Task Performance under Stressed and Non-stressed Conditions: Emphasis on Physiological Approaches

Nam Yong Jo[1], Kun Chang Lee[2,*], and Dae Sung Lee[3]

[1,3] SKK Business School, Sungkyunkwan University,
Seoul 110-745, Republic of Korea
[2] SKK Business School
WCU Professor at Department of Interaction Science
Sungkyunkwan University, Seoul 110-745, Republic of Korea
{namyong.jo,kunchanglee,leeds1122}@gmail.com

Abstract. By using a physiological approach, we examined performance in the Minesweeper^R game. In this experiment, we measured subjects' Galvanic Skin Response (GSR) and electrocardiogram (ECG) during game play. We divided subjects into two groups, one of which was exposed to two types of manipulated stress. Additionally, a questionnaire was given to the subjects in order to measure perceived stress. We investigated how much stress each group endured by measuring physiological data and by administering the perceived stress scale (PSS). The results showed that there was no difference for multi-relational performance between the control group and the experimental group. For future studies of multi-relational performance under stress, we suggest that researchers should consider other factors that might influence stress and multi-relational performance.

Keywords: stress, game, performance, physiological signals, GSR, ECG.

1 Introduction

Psychological, organizational, and educational literatures have all examined the relationship between stress and performance. This study used a physiological approach to analyze the effect of stress on performance. For this experiment, we subjected the experimental group to two stress manipulations, threat of time pressure and performance feedback. The physiological measures used in our experiment were the Galvanic Skin Response (GSR) and electrocardiogram (ECG). A total of 32 subjects participated in this study. Their mean age was 22 years. Half of the subjects were randomly assigned to the stressed group, the other half were controls (stressed group, n = 16; non-stressed group, n = 16). The subjects were instructed to start meditating for seven minutes in order to acquire baseline data from GSR and ECG electrodes. After that, the subjects were asked to play the Minesweeper^R game for seven minutes. During this period, GSR and ECG data were recorded. After the

[*] Corresponding author.

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physiological experiment, the subjects were requested to complete a questionnaire, which consisted of stress-related questions.

The data analysis explored whether or not our stress manipulations coincided with a) self-reported stress, as measured by the Perceived Stress Scale [PSS] and b) the physiological measures of GSR and ECG. We also investigated under which stress condition game performance was better.

2 Theoretical Background

2.1 Stress and Performance

There has been considerable controversy about the influence of stress on performance. Some researchers insist that stress has a negative influence on performance; others maintain that the effect of stress on performance is positive [1]. According to prior studies, this inconsistency seems to be rooted in two major findings. First, the arousal associated with stress appears to increase performance up to a certain point, but thereafter, as arousal continues to increase, performance declines. Second, there are forms of stress that are referred to as “challenging stress” (e.g., demands of work); these are positively related to performance. There is also “hindrance stress” (e.g., role ambiguity; role conflict), which is assumed negatively related to performance.

For the purpose of our study, we define stress as challenging stress, or stress that has reached a level at which it exhibits positive effects on cognitive performance. Lepine et al. [14] maintain that, although hindrance stress is negatively related to performance, challenging stress promotes motivation to learn and influences performance positively. Thus, in our experiment, we used two challenging stress manipulations (time pressure and performance feedback) with a specific group as they played the Minesweeper^R game.

2.2 Minesweeper^R and Learning Task

In previous studies, the Minesweeper^R game has been used to illustrate the complexity of a multi-relational learning task [2]. Minesweeper^R has two major aspects that can be used to describe a user’s learning task. First, one realizes the complexity of the game by calculating an estimate for the size of its search space. Consider a 9 what? × 9 board with M = 10 mines (see Fig. 1). At the beginning of the game, the player has 81 tiles from which to uncover tile. In Minesweeper^R, there are situations that can be “solved” with nontrivial reasoning. For example, consider Fig. 1 (left) where the only available information about the board status is the numbers. After careful analysis one finds the squares with a mine (see Fig. 1, right) and those that do not contain a mine, one realizes that a square with a flag is a mine, and the state of the blank tiles cannot be determined if one does not know how many mines are hidden in the board. There are other Minesweeper^R situations where the information available is not sufficient to identify a safe square or one with a mine, as in Fig. 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 study, we consider the learning task in Minesweeper^{R} to be the deduction of rules to identify all the *safe squares*[1] and squares with a mine that can be deduced given a board's state[2].

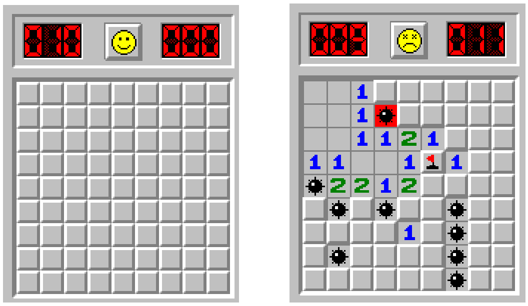

Fig. 1. Left: the initial status of the Minesweeper, Right: the lost status of the Minesweeper (flag and bomb symbolize the place of bomb)

2.3 Assessment of Stress

Psychological Assessment

A 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-report questionnaires are the most common instruments used to measure stress [8]. Representative measures are the Perceived Stress Scale (PSS) [7], the Life Events and Coping Inventory (LECI) [10], and the Stress Response Inventory (SRI) [11]. In this study we used the PSS.

Physiological Assessment

The physical response to stress has two components: a physiological response indicative of central-autonomic activity and a biochemical response involving changes in the endocrine and immune systems [8]. Stress induces a change in autonomic functioning [15]. It affects blood pressure and heart rate, reflecting a predominance of sympathetic nervous system (SNS) activity [13]. Heart rate variability (HRV) is the beat-to-beat variation in heart rate, and it has recently been used as a biomarker of Autonomic Nervous System (ANS) activity associated with mental 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. Frequency-domain analysis involves calculating the power of the respiratory-dependent high frequency (HF) and low frequency (LF) components of HRV. In this study, we selected the standard deviation of RR intervals (SDNN) and LF/HF ratio as ECG information. Mental stress is reported to evoke a decrease in the high-frequency component and an increase in the low-frequency component of HRV [3]. Therefore, LF/HF ratio increases if mental stress occurs. On the other hand, a decrease of SDNN is also related to metal stress.

GSR is a measure of the electrical resistance of the skin. A transient increase in skin conductance is proportional to sweat secretion [9]. When an individual is under mental stress, sweat-glands are activated; this increases skin conductance. Because the sweat glands are also controlled by the SNS, skin conductance acts as an indicator for sympathetic activation due to the stress reaction.

3 Method

3.1 Participants

Thirty-seven healthy subjects recruited from the undergraduate student population at a Korean university participated in this experiment. 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 his or her participation. Among them, six subjects with corrupted data were eliminated from the study. A total of 32 subjects (23 men and 9 women) were employed in this study. The mean age was 22 years (range of 18-26 years). The subjects were randomly divided into two groups (stressed group, n = 16; non-stressed group, n = 16).

3.2 Experimental Procedure

Before the experiment, the subjects were asked if they knew how to play the Minesweeper^R game. In those cases in which a subject did not know the game, they were instructed to practice it for 15 minutes to become accustomed to how to play. Then they were instructed to cleanse their hands and remove all accessories from their bodies. Next, the subjects were asked to sit comfortably and keep their left hand still when the experiment started. Each subject was asked to attach two GSR electrodes to the index and middle fingers of their left hand and to place three ECG electrodes on their chest and abdomen. In this experiment we used a Biopac MP100 series for recording and an AcqKnowledge 4.1 for analysis of physiological data. After GSR and ECG signals showed normal waves, the subjects were instructed to start meditating for seven minutes in order to acquire baseline data from the GSR and ECG electrodes. Finally, they were asked to play the Minesweeper^R game for 7 minutes. In the course of task implementation, GSR and ECG signals were measured for both the stressed and non-stressed groups. In addition, stress manipulations were inserted into the stressed group. Their performances were recorded in the form of the number of winning and losing games and the time spent playing. After the physiological experiment, the subjects were requested to complete the questionnaire on perceived stress. Fig.2. shows how to record the subjects' scores and the physiological data.

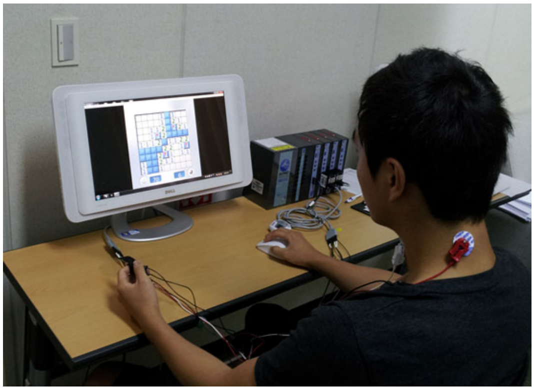

Fig. 2. Results of the structural model

Performance Task

[2] also used the Minesweeper^{R} game to assess performance. In their study, subjects' performance was measured only as accuracy, not speed. [5] used the number of correctly placed flags per second (Pmines) to measure performance. We adopted both of these measures, thus normalizing both the number of games won and the average time to win a game. We then integrated both variables into a performance index using Principal Component Analysis (PCA).

Stress Manipulation

This experiment used two stress manipulations in the stressed group (threat of shock and performance feedback). These two stress manipulations had been used by [4]. In the case of the threat-of-shock manipulation (no shock was ever actually delivered), the subjects were informed that they might receive an "unpleasant but not painful" electrical shock through the electrodes attached to their bodies. They were instructed that the possibility that they would receive a shock was dependent upon their performance in comparison to past subjects. In the performance-feedback manipulation, the subjects were told that they must be lacking in creativity and that they were less creative than previous participants. These manipulations were implemented according to a fixed pattern, independent of actual performance.

Questionnaire Survey

In order to compare manipulated stress in the experiment with perceived stress, we selected PSS as our survey tool [6, 7]. The PSS measures the degree to which situations are considered stressful, by addressing events experienced beforehand. It was designed to quantify how unpredictable and uncontrollable adults find their lives. 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.

3.3 Statistics

For physiological data and performance assessment, the differences between the stressed and non-stressed groups were analyzed with the Mann-Whitney U Test. This test was performed to test the null hypothesis that the stressed group was not different from the non-stressed group. The results from the Mann-Whitney U Test are presented with the p-value. Statistical significance was assumed for $P < 0.05$. We investigated the two types of performance ratings for each group with the Wilcoxon signed ranks test. Finally, we examined the relationship between stress and performance through descriptive statistics.

4 Results

4.1 Differences between Stressed Group and Non-stressed Group

Physiological Data and Performance Assessment

The relationship between manipulated stress and physiological data (Normalized Δ GSR, Δ SDNN, and Δ LF/HF ratio) was investigated using the Mann-Whitney U Test. This test is one of the most powerful nonparametric tests, and is a most useful alternative to parametric tests when the researcher wishes to avoid the t test's assumptions or when sample sizes are relatively small [14]. Although there was no significant difference between the stressed and non-stressed groups for normalized Δ GSR and Δ SDNN, as shown in Table 1, we confirmed that the stressed group had a significantly higher Δ LF/HF ratio than the non-stressed group. On the other hand, performance as assessed by game results was not statistically different between the two groups.

Table 1. Mann-Whitney U Test Results for Physiological Signals and Learning Performance

Group	N	*Normalized* Δ GSR		*Normalized* Δ SDNN		*Normalized* Δ LF/HF ratio		Performance	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Stress	16	-0.029	0.215	0.161	0.418	0.993	1.292	0.308	1.741
Non-stress	16	-0.045	0.234	0.471	0.789	0.109	0.642	-0.352	1.798
Total	32	-0.037	0.221	0.316	0.641	0.551	1.099	-0.022	1.773
Two-Tailed Probability		0.624		0.122		**0.042 ***		0.344	

* Statistically significant at $p < 0.05$

Self-reported Stress

Statistically significant differences between the two groups were observed for perceived stress and self-reported stress. This result shows that our manipulation of stress was well controlled in the experiment and that it discriminated the stressed group from the control group. While we did not verify the difference between the two groups for performance through the Mann-Whitney U Test, we made sure that the stressed group had more perceived stress than the control, as shown in Table 2. In this view, the subjects are thought to be properly divided. Therefore, we would confirm which group could separately explain performance by comparing physiological and self-reported stress.

Table 2. Mann-Whitney U Test Results for Physiological Signals and Self-reported Stress

Group	N	*Normalized* Δ GSR		*Normalized* Δ SDNN		*Normalized* Δ LF/HF ratio		Self-reported Stress	
		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 $p < 0.01$

5 Discussion

There has not been an abundance of research regarding the effects of stress on performance. Thus, we assessed those effects to see if we could demonstrate different relationships with performance between stressful and non-stressful conditions. Although our hypotheses regarding stress's effect on performance were not supported by our statistical results, we suggest it should not be concluded that there are no such effects, as there were some limitations in our experiment's design. In our opinion, these limitations deserve to receive attention in future research, because an agreement has not yet been reached on the relationship between stress conditions and performance. We suggest further work on two main design issues in the stress-performance experiments. First, the stressed condition should be more concrete and narrow. In our experiment, we gave subjects challenging stress in the form of time pressure. Compared to other subjects, it was not clear whether ours actually felt challenged, which might also differ depending on the subjects' personalities and perceptions of challenging stress.

Moreover, it has not been verified that time pressure and apparent comparison to other players constitute homogeneous stress. Third, as in previous research, mediating constructs should be considered. For example, although relationships between the stress variables and motivation to learn can be examined, existing theories describing this have not been much studied, nor has an agreement about these relationships been reached [17]. Finally, to reduce unnecessary variability, subjects should be selected based on an existing familiarity with the game. When subjects are not fully familiar with the learning tool (i.e., Minesweeper[R] in this study), simply learning the game produces stress. Consequently, the performance deviation is associated with skill, rather than the experimental condition. That is, although challenging stress may be motivational and promote performance, the relationships could not be demonstrated statistically in this study. We recommend that the factors we discussed be controlled strictly in future research.

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