Chapter 2
Computer-Mediated Task Performance Under Stress and Non-stress Conditions: Emphasis on Physiological Approaches

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2.1 Introduction

Recently, as competition in most industries grows more fierce, the performance of tasks managed by human labor is also strongly required to be improved. These environments make an employee be more anxious for their job performance, and more demands are requested to employees giving them more time pressers. The anxiety and time pressure are distinguishing features of job related stress in the organizational field of studies. The human performance in the working environments has attracted researchers' interest for a long time. Also, psychological, organizational, and educational literatures have discussed the relationship between stress and performance with considerable attention. However, little research has focused on the performance of computer-mediated task in physiological manners. The computer-mediated task performance is worthy of our attention because most of tasks in the office workplace are performed with personal computers. Thus, considering the prior research about the relationship between stress and performance, this study suggests physiological approach to measure stress and analyze the effect of it on task performance. For the experiments, we adopted two stress manipulations, performance feedback for arising anxiety and time pressure, for stress conditions. The well-known Window's game Minesweeper is employed as a substitute for computer-mediated task; subjects are requested to play Minesweeper under controlled

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conditions. To measure subjects' stress physiologically, galvanic skin response (GSR) and electrocardiogram (ECG) are recorded with Biopac MP100. A total of 32 employed subjects are randomly assigned two groups (e.g., stress group and non-stress group) then GSR and ECG signals are recorded during their game playing. After the experiment, the subjects are requested to complete the questionnaire using the perceived stress scale (PSS) which consisted of stress-related questions to underpin the results of physiological signals.

The remainder of the paper is organized as follows: We start with reviewing previous studies about stress, task performance and stress. In section three, the methodology adopted in this study is introduced with explanation of subjects. The statistical analysis is put in fourth. Finally, concluding remarks with implications and limitations are discussed in the last sections.

2.2 Theoretical Background

2.2.1 Stress and Task Performance

There has been controversial study about the influence of stress on performance [1–6]. Some researchers insist that stress has negative impact on the performance; other researchers insist that stress has a positive influence on the performance [7]. According to prior studies, this inconsistency seems to be rooted in two major findings. For one thing, the arousal level come from stress increase performance up to a certain threshold, but it decreases performance after reaching that point of over-arousal; thus, positive/negative stress' influence on performance is dependent on which level of arousal the stress is measuring at purposely or coincidently. For another, some researches insist there is challenge stress (i.e., the level or the demands of the work itself and workload), which is positively related to the performance, and hindrance stress (i.e., role ambiguity, role conflict, and hassles), which influence negatively on the performance. For instance, in study of [8] shows that hindrance stress is negative related to the performance, however, challenging stress promotes motivation and positively influences performance.

In this paper we apply the challenge stress in that, first, we are interested in how the stress affect positive influences the task performance to give practical implications to the leaders in an industry. Second the hindrance stresses, such as that role ambiguity and role complicit, are not easy to be adopted in the controlled experiments because the manipulation of stress should control interactions among various roles of related to a subjects' role. Thus, the stresses are use manipulated as time pressure and performance feedback on a specific group during playing Minesweeper game in this paper.

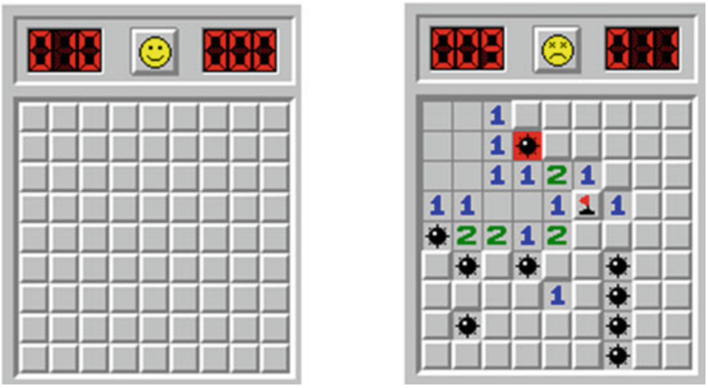

Fig. 2.1 (*Left*) The initial status of the Minesweeper. (*Right*) The last status of the Minesweeper (flag and bomb symbolize the place of bomb)

2.2.2 Minesweeper and Computer-Meditated Task

This study adopts the famous computer game for manipulating computer mediated task. The Minesweeper is a well-known Windows-based embedded game which is enjoyed by Windows users around the world. The other advantage of it is easy to learn even for a novice and the level of difficulty is controlled by the player. Thus, it has to be introduced in some researchers to discuss about algorithms of programs as well as users' behaviors in playing games [27].

In the study of [9], the Minesweeper game is introduced to explain the complexity of multi-relational learning task. Minesweeper has two major aspects to describe user's task performance. First, one realizes the complexity of the game by calculating an estimate for the size of its search space. In the given 9×9 board with $M = 10$ mines (see Fig. 2.1) at the beginning of the game, the player has 81 tiles from which to uncover tile; moreover, there are situations that can be "solved" with nontrivial reasoning in the process of playing the game. For example, considering Fig. 2.1 left where the only available information about the board states is the numbers. After careful analysis, one finds that the squares with containing a mine (see Fig. 2.1 right) and no mine, the square with a flag is a mine, and the state of the blank tiles cannot be determined until we know how many mines are hidden in the board. There are other Minesweeper situations where the available information is not enough to identify a safe square or a mine, as in Fig. 2.2, and the best option available to the player is to make an informed guess (i.e., a guess that minimizes the risk of being blown up by uncovering a mine).

In this work, we consider playing Minesweeper is closer to performing the task in the working environments in that player are first supposed to find the problem (i.e., realize the complexity of the game), then recognize that problem and choose alternatives to solve the problems (i.e., uncovering the tile), which are the typical

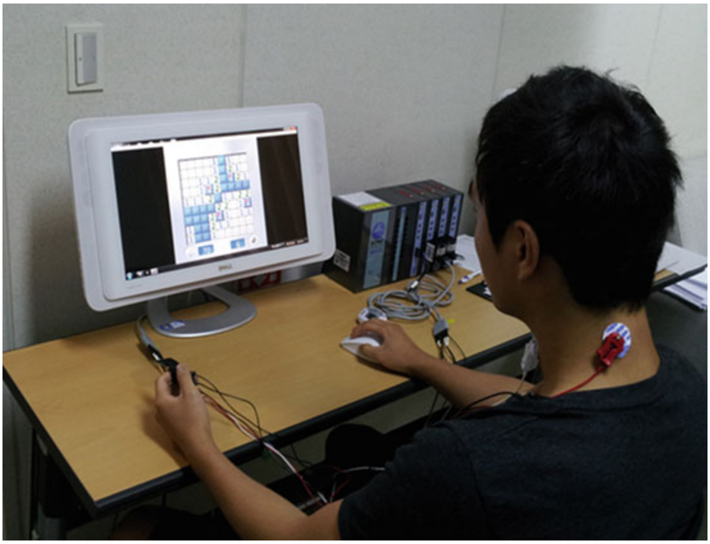

Fig. 2.2 Measuring physiological sign during playing Minesweeper

processes of humans in performing their work; moreover, all of this work is mediated by personal computer.

2.2.3 Assessment of the Stress

In this research, the stress is measured psychologically as well as physiologically. Psychological measures are dominantly used in the organization fields of studies, physiological measures are typically adopted in the fields of physiological psychology frequently. We mainly focus on the physiological measures, because they are the only method to measure real-time stress of subjects in performing their tasks, which makes this study differentiate from prior researches. Brief introductions of both of the assessments are as follows.

2.2.3.1 Psychological Assessment

Stress response can be measured and evaluated in terms of perceptual, behavioral, and physical responses. The evaluation of perceptual responses to a stressor involves subjective estimations and perceptions. Self-reported questionnaires have been the most common instruments used in measuring stress [10]. There are well-know representative measures such as PSS [11], the Life Events and Coping Inventory (LECI) [16], and the Stress Response Inventory (SRI) [12].

The physical response to stress has two components: a physiological response indicative of central-autonomic activity and a biochemical response involving

Table 2.1 Stress manipulation stimuli

Question	Ref.
In this experiment, how have you been upset because of something that happened unexpectedly?	[11]
In this experiment, how have you felt that you were unable to control the important things?	
In this experiment, how have you felt nervous and stressed?	
In this experiment, how have you felt confident about your ability to handle your personal problems? (Reverse)	
In this experiment, how have you felt that things were going your way? (Reverse)	
In this experiment, how have you found that you could not cope with all the things that you had to do?	
In this experiment, how have you been able to control irritations? (Reverse)	
In this experiment, how have you felt that you were on top of things? (Reverse)	
In this experiment, how have you been angered because of things that were outside of your control?	
In this experiment, how have you felt difficulties were piling up so high that you could not overcome them	

changes in the endocrine and immune systems [13]. PSS is adopted in thin study because it is very common in the prior research about stress. Table 2.1 shows the description of the questionnaire.

2.2.3.2 Physiological Assessment

Stress induces a change in autonomic physiological functioning [14]. Stress also has an impact on blood pressure and heart rate, which is reflecting a predominance of sympathetic nervous system (SNS) activity [15]. Heart rate variability (HRV) is beat-to-beat variation in heart rate, and it has been used as a biomarker of autonomic nervous system (ANS) activity associated with stress [16]. HRV analysis is generally divided into two categories: time-domain and frequency-domain methods. Time-domain analysis of HRV involves quantifying the mean or standard deviation of RR intervals (SDNN). In the one hand, frequency-domain analysis involves calculating the power of the respiratory-dependent high frequency (HF) and low frequency (LF) components of HRV. For our experiment, we select the standard deviation of RR intervals and LF/HF ratio as ECG information. Stress has been reported to evoke a decrease in the high-frequency component and an increase in the low-frequency component of HRV [17]. Therefore, LF/HF ratio is supposed to increases if stress arises. On the other hand, a decrease of SDNN is reported to be related to an increased level of stress. In addition, GSR is a measure of the electrical resistance of the skin. A transient increase in skin conductance is proportional to sweat secretion [18]. Thus, whenever an individual is getting stress, sweat-gland activity is activated and increases skin conductance. Since the sweat glands are also controlled by the SNS, skin conductance works as an indicator for sympathetic activation due to the stress reaction.

2.3 Method

2.3.1 Participants

Thirty-seven healthy subjects participated in this experiment from undergraduate students at a Korean university whose saw the post of Internet bulletin board. Prior to the experiment, the subjects were given written and verbal information explaining the experimental procedures. We confirmed through interviews that none of the subjects used medication for hypertension or any other cardiovascular disease and they were all free of any nervous or other psychological disorder. We received written informed consent from all participants and each subject was paid 20,000 Korean won for reward of participation. Among them, six subjects with corrupted data were eliminated from this study, then finally total of 32 subjects were employed for the tests (see Table 2.2). The mean age was 22 years (range of 18–26 years). Some of the subjects were randomly assigned to stress manipulations. Consequently, the subjects were divided into two groups (stress group, $n = 16$; non-stress group, $n = 16$).

2.3.2 Experimental Procedure

Before the experiment, the subjects were asked to know and show how to play the game Minesweeper. In the event subjects were unfamiliar with the game, they were instructed how to play the game and, under research assistant guidance, to practice it over 20 min until they were accustomed to play. Then, they were requested to cleanse their hands and remove all accessories from their body before measurement to avoid noises of recoding physiological signs. Then, the subjects were directed to sit comfortably and keep their left hand motionlessly when the experiment started.

Table 2.2 Stress manipulation stimuli

	Non-stress group		Stress group	
AGE	Female	Male	Female	Male
19	2	2	1	
20	2	2	1	2
21	1	1	1	
22				1
23		1		2
24	1	1		5
25		2		3
26		1		
Total	6	10	3	13

Each subject was asked to attach two GSR electrodes to the index and middle finger of the left hand and place three ECG electrodes on their chest and abdomen. This experiment used a Biopac MP100 series for the measuring and an AcqKnowledge 4.1 for the analysis. After GSR and ECG signals had showed normal waves, the subjects were instructed to start mediating for 7 min in order to acquire baseline data from GSR and ECG signals. And then they played the Minesweeper in7 min. They could play as many games as they could finish during the given time, regardless of their win or loss of game play. In the course of playing, GSR and ECG signals were measured for both the stress and non-stress group. Their computer-mediated performances were recorded in the form of number of winning or losing games and time spend for those. After finishing the game and their physiological signs were recorded, the subjects were requested to complete the questionnaire survey, which consisted of stress items. Figure 2.2. represents the circumstance of subjects and physiology signal recording when playing the Minesweeper.

2.3.2.1 Performance of Task

The performance measure of playing Minesweeper was also suggested in [9]. In that research the performance is measured with the accuracy of sweeping numbers of mines rather than sweeping speed. In the study of [19], the number of correctly-placed flags-per-second (Pmines) is counted. In our experiments, both measures of prior researches are adopted after manipulation to evaluate the performance of task. For the purpose, we normalize both the number of wins of games, which is the perfect sweeping of the mines, and the average time of the game. Then both variables are integrated into one variable by Principal Component Analysis (PCA) to make a performance index of for the test (see Table 2.4).

2.3.2.2 Stress Manipulation

Four types of stress manipulations (e.g., competition, performance feedback, reward, and time pressure) were used on the subjects of the stress group. The performance feedback under stress manipulations has been also used by [20] study. During the experiments, the subjects were informed and stimulated every 30 s with verbal comments by an assistant. Every comment is typically manipulated to stimulate subjects' stress of anxiety or stress of time pressure. For example, after 30 s they start to play the assistant say, “The best recode of previous tries of subject was 11 s. for a game” then another 30 s later the assistant gave them a comment of, “Try to play better!” to stimulate their anxiety of competition. Again, they are told, “If you can't complete more than ten games you get only half of the expected reward,” and “Speed up!” to give them time pressure. These manipulations were implemented according to a fixed pattern, independent of actual performance. The effectiveness of these comments to create stress conditions are verified by analyzes records of physiological signals and questionnaire survey. Table 2.3 describes comments of stimuli used in the experiments.

Table 2.3 Stress manipulation stimuli

Types	Stimuli	Interval	Repetitions
Competition	The best recode of previous tries of subject was 11 s for a game	30 s	3
	I can do better than you	2 min 30 s	
	Female/male student do play better	4 min 30 s	
Performance feedback	Try to play better!	1 min	4
	You are no better than expected!	3 min	
	You can do better!	5 min	
Reward	If you cannot complete more than ten games you get only half of the expected reward	1 min 30 s	3
	If you break new record, you be paid extra reward	3 min 30 s	
	It seems you may come tomorrow and do the play again	5 min	
Time pressure	Speed up!	2 min	N/A
	You have 3 min	4 min	
	Try to complete one game in 30 s	6 min	

2.3.2.3 Questionnaire Survey

In order to compare physiological signals under manipulated stress with perceived stress of individuals, we conducted questionnaire survey, which has been more familiar method to measure level of stress in the organizational field of researches. The degree of stress given to the subjects can be measured with more confidence. In other words, by observing the stress from view of different angle, we can improve the accuracy of measures and be more confident. This kind of measure is called *Triangulation* of measures. For this study, we adopt PSS for survey items [10, 11]. The PSS measures the degree to which situations are considered stressful by addressing events experienced beforehand. It is designed to quantify how unpredictable, uncontrollable, and overloaded adults find their lives. We conducted another survey to see whether or not self-reported creativity [21, 22] would agree with actual creative performance. Each item in our survey was measured on a seven-point Likert scale, with answers ranging from “strongly disagree” to “strongly agree.” The items in the survey were developed by adopting existing measures validated by other researchers Table 2.4.

2.3.3 Statistics

For physiological signals and task performance assessment, the differences between the stress group and the non-stress group are analyzed with the Mann–Whitney *U* Test.

Table 2.4 Physiological signals and task performance of subjects

	Signals			Performance of win		
Conditions	GSR	STD RR	LF/HF	Repetitions	Sum of sec.	Average
(a) Under non-stress condition						
Non-stress	0.084	0.107	–0.422	5	113	22.60
	0.109	–0.125	0.468	2	174	87.00
	–0.228	0.688	0.324	2	146	73.00
	–0.050	0.063	–0.287	6	150	25.00
	–0.149	0.170	0.281	2	213	106.50
	–0.168	0.705	–0.379	7	247	35.29
	–0.332	0.205	0.939	7	258	36.86
	–0.178	0.069	1.763	4	194	48.50
	0.040	0.343	–0.569	9	256	28.44
	0.252	0.036	–0.138	14	238	17.00
	0.124	0.263	0.744	2	58	29.00
	–0.228	1.311	0.169	0	0	0.00
	–0.069	–0.204	–0.693	4	235	58.75
	–0.139	0.330	0.018	1	76	76.00
	–0.342	3.084	–0.078	1	161	161.00
	0.559	0.493	–0.403	0	0	0.00
(b) Under stress condition						
Stress	0.208	–0.159	–0.742	2	183	91.50
	0.104	0.288	–0.153	4	169	42.25
	0.035	–0.266	0.125	6	267	44.50
	–0.020	0.359	0.472	8	122	15.25
	0.297	–0.209	2.085	0	0	0.00
	0.332	1.072	2.179	2	89	44.50
	–0.173	0.160	0.530	1	42	42.00
	–0.480	0.265	1.372	0	0	0.00
	–0.307	0.009	1.927	8	238	29.75
	–0.020	0.065	2.646	0	0	0.00
	–0.094	–0.111	–0.225	0	0	0.00
	0.010	–0.126	–0.143	7	153	21.86
	–0.079	0.391	0.266	1	114	114.00
	–0.025	1.082	1.581	0	0	0.00
	0.030	–0.296	0.047	4	193	48.25
	–0.287	0.059	3.921	2	207	103.50

Notice: all values in the table are normalized

Mann–Whitney *U* Test is one of the most well-known and nonparametric significance tests. It is a nonparametric statistical test to see if one of two samples of independent observations tends to have larger values than the other out of small samples. Thus, it is suitable for the analysis because, we have only 32 subjects who participated independently in the study. In our test, the null hypothesis is the computer-mediated task performance of the stress group is not different from that of the non-stress group. The results from the Mann–Whitney *U* Test are presented with the *p*-value; thus, statistical significance was assumed for p-value <0.05 under 99.5% confidence level in our test.

Then, we investigated the performance ratings for each group with the Wilcoxon signed ranks test. Finally, we examined the differences between the computer mediated job performance of stress group and that of non-stress group through descriptive statistics.

2.4 Results

2.4.1 Differences Between Stress Group and Non-stress Group

2.4.1.1 Physiological Signals and Self-Reported Stress

The relationship between manipulated stress and physiological signals (Normalized ΔGSR, ΔSDNN, and ΔLF/HF ratio) are investigated using the Mann–Whitney *U* Test. This test is one of the most powerful nonparametric tests, and it is a most useful alternative to the parametric test when the researcher wishes to avoid the test's assumptions or when the sample sizes are relatively small [23]. The results of physiological signals show that there are no significant difference between the stress and non-stress groups for normalized ΔGSR (p-value = 0.62 > 0.05) and ΔSDNN (p-value = 0.12 > 0.05). We confirmed that the stress group had a higher ΔLF/HF (p-value = 0.04 < 0.05) ratio value than the non-stress group, with statistical significance (see Table 2.5).

As is discussed in the prior paragraph, questionnaire survey (PSS) is also conducted to compare subjects in stress group with them of non-stress group. Statistically significant differences between the two groups are also analyzed by the Mann–Whitney *U* Test. The result shows that the cognitive stress of the stress group is significantly higher than the other (p-value < 0.01). Thus, we assure that our manipulation of stress conditions has been well controlled in the experiment and we can be sure to discriminate the stress group from the other. In other words, although we could not verify the difference between the two groups for task performance through the Mann–Whitney *U* Test, we made sure that the stress group has more perceived stress than the non-stress group.

2.4.1.2 Task Performance Assessment

To measure computer-mediated task performance, the number of wins out of all iteration of playing and the averaged duration time of them are considered at the same time. Not only doing things correctly but also doing it productively is considered as a performance in a real working environment. Thus, both factors are integrated to make index of performance using PCA. Then, Mann–Whitney *U* Test is applied also for analysis of the differences between the two groups. The result shows no significant difference between the performances of task of the stress group and the other (see Table 2.6).

Table 2.5 Mann–Whitney *U* test results for physiological signals and task performance

		Normalized ΔGSR		*Normalized* ΔSDNN		*Normalized* ΔLF/HF ratio		Self-reported stress	
Group	*N*	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Stress	16	–0.029	0.215	0.161	0.418	0.993	1.292	4.475	1.012
Non-stress	16	–0.045	0.234	0.471	0.789	0.109	0.642	3.213	1.018
Total	32	–0.037	0.221	0.316	0.641	0.551	1.099	3.844	1.187
Two-tailed probability		0.624		0.122		**0.042***		**0.007****	

*Statistically significant at $p < 0.05$
**Statistically significant at $p < 0.01$

Table 2.6 Mann–Whitney *U* test results for physiological signals and self-reported stress

		Performance	
Group	*N*	Mean	SD
Stress	16	0.308	1.741
Non-stress	16	–0.352	1.798
Total	32	–0.022	1.773
Two-tailed probability		0.344	

*Statistically significant at $p < 0.05$
**Statistically significant at $p < 0.01$

2.5 Discussion

There has been consistent research regarding the effect of stress on task performance, but the prior studies have not reached on the agreement of majority in terms of relationship. Some of the researches insist that stress positively affects task performance; however, other researches are arguing opposite results even curvilinear relationship [24, 25]. Those contradictable results, sometimes, come from focusing on different type of stress (e.g., challenging stress and hindrance stress) or level of difficulties of the tasks. Moreover, most of studies about challenging stress have analyzed subjects' cognitive level of stress but physiological approaches have not tried abundant. In this research, the direct relationship between real-time challenging stress and performance of computer mediated task is discussed.

For differentiated approach, we adapt physiological measures to examine the direct relationship between stress and the performance of computer mediated task. For the purpose, we employed 32 volunteered students randomly and then placed them under the manipulated stress condition that mainly consists of task anxiety and time pressure. They were separated into two groups that are stress group and non-stress group. Under the manipulated conditions they were required to play Minesweeper which is assumed to be operationally common to computer mediated task. During playing games their physiological signals were recorded as an index of real-time stress, then they have been analyzed to see if there are statistically different degrees of stress between two groups. The result of analysis of ΔLF/HF ratio and questionnaire survey shows their stress level of each group is significantly different physiologically and cognitively. Nevertheless, their analyzed performances showed that they are not significantly different from each other; thus, we carefully assume that the real-time stress level does not significantly affect the level of performance.

To conclude, our major implications and findings are follows. First, although we measured three kinds of physiological signals that are reported to be useful signals (e.g., GSR, SDNN, and LF/HF) for tracing stress level, only LF/HF shows significant difference between the stress group and non-stress group. That means the frequency-domain method, which is calculating the power of respiratory, is the better choice. In other words, for the manipulated conditions characterizing real-time and short period (e.g., 7 min in this study), LF/HF is effective signals to analyze. Second, the real-time stress conditions do not influence computer-mediated tasks in this study. Stress and performance has not been consistent in the prior research; rather than concluding the results as pointless, we can suggest further possibilities of stress' affect on task performance if it is combined with various factors, for example, the skills and knowledge for doing specific tasks.

Some limitations are worth attention for the future research. We suggest two main design issues on the stress–performance experiments. First, the characters of subjects should be considered because it is not clear if they are encouraged to challenge under manipulated challenging stress. Depending on subjects' personality, they are neither anxious nor easy to feel timely pressure. Second, as is in prior researches, mediating variables should be sufficiently considered. For example, relationships between stress and motivation have not been studied much, nor has an agreement been reached in the existing theories [26], so they can chose topic of motivation and stress. Finally, the performance deviation can be aroused by skill, rather than stress condition, which means although challenge stress is motivational and promoting performance, the influence of skill cannot be effectively detected. We suggest these findings should be strictly controlled in future research.

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