Do the first task continuously for seven minutes.

(3) Close your eyes again and keep your mind in a relaxed state while awake for five minutes.

(4) Do the second task continuously for seven minutes.

(5) Close your eyes and keep your mind in a relaxed state while awake for three minutes.

The order of the two tasks and the three types of CRT display were varied for the different subjects. The differences between A, B, and C CRT displays were not explained to the subjects.

The data for each subject were recorded automatically as follows:

(a) EEG recording was continuous. We paid particular attention to EEG recordings from the "task breaks monitoring" i.e. steps (1), (3), and (5) above.

(b) ECG was recorded in all steps (1)–(5).

(c) A voltage value for GSR was recorded in all steps (1)–(5).

3.4 Index of Measurement and Method

(1) EEG Topography: Based on the International 10–20 System, electrodes were applied to 19 scalp sites (Fp_1, Fp_2, F_7, F_3, F_2, F_4, F_8, T_3, C_3, C_2, C_4, T_4, T_5, P_3, P_2, P_4, T_6, O_1, O_2). The referential montages of the 19 scalp electrodes were linked via the earlobes (A_1, A_2) with standard electrodes. Electrical potential data were graphed and converted into a bit map by ATALAS which is EEG analysis software. The frequencies represented in these topographical images were separated by a digital filter into delta, theta, alpha 1, alpha 2, beta 1 and beta 2 waves. The alpha 1 wave was the focus of our attention when EEG recordings were analyzed at break time because it is known that alpha waves are present in the occipital lobe when relaxing, and that they extend toward the frontal lobe when the degree of relaxation is deeper [14]. At the beginning of each break, beta waves gradually become less intense and alpha waves begin to appear. The alpha waves progressively increase with the rising of the electrical potential as the break continues. In this analysis we calculated the area of the alpha 1 waves (8–10 Hz) as a percentage of the EEG topography and used it as an index of the level of relaxation. Because alpha 2 waves (10–13 Hz) do not vary significantly they have no influence on this index. Initially the area of the alpha 1 image, representing specific electrical potential, was isolated and a bit map image was obtained. Then the bit map image was converted into a PICT image with "Graphic Converter" software. Then the number of pixels was counted using NIH image software. Finally the area of the alpha 1 wave image was calculated as a percentage of the entire area monitored.

(2) LF/HF ratio: This is an index derived from heart rate variability (HRV) for expressing changes in the balance between the sympathetic and parasympathetic nervous systems. The electrocardiogram's time series data regarding fluctuations between R-R intervals was converted by Fast Fourier Transformation (FFT) into frequency data. The power spectrum of 0.15–0.4 Hz (HF) (the area under the curve) was assumed to be the high frequency range, the power spec-

trum of 0.05–0.15 Hz (LF) was assumed to be the low frequency range, and the ratio between them was assumed to be the LF/HF ratio. It is known that as the LF/HF ratio increases the sympathetic nervous system becomes active. ECG data from the last two minutes of each break was analyzed. Quantification of this data showed that the sympathetic nervous system becomes active immediately after a computer interaction then gradually becomes weaker and the LF/HF ratio becomes correspondingly smaller.

(3) GSR: This is a voltage display indicating the degree of relaxation [8]. Resistance variations in two electrodes attached to the index finger and the ring finger are measured. Because GSR reflects changes in excitation of sweat glands located in various layers of the skin [15], slight perspiration appears when the user is under stress causing the resistance to decrease. But the resistance increases when the user relaxes. In this experiment we proposed a quantitative evaluation method as follows: The minimum value (electrical potential, regarded here as the subject's base value) at the end of the break was recorded, and the maximum value (electrical potential, regarded here as the subject's highest level of fatigue) at the end of the task was also recorded. The difference between the maximum and minimum value was calculated and assumed to be an index for evaluating the level of relaxation.

All values are expressed as means ± SE (Standard Error). Statistical analyses were performed with StatView Software using a pair t test. There was a significant difference between CRT groups when $p < 0.05$.

4. Results

On the basis of EEG and heart rate variability monitoring, the results show that CRT C permitted the most relaxation and faster recovery after the task and was thus considered to have caused less fatigue during the task: (i) there were significant increases in alpha 1 waves for CRT C display when compared with CRT A display ($p < 0.01$); (ii) there was a decrease for CRT C display in the ratio of LF to HF when compared with CRT B display ($p < 0.05$). But there was no significant difference between the CRT C and CRT A with regard to this index.

On the basis of GSR values (Max-Min) it was found that CRT B and CRT C display permitted almost the same degree of relaxation to be achieved, both being more effective than CRT A display ($p < 0.05$). In other words, no significant difference between the CRT B and CRT C display was found based on GSR values.

4.1 Results of EEG Topography

There were nine pages of data from three break periods after each participant used the three CRT displays.

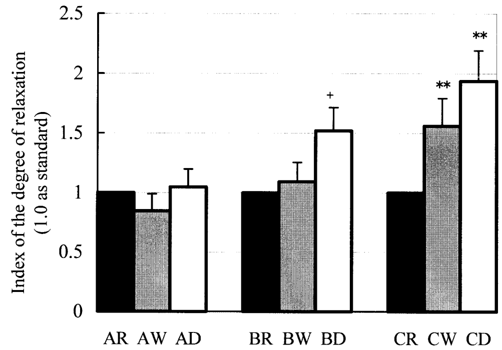

Fig. 4 Alpha 1 waves for three types of CRT displays. Mean ± SE, **: $p < 0.01$ vs. AW, AD, +: $p < 0.05$ vs. AD. A, B, C refer to different types of displays. R means Rest, W means after Word Processing, D means after Drawing. The vertical axis shows the appearance of alpha 1 waves after workload. These values indicate the percentage of the alpha 1 wave image in relation to the entire EEG topography area monitored, measured in pixels. Each value was divided by the standard values AR, BR and CR.

Delta, theta, alpha 1, alpha 2, beta 1 and beta 2 waves were each isolated and analyzed according to their respective areas. To reduce error we analyzed the data over as wide an EEG period as possible. For the purpose of analysis we assumed 1024 points of data (10.4 seconds) to be one unit. Moreover, the data for EEG analysis (via the alpha 1 bit map) was recorded as near to the end of each break as possible when the subjects were most relaxed. For example the results for CRT A display from the break are shown as AR where A = CRT A and R = Rest. The results from the break after the word processing exercise are similarly shown as AW where W= Word Processing. The results from the break after the drawing (D) exercise are shown as AD. Values for other CRT displays are similarly shown as BR, BW, BD, CR, CW, and CD. The first values AR, BR, and CR were assumed to be the standard values for each CRT display from which we calculated the values of AW, BW, CW, AD, BD, and CD for further statistical analysis.

As shown in Fig. 4, where alpha 1 waves for each CRT display are compared, it can be seen that CRT C display induces more alpha 1 waves with a correspondingly higher degree of relaxation in the subjects [4], [5]. It may be assumed also that the recovery time is reduced. We therefore concluded that CRT C display causes significantly less fatigue than CRT B and CRT A display.

4.2 Assessment of Relaxation Based on the LF/HF Ratio

The first value for each CRT display (AR, BR, CR) was used as the standard (value 1) for each subsequent interaction with each CRT display. When the LF/HF ratio is greater than 1 the sympathetic nervous system

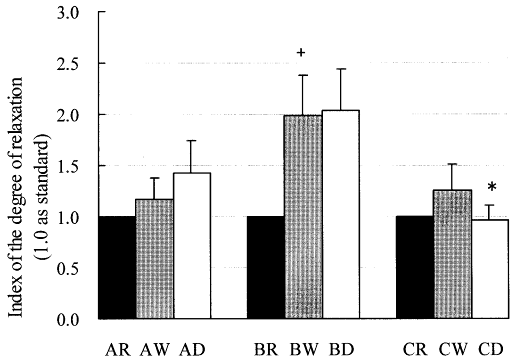

Fig. 5 LF/HF ratios for the three types of CRT displays. Mean ± SE *: p < 0.05 vs. BD, +: p < 0.05 vs. AW. A, B and C refer to different types of displays. R means Rest, W means after Word Processing, D means after Drawing. The vertical axis expresses the activity of the sympathetic nervous system as LF/HF which was then divided by the standard values AR, BR and CR.

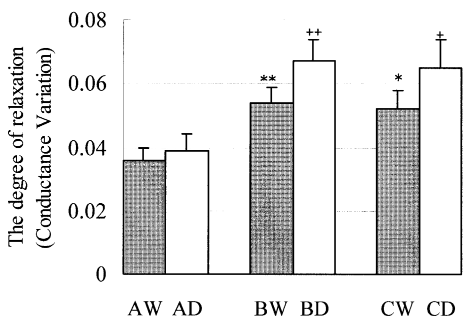

Fig. 6 GSR values for the three types of CRT display. Mean ± SE, **: p < 0.005, *: p < 0.05 vs. AW, ++: p < 0.005, +: p < 0.05 vs. AD. A, B, C refer to different types of display. W means after Word Processing, D means after Drawing. The vertical axis is the difference in voltage between the two electrodes which were attached to the index finger and the ring finger.

is active and the degree of relaxation is correspondingly decreased. Conversely, it can be said that the sympathetic nervous system does not play an important role when the LF/HF ratio is less than one. Figure 5 shows that the average LF/HF ratio for CRT C display is nearer one than for CRT B display. The average ratio for CRT C is less than the ratio for CRT A.

4.3 Evaluation of Changes in Relaxation Levels according to GSR Values (Max-Min)

Figure 6 shows the degree of relaxation achieved by users. The greater the height, the greater the relaxation achieved. CRT C and B create higher relaxation levels than CRT A. But CRT C and CRT B allow almost the same level of relaxation.

5. Discussion

The evaluation experiment demonstrates overall that the CRT C display induced the lowest level of fatigue thus permitting the highest level of relaxation of the three displays. This display sinusoidally radiates modulated far-infrared rays (1 Hz) from the front of the cathode ray tube (CRT). The tube surfaces of CRT C and CRT B displays are coated with aluminium trioxide (Al_2O_3) which strongly radiates the far-infrared rays to the side of the tube. It is generally assumed that the greater the relaxation achieved in TBM, the less fatigue there has been in the interaction. The results show that fatigue and stress from these new types of CRT displays are significantly less than fatigue and stress induced by normal CRT displays of the type A.

The CRT C display permitted a greater degree of relaxation than CRT A because far-infrared rays which are sinusoidal emitted and concentrated in the direction of the user are absorbed through the user's body, especially through the skin and eyes, while working. The absorption of far-infrared rays encourages the metabolism and blood circulation resulting in changes to the nervous system and the endocrinological system. Thus when FIR absorption is encouraged by the enhanced FIR CRT display fatigue is reduced and a greater level of relaxation is achieved.

This new type of CRT (display C) permitted the most relaxation after the task but did not cause the user to be sleepy. If users are made sleepy by a CRT during an interaction with a computer, at first they cannot work effectively, Secondly alpha wave's amplitude will decrease and rhythm will become irregular, and theta waves will appear during the workload [16]. In this experiment, the subjects typed an article and drew a picture as well as they could, so that they were active but not in a special state of deeper concentration or imagination. We observed that during these tasks, beta waves appeared, but no theta or alpha waves appeared. Immediately after the task was finished, the subjects began to relax while awake but with eyes closed. Alpha waves began to appear and increase while beta waves progressively decreased, as the subjects became more relaxed.

The physiological indices showed that CRT C display, with far infrared rays sinusoidally emitted, allowed a greater degree of relaxation. However, there were no significant differences between CRT B and C display. Priority was given to EEG and ECG monitoring over GSR monitoring. This may explain the fact that the difference between CRT B and C display are not as significant in the GSR tests. Clearly CRT B and C displays are better than A display. Future tests could more closely define the difference between CRT B and C displays with special reference to the functions of the modulator (FIR-fan) based on longer interaction times. It is likely that the differences between the CRT displays may become greater as the interactions become longer. If fatigue increases when a user is interacting with a CRT display for a longer time, we may expect the significance of the fatigue reducing functions of the

CRT C display to increase accordingly. This is important because many people interact with CRT displays every day for much longer periods than represented in these tests. To confirm the trends indicated in our experiment further testing could be done on users who have a heavy mental workload and on subjects who use CRT displays on a daily basis. Moreover, it is necessary to study how to increase the efficiency and reliability of the modulator to maximize its effect. Experimentation with the modulator's position and modulation frequency may also increase its effect.

6. Conclusion

We proposed a useful evaluation strategy which we called "Task Break Monitoring (TBM)." The physiological indices show that task break monitoring was effective for obtaining alpha wave information. Moreover, we combined EEG monitoring with ECG and GSR monitoring so that we could evaluate user levels of relaxation. While traditional ECG and GSR monitoring have previously proved effective, the addition of EEG topography in "TBM" has added further validation to these tests. We feel that EEG "TBM" is a significant index for research in the human computer interaction field. This method may not only be useful in the evaluation of output interaction, but may also be applied to the evaluation of input interaction and interaction style in human computer interface studies. We also believe that our proposal and the results are a useful contribution to research in the area of user fatigue/relaxation levels and to general productivity.

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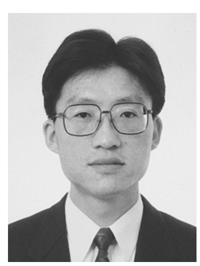

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