Effects of Time Stress on Psychophysiological Responses during Data Entry Tasks

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Abstract. Six male and six female students (19-23 yrs) volunteered as subjects in the present experiment. Subjects performed the data entry tasks. A hundred and twenty single digit numbers 12 by 10 lines matrix were displayed in a random sequence on the left side of monitor. Subjects input the same numeral as these numbers one by one with clicking of the mouse on the ten keys displayed on the right side of the monitor. Each task consists of the following conditions: 1) system response time is fast or slow; 2) delete the input numerals from 120 numbers or not ; 3) button flashes after input or not; and 4) the remaining time is displayed or not during performing the tasks. These tasks are programmed to be finished automatically after 200 seconds independent of the rate of completing all inputs. We measured heart rate (HR), systolic and diastolic blood pressure (SBP and DBP), skin blood flow (SBF), skin potential level (SPL), number of errors (Es), total number of input and subjective ratings concerning the degree of irritation (SR1), difficulty of input (SR2) and unpleasantness in operation (SR3). It was shown that when system response time was slow, even the average of heart rate and blood pressure were lower than fast system response time, however, the subjects felt greater emotional irritation, difficulty of input and unpleasantness in operation hence making more errors.

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Keywords: system response time, time pressure, human computer interaction, physiological response

Introduction

Recent development in computer science and technology provides us convenient tools or apparatuses such as the word processor, the remote controller, the automatic teller machine and control system of electric appliances in our daily life. On the other hand, it has been realized that computer causes many stress to users. One of the important aspects of human computer interaction is system response time which is the delay from

the input to the next input (Kuhmann, 1989). The system response time of computer is considered as a major stressor in human computer interaction (Johansson and Aronsson, 1984).

Furthermore, time pressure is also an important factor for the operation. For example, when people operate the automatic teller machine, especially the elderly become confused and/or stop their operation, if they receive the time pressure provided by a queue of users standing behind (Adams and Thieben, 1991).

The effects of time stress on operators have been studied by means of physiological measurements such as heart rate (Wierwille et al., 1985), blood pressure (Gao et al., 1990; Lundberg et al., 1993) and skin potential level (Kuhmann, 1989). According to these reports, the results seemed to be not consistent. The reason might be due to the different experimental conditions used in those reports. Therefore, it is necessary to find out the effects of time stress on the operator systematically for designing better visual display terminals (Yamamoto and Kuto, 1992) by means of psychophysiological measurements.

The purpose of the present study is to examine the effect of time stress on the operator for better display design under various experimental conditions using the psycho-physiological measurements such as heart rate (HR), blood pressure (BP), skin blood flow (SBF), skin potential level (SPL) and subjective ratings. HR, BP and SBF were used as an index of changes in activation level of autonomic nervous system. SPL was used as an index for mental sweating. As the effect of time stress on operator can be assessed by manipulating the time available to process the task (Corry, 1992), time stress was manipulated by means of changing system response time and/or displaying the remaining time for the task in this study.

Methods

Subjects

Six male and six female students (19 to 23 years old) volunteered as subjects in the experiment. Three of the

subjects had never used a personal computer. Eight of them had some experience in using the computer. One of them had often used the computer. Alcohol intake, too much food intake and heavy exercise were prohibited before the experiment.

Experimental condition

Experiment was conducted in a climatic chamber controlled at 22°C (RH:50%). Overhead fluorescent lamps were used for lighting. Illumination of desk surface (64 cm height) and vertical surface of the CRT color monitor on the desk were 500 and 250 lx, respectively. Luminance of the display was 100 cd/m².

Tasks

All the tasks were designed using the Hyper Card (Macintosh Hyper Card J 2.1, Apple) displayed on the 13 inches CRT color monitor (Macintosh M1198J/A, Apple). The display was monochromatic (black on white). Program for tasks were run on a personal computer (Macintosh LC III, Apple). A sample screen was shown in Fig. 1. A hundred and twenty single digit numbers 12 by 10 lines matrix were displayed in a random sequence on the left side of the monitor once for one task condition. Subjects were instructed to input the same numeral as these numbers one by one with clicking of the mouse on the ten-key displayed on the right side of the display. Beep or booing sound was presented from a speaker (SRS-48 Active Speaker System, Sony) after each input. The speaker was connected to the sound output of the personal computer (Macintosh LC III, Apple). Correct and incorrect input gives beep sound (65 dBA) and booing sound (65 dBA), respectively. The next number

could not be received unless the correct number is clicked. Remaining time for the task was displayed above the ten keys.

Each task was designed by the combination of the following conditions: 1) system response time was fast (<0.1 sec) or slow (0.3~7 sec); 2) deleted the input numerals from 120 digit or not; 3) button flashed after input or not and 4) remaining time was displayed or not during performing the tasks. Conditions of 1) and 4) were used as the time pressure. Conditions of 2) and 3) were used as input feedback to the operator. These tasks were finished automatically after 200 seconds independent of the rate of completing all inputs. System response time was defined as the time between first input and system readiness for next input. The fast system response time was not controlled by the program, that is, immediately responded after the input (<0.1 sec). The slow system response time occurred at random according to the characteristics of the system response time shown in Fig. 2. In this case, 79.1% of the response time was less than 0.5 second. When the system response time was fast, the task would be finished within 200 sec. Therefore, not all the experimental conditions of displaying the remaining time for the tasks of fast system response time were conducted. Thus, 12 conditions (2 x 2 x 2 x 2 - 4) were conducted in this experiment (Table 1). The order of these conditions was counterbalanced for the subjects. Subjects performed 12 tasks continuously, taking 3 minutes rest after each task.

Procedure

Subjects were involved in the experiment for about one and half hours a day. Procedure of the experiment was explained to subjects before the start of experiments. When the electrodes were attached on the subjects, they sat in a chair and relaxed wearing short T-shirts for about half an hour in a climatic chamber.

Heart rate (HR), mean blood pressure (MBP), systolic blood pressure (SBP) and diastolic blood pressure (DBP) were measured using the Finapres cuff (Oh-

Fig. 1 A sample screen of the display of the task on the monitor. Details are shown in the text.

Fig. 2 Characteristics of the slow system response time is shown. Slow system response time (0.3~7 sec) occurs at random.

Table 1 Tasks are designed by combination of the following conditions. 1) system response time is fast or slow, 2) delete the input numerals from the display or not, 3) button flash or not and 4) display the remaining time or not.

Tasks	Conditions	System Response Time	Delete the Input Numerals	Button Flash	Display the Remaining Time
A		fast	on	on	off
B		fast	on	off	off
C		fast	off	on	off
D		fast	off	off	off
E		slow	on	on	on
F		slow	on	on	off
G		slow	on	off	on
H		slow	on	off	off
I		slow	off	on	on
J		slow	off	on	off
K		slow	off	off	on
L		slow	off	off	off

meda 2300) attached on the left middle finger of phalanx media position. Skin blood flow (SBF) was measured from a left hand during performing the task using a laser flow meter (Advance ALF21D) whose sensor was attached on a palm. Skin potential level (SPL) was measured from a left hand using recording electrodes. Electrodes which were disposable self-attaching electrodes with a Ag/AgCl paste applied for ECG (Vitrode Y-250, Nihon Kohden), were attached on the palm and forearm. The electrode on the forearm was used as a reference. A ground electrode was attached on the left ankle. Before attaching the electrodes, the skin was dried and rubbed with a skin preparation gel (Skin pure, Nihon Kohden). Amplified signals were transferred to a personal computer (PC-9801 BX, NEC) after converting from analog to digital signal using a AD converter (ANALOG-PRO II, Canopus, transforming error: $\pm 0.5\%$ max.). Digital signal was stored on a hard disk by a software package (Wave Master II, Canopus, sampling frequency: 100Hz). The HR, MBP, SBP, DBP, SBF and SPL were recorded for 120 seconds (20 seconds x 6 times) between 80 and 200 seconds during performing the tasks. The number of errors (Es) and total number of input were recorded for each condition.

Subjective ratings were obtained after each task by visual analogue scale (10cm) according to the following three items: 1) irritation (SR1), 2) difficulty of input (SR2) and 3) unpleasantness in operation (SR3).

All the data were standardized for each subject. Standardized values were calculated as shown in the following equation: (each value - average value) / standard deviation. Three way ANOVA (system response time, delete the input numerals, button flash) was used for the task conditions of A, B, C, D, F, H, J and L. Three way ANOVA (delete the input numerals, button flash, display the remaining time) was used for the task

conditions of E, F, G, H, I, J, K and L. A paired t-test was also used. The level of significance was chosen at less than $p < 0.05$.

Results

Effects of system response time, delete the input numerals and button flash

Averaged data of six samples (20 second x 6) from each task condition of A, B, C, D, F, H, J and L were used for three way ANOVA (system response time, delete the input numerals and button flash). Table 2 shows the effects of the above three factors on the HR, SBP, DBP, ABP, SBF, SPL, SR1, SR2, SR3 and Es. The main effect of system response time was significant on the HR ($F(1,3)=11.38$, $p < 0.05$), DBP ($F(1,3)=34.41$, $p < 0.01$), ABP ($F(1,3)=28.74$, $p < 0.05$), SR1 ($F(1,4)=23.63$, $p < 0.01$), SR2 ($F(1,4)=28.29$, $p < 0.01$), SR3 ($F(1,4)=53.81$, $p < 0.01$) and Es ($F(1,2)=18.66$, $p < 0.05$). The main effect of delete the input numerals was significant on only the HR ($F(1,3)=16.66$, $p < 0.05$). The main effect of button flash was significant on the DBP ($F(1,3)=16.94$, $p < 0.05$) and the ABP ($F(1,3)=11.34$, $p < 0.05$).

There were significant interactions of delete the input numerals by button flash on HR ($F(1,3)=25.89$, $p < 0.05$), DBP ($F(1,3)=24.52$, $p < 0.05$) and ABP ($F(1,3)=14.42$, $p < 0.05$). These interaction effects show that the effects of delete the input numerals on the HR, DBP and ABP were dependent on the button flash. The interaction of system response time by button flash was significant on the SPL ($F(1,3)=10.37$, $p < 0.05$). This interaction means that the effect of system response time on the SPL was dependent on the button flash. The SPL showed a trend of higher value under the conditions of slow system response time (not shown in the Fig.).

Average values of 6 samples from each condition

Table 2 Results of ANOVA on the HR, SBP, DBP, ABP, SBF, SPL, SR1, SR2, SR3 and Es from the experimental conditions of A, B, C, D, F, H, J and L. F-values are shown in this table. If the mean square is less than 0.2, the value of the mean square is considered as an error, which is shown by the oblique lines. Abbreviations are as follows: 1) HR: heart rate, 2) SBP and DBP: systolic and diastolic blood pressure, 3) SBF: skin blood flow, 4) SPL: skin potential level, 5) Es: the number of errors, and 6) SR1, SR2 and SR3: subjective ratings for irritation, easiness of input and pleasantness in operation. Factor A: system response time, Factor B: delete the input numerals, Factor C: button flash.

*: $p < 0.05$, **: $p < 0.01$

Responses Sources	HR	SBP	DBP	ABP	SBF	SPL	SR1	SR2	SR3	Es
A	11.38*		34.41**	28.74*			23.63**	28.29**	53.81**	18.66**
B	16.66**									
C			16.94*	11.34*						
A×B										
A×C						10.37*				
B×C	25.89*		24.52*	14.42*						

were shown in Fig. 3 to Fig. 6. When the system response time was slow, the HR, DBP and ABP were lower than when it was fast. In this case, the subjects felt more emotional irritation, more difficulty in input, unpleasantness in operation and made more errors (Fig. 3). When the input numerals were deleted from the display, HR was lower than when they were not deleted (Fig. 4). In the case of not displaying the remaining time, when the button flashed, DBP and ABP were higher than when it did not (Fig. 5).

Effects of delete the input numerals, button flash and display the remaining time

Averaged data of six samples from each task conditions of E, F, G, H, I, J, K and L were used for three way ANOVA (delete the input numerals, button flash and

display the remaining time). Table 3 shows the effects of the above three factors on the HR, SBP, DBP, ABP, SBF, SPL, SR1, SR2, SR3 and Es. The main effect of button flash was significant on the SBF ($F(1,4)=29.54$, $p < 0.01$) and SR2 ($F(1,3)=24.49$, $p < 0.05$). There was significant interaction of button flash by display the remaining time on SPL ($F(1,3) = 22.07$, $p < 0.05$). The effect of button flash on the SPL was dependent on displaying the remaining time. There was also a significant interaction of delete the input numerals by button flash on SR3 ($F=69.72$, $df\ 1,3$; $p < 0.01$). The effect of delete the input numerals on the SR3 was dependent on the button flash.

On the other hand, when the button did not flash, SBF was larger than when it did. In this case, the subjects felt the difficulty more in operation (Fig. 6)

Fig. 3 Effects of the system response time on the HR, DBP, ABP, SR1, SR2, SR3 and Es. Mean values of standardized data are shown.

Fig. 4 Effects of the delete the input numerals on the HR. Mean values of standardized data were shown.

Fig. 5 Effects of the button flash on the DBP and ABP in the case of not displaying the remaining time. Mean values of data for all the subjects during 120 seconds. Abbreviations are as follows: DBP and ABP: diastolic and average blood pressure.

Total number of input

Total number of input (amount of task) was significantly larger ($p < 0.0001$) in the case of fast system response time than the slow system response time (Fig. 7).

Discussion

System Response time

According to the results of three way ANOVA, system response time was the most effective factor on the HR, DBP, ABP, SR1, SR2, SR3 and Es (Table 2). When system response time was fast, HR, DBP and ABP were higher than when it was slow. Schleifer (1990) reported that heart rate and blood pressure did not vary

Fig. 6 Effects of the button flash on the SBF and SR2 in the case of displaying the remaining time. Mean values of data for all the subjects during 120 seconds. Abbreviations are as follows: SBF: skin blood flow and SR2: subjective ratings for difficulty.

significantly with slow or rapid system response times. Furthermore, Kuhmann (1989) found that there were no effects of the different system response time conditions on heart rate and blood pressure. These findings were inconsistent with the present results. This discrepancy might be explained by the fact that the longer system response times (2 - 10 sec) were used in their experiments. On the other hand, the subjective and performance data suggested that subjects under system response time of 6 seconds developed the lowest level of stress, which was associated with the best performance of all groups (Kuhmann, 1989). Furthermore, Johansson and Aronsson (1984) observed that preferred system response time was not more than 5 sec. However, Martin and Corl (1986) found that user productivity

Table 3 Results of ANOVA on the HR, SBP, DBP, ABP, SBF, SPL, SR1, SR2, SR3 and Es from the experimental conditions of E, F, G, H, I, J, K and L. F-values are shown in this table. If the mean square is less than 0.2, the value of the mean square is considered as an error, which is shown by the oblique lines. Abbreviations are as follows: 1) HR: heart rate, 2) SBP and DBP: systolic and diastolic blood pressure, 3) SBF: skin blood flow, 4) SPL: skin potential level, 5) Es: the number of errors, and 6) SR1, SR2 and SR3: subjective ratings for irritation, easiness of input and pleasantness in operation. Factor A: delete the input numerals, Factor B: button flash, Factor C: display the remaining time. *: $p < 0.05$, **: $p < 0.01$

Sources	HR	SBP	DBP	ABP	SBF	SPL	SR1	SR2	SR3	Es
A										
B					29.54**			24.49*		
C										
A × B									69.72**	
A × C										
B × C						22.07*

Fig. 7 Total number of input during the fast and slow system response time. Mean and standard error are shown.

****: $p < 0.0001$

increased for data-entry tasks under decreased system response time (5 to 0.1 sec). According to these reports, it was assumed that an optimum system response time was dependent on tasks.

In the present experiment, the slow system response time was ranged from 0.3 to 7 seconds and 79.1% of them were within 0.5 seconds. In this case, the subjects felt more irritation and made more errors compared with the fast system response time (< 0.1 sec). Therefore, it was considered that slow system response time (< 7 sec) used in this study might psychologically give more strain to operators for data-entry tasks than when the system response was fast. When the system response time was slow, HR, DBP and ABP were lower than the fast system response time. These responses usually occurred under less strain or monotonous situation. However, total numbers of input for the condition of slow system response time were almost half of the fast system response time (Fig. 6). Therefore, less amount of work might cause a less physiological strain under the slow system response time.

The SPL showed a tendency of higher value under the conditions of slow system response time in the present study. Kuhmann (1989) reported that the greater electrodermal activity resulted from the aversive emotional aspects of prolonged SRT (8 sec). Although the system response time of Kuhmann's experiment was longer than the system response time of the present experiment (0.3~7 sec), it was assumed that changes of SPL became higher under the increased emotional strain.

Delete the input numerals

When the input numerals were not deleted from the display, the HR was higher than when they were deleted

(Fig.4). This result implied that the HR was affected by strain, which is controlled by the autonomic nervous system. Lundberg et al. (1993) reported that the VDT work caused the increment of the HR, and the HR did not change during the VDT work. In the present experiment, the HR did not change during 120 seconds before the task finished (not shown in the Fig.). This was consistent with the results of Lundberg et al. (1993). However, the HR might not be an adequate index for the VDT work load (Wierwille et al., 1985).

Button Flash

When the button flashed, DBP was higher than when it did not (Fig.5). This result was inconsistent with the report that higher diastolic blood pressure was induced by acute psychologic stresses such as difficult or frustrating cognitive tasks (Sedgwick et al., 1981). However, when the button flashed, skin blood flow showed lower values and the subjects felt less difficulty of input than when it did not. These results suggested that even button flash showed a sign of stress on the subjects, the stress might be not serious to the subjects, therefore subjects could perform the task under better psychological condition.

Display the Remaining Time

Remaining time for the task was displayed only when the system response time was slow in the present experiment. However, physiological responses were not affected by the time stress which was controlled by displaying the time available to perform the tasks in the present experiment (Table 3). This was inconsistent with the evidence that the task performance was affected by the time stress (Kuhmann, 1989). This discrepancy might be explained by the fact that the task was not complicated in the present study. Furthermore human response might be affected by individual body conditions such as personality and motivation even under the same stimulation (Levi, 1972 ; Gallacher et al., 1988; Emurian, 1989).

Interactions

According to the result of interaction effects, the effect of system response time on HR, DBP and ABP, the effect of system response time or displaying the remaining time on SPL, the effect of delete the input numerals on SR3 depended on button flash. These results implied that button flash (receive the input feed back) together with one of the above three factors might cause opposite effects on HR, DBP, ABP, SPL and SR3.

Rissler (1977) reported that stress at work was reflected in high stress levels after work. Furthermore, it was found that work stress associated with the computerization of clerical functions may have a negligible

impact during working hours but demand a physiological toll after work (Lundberg, 1993). In this experiment, although only the effect of time stress during performing the tasks was investigated, it was evident that the slow system response time (<7 sec) caused more stress for operator to perform the data-entry task. However, further study is required in order to assess the human computer interaction during and after work (Wierwille et al., 1985).

Conclusion

When the system response time was slow, the average of heart rate and blood pressure were lower than the slow system response time during performing the data entry task. However, subjects felt greater emotional irritation, difficulty of input and unpleasantness in operation hence made more errors.

In the present experiment, when system response time was fast, even physiological parameters showed a sign of stress on the subjects, but the stress might not be serious for the subjects, therefore, subjects could perform the task under better psychological conditions. Furthermore, physiological responses might not always reflect the subjective feelings due to personality and motivation of the subjects.

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