DIFFERENCES IN PHYSIOLOGICAL RESPONSES TO THE INTENSITY OF MENTAL STRESS

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Abstract: It is widely understood that mental stress produces various physiological changes. Though the relationship between mental stress and physiological response has been extensively reported, few reports have tried to clarify the relationships between various physiological responses and the intensity level of stress. In this study, we investigated autonomic nervous system activities to find a physiological index based on which we can evaluate the intensity of mental stress. As a result, we found that there were different response patterns for each physiological index. We consider that each physiological index shows different feelings and/or situations related to mental stress.

1 INTRODUCTION

In our country, the increase in psychiatric disorders, such as depression and schizophrenia, is noted. The number of suicides per year has been steadily high in recent years, with more than 30,000 people a year since 1998. This increase in psychiatric disorders and high rate of suicide are serious problem in Japan.

It is believed that these daily stresses play a role in a number of psychiatric disorders. If we can evaluate daily stress quantitatively and determine our own or other people mental state, this could contribute to the prevention of various diseases caused by mental stress.

It is widely understood that physiological changes induced by mental stress are related to the autonomic nervous system, and can affect the heart rate, blood pressure and plethysmogram. The relationship between mental stress and physiological feedback has been extensively reported (Takatsu et al., 2000, Mishima, Kubota and Nagata, 1999).

We also consider that establishing a quantitative evaluation method for mental stress will help prevent diseases caused by mental stress. It is necessary to examine the intensity of stress to realize a quantitative evaluation of mental stress. However, few reports have tried to clarify the relationships between physiological responses and the intensity of stress. In this paper, we investigated the autonomic nervous system activity in the three conditions for the intensity of mental stress.

2 METHOD

We used a mental arithmetic task as the mental workload and measured the physiological and subjective responses.

2.1 Task

A target three-digit number, several two-digit numbers and an OK button were displayed on a computer screen. The participants were required to select the combination of three two-digit numbers whose sum is equal to the target number and click the OK button. Whenever a participant clicked the

OK button, the sum of the selected numbers was shown on the screen. If the sum was equal to the target number, the next arithmetic question was displayed. The participant could choose different combinations of numbers until the right one was chosen. The elapsed time and the number of correct answers were also displayed on the screen. The task screen is shown in Figure 1.

The three conditions were used for the intensity of mental stress. The conditions were as follows:

TASK1 (High level): The number of two-digit number is ten.
TASK2 (Medium level): The number of two-digit number is eight.
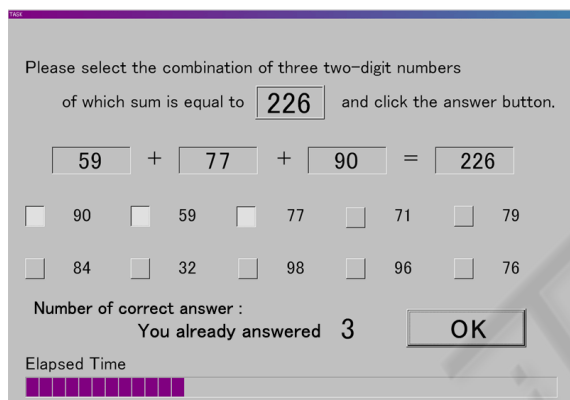TASK3 (Low level): The number of two-digit number is five.

Figure 1: Mental arithmetic task screen of high level.

2.2 Physiological Measurements and Subjective Assessment

We measured the electrocardiogram (ECG), plethysmogram (PTG), blood pressure (BP), tissue blood pressure (TBV) and skin potential levels (SPL). These signals were recorded in a PC at a 1-kHz sampling rate. Also, stroke volume (SV) and cardiac output (CO) were obtained every heartbeat.

The R-R interval (RRI), LF/HF ratio, systolic blood pressure (SBP), diastolic blood pressure (DBP), mean blood pressure (MBP=DBP+(SBP-DBP)/3), baroreceptor reflex sensitivity (BRS=square root of (LF of SBP/LF of RRI)), amplitude of the PTG and total peripheral resistance (TPR=MBP/CO) were calculated.

The National Aeronautics and Space Administration Task Load Index (NASA-TLX), Profile of Mood States (POMS) and the semantic differential method (SD method) were used to obtain the subjective responses.

The NASA-TLX is a widely used subjective workload assessment technique (Hart and Staveland, 1988). The WWL value was calculated. The POMS consists of 65 adjectives and assesses six mood states dimensions. We used 24 adjectives related to Tension-Anxiety (TA), Vigor (V) and Fatigue (F) for reducing the participant's burden. The SD method comprising seventeen items was used to assess the participants' emotions.

2.3 Procedure

The participants were familiarized with what to expect during the task before the start of the experiment. Each participant underwent the experiment procedure once.

The experimental procedure was as follows:

1. Rest1 (6 min: PRE1)
2. High level arithmetic (6 min: TASK1)
3. POMS, NASA-TLX and SD method
4. Rest2 (6 min: PRE2)
5. Medium level arithmetic (6 min: TASK2)
6. POMS, NASA-TLX and SD method
7. Rest3 (6 min: PRE3)
8. Low level arithmetic (6 min: TASK3)
9. POMS, NASA-TLX and SD method
10. Rest4 (6 min: POST)

The participants were instructed to provide at least fifteen correct answers in six minutes and not to give up until the six-minute run was finished. If the participants completed the task (i.e. gave the minimum number of correct answers) before the deadline, they were required to continue giving correct answers. After six minutes, the run was finished, and the participants were asked to cease the mental arithmetic activity even if they had not completed the task. The number of correct answers was displayed on the screen to let the participants know when the task was completed.

2.4 Participants

Sixteen healthy male graduate students aged 21 to 32 (average: 23.8 yrs.) participated in this study. All participants gave their written informed consent.

3 DATA ANALYSIS

3.1 Statistical Analysis

The data were divided into seven 6-minute blocks (PRE1, TASK1, PRE2, TASK2, PRE3, TASK3 and POST). All parameters were standardized for each participant.

The results were analyzed by repeated measures of analysis of variance (ANOVA) using SPSS 11.0J. The degree of freedom was adjusted using the Greenhouse-Geisser correction. Tukey's honestly significant difference (Tukey's HSD) test was used in the *post-hoc* analysis.

3.2 Subjective Assessment

Three factors (FACTOR1, FACTOR2 and FACTOR3) were obtained from the seventeen items of the SD method using Factor Analysis. The factor scores, NASA-TLX scores, POMS scores and all physiological indices were standardized for each participant. The correlation coefficients of 48 pairs of subjective assessments and physiological indices were calculated.

4 RESULTS AND DISCUSSION

4.1 Differences in Physiological Response

The WWL value of Task3 was significantly low ($p<0.05$). The results of the multiple comparison revealed that there were no significant differences in WWL value between Task1 and Task2. This result indicated that the condition of Task3 was simpler than the conditions of the other two tasks.

There were two patterns for each physiological response in both different cases: task periods and the resting periods. Figure 2 shows the averages of the SPL and the amplitude of the PTG for all the participants. Both parameters were significantly lower in TASK1 and TASK2 comparing with resting periods. The SPL values indicated that the changes during the task were smaller when the difficulty level became low. The RRI, SBP, DBP, BRS and TPR showed a tendency similar to that of the SPL. The amplitude of the PTG indicated that the responses after the completion of the task (during rest) were smaller when the difficulty level became low. The TBV, CO and SV showed a tendency

similar to the amplitude of the PTG. There was no discernible tendency in the LF/HF ratio.

In a previous study, we found that there were different recovery patterns for each physiological index (Soga, Miyake and Wada, 2007). In this study, there were also different recovery patterns for the various physiological indices. These results suggest that each physiological response corresponds to different feelings and/or situations. A difference in response during the task might correspond to "Executing task" and the feeling of "Tension." A difference in response after the task might correspond to "Task performance" and the feeling of "Regret."
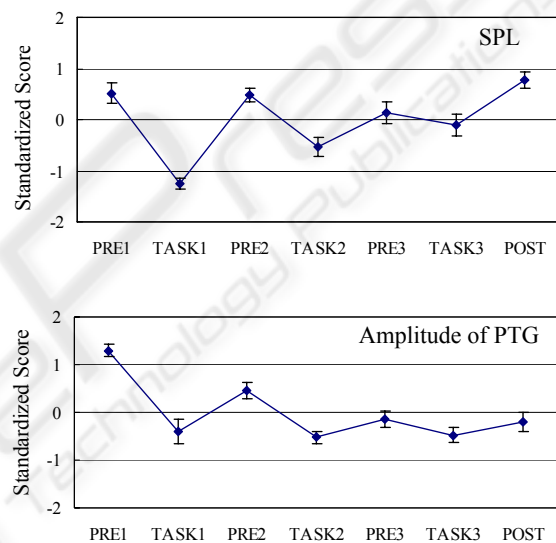

Figure 2: The average changes in the physiological responses for each block. The bars indicated the standard errors of the mean.

4.2 Correlation Coefficient between the Subjective Measurements and the Physiological Indices

There were significant correlation between the FACTOR1 score and the DBP ($r=-0.340$; $p<0.05$), MBP ($r=-0.312$; $p<0.05$) and SPL ($r=0.506$; $p<0.001$). There were significant correlation between the FACTOR2 score and the SPL ($r=0.322$; $p<0.05$). The FACTOR3 score significantly related to the SBP ($r=-0.350$; $p<0.05$), DBP ($r=-0.378$; $p<0.05$), MBP ($r=-0.364$; $p<0.05$), BRS ($r=0.415$; $p<0.01$), RRI ($r=0.433$; $p<0.01$) and SPL ($r=0.312$; $p<0.05$). The FACTOR1 consisted of the following items: "Difficult-Easy," "Troublesome-Smooth," "I felt the task duration was short-I felt the task duration was long," etc. Therefore we consider that

the FACTOR1 relates to the degree of difficulty of the task. The FACTOR2 consisted of the following items: "Dislike-Like," "Boring-Interesting" and "I want to execute the task-I don't want to execute the task." The FACTOR3 was as follows: "Respond randomly-Respond after proper calculation." We consider that the FACTOR2 relates to the participants' concentration and the FACTOR3 relates to the participants' attitude.

The NASA-TLX revealed that there were significant correlation between the TD and SPL (r=-0.676; p<0.001), and the OP and the amplitude of the PTG (r=-0.324; p<0.05). The POMS showed that there were significant correlation between V and the SPL (r=-0.381; p<0.05), and F and the amplitude of the PTG (r=-0.308; p<0.05).

Although some physiological indices seemed to correlate with the subjective assessments because the correlation values were small, there were only three blocks for standardization, and all the data were pooled. At least, we consider that each physiological response corresponds to different feelings and/or situations. This suggests that the classification of physiological responses according to the results of the subjective assessment is helpful in investigating the complex information contained in each physiological index. In our past study, we found that the SPL related to the time pressure (Soga, Miyake and Wada, 2007). In this study, the SPL results showed a tendency similar to that found in our past study. Therefore we consider that the SPL is a sensitive index for the estimation of mental stress.

5 CONCLUSIONS

We found that there were two patterns for each physiological response of the autonomic nervous system during the task periods and the resting periods at three different difficulty levels (high, medium and low). Significant difference in PTG amplitude between task and after task resting period was disappeared in the last two blocks (TASK3 and POST). In addition, we found that there were significant correlation between the physiological changes and the subjective assessments.

These results suggest that each physiological response corresponds to different feelings and/or situations related to mental stress. Further experiment should be done to confirm this result. Our final aim is to establish a quantitative evaluation method for mental stress.

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