ORIGINAL ARTICLE

An Analysis of a Stress Checking System

– The Evaluation of VDT Work Fatigue by Electrocardiogram RRI Analysis –

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Abstract: We developed a system that can objectively evaluate fatigue of long Visual Display Terminals, using both electrocardiogram data and self-reporting questionnaires. The objective was to identify the elements that contribute to stress within the organization. R-to-R interval (RRI) analysis of the electrocardiogram data allows the establishment of objective stress indices, and the rationalization of diagnosis. We therefore propose the introduction of biometric measurement to stress checking systems.

Keywords: *Introduction of stress check system, Evaluation of VDT work fatigue, RRI analysis*

1. INTRODUCTION

Jenkins, McCulloch, and Parker (1998) define mental health as the “the ability of the mind to heal itself after shock or stress” [1]. The development of mental health promotion measures in general environments such as the workplace is noted as a common strategic framework. Measures to promote mental health in the workplace include organizational activities that have been approved by staff, managers, and labor unions.

In Japan, a law amending part of the Industrial Safety and Health Act (Act No. 82 of 2014) was promulgated on June 25, 2014, and from December 2015, stress checks became mandatory. The law specified that stress checks must be conducted [Note 1]. The guideline of Basic Standards Concerning Measures to be Taken by the employer to Grasp Working Hours Properly placed the responsibility for managing the working hours of workers on the employer. Even in well-run companies, however, problems remain, including improper use of the self-declaration system for working hours, unpaid extra working hours, and long working hours. In addition, while laws and regulations exist to regulate excessive workloads [Note 2] (including death from overwork) and mental health [Note 3] measures have been put in place, there remains a gap between these preventative measures and the subjective symptoms and biological reactions of workers.

In recent years, information technology has developed rapidly, and Visual Display Terminals (VDTs) have been widely introduced in the workplace. As a consequence, the number of workers using VDT equipment is increasing rapidly. Disorders such as VDT syndrome, the main

symptoms of which are a stiff neck, headaches, eye fatigue, anxiety, and irritability, are also becoming more widespread. Demand is therefore growing for equipment to allow self-checking of stress, which is the basis of many human diseases. Many studies have measured and analyzed stress, which causes changes in the human endocrine and autonomic nervous systems. The variability in heart rate is related to the work content [2], and so biological tests have been used that measure levels of an endocrine substance (SIgA in saliva) while the participant is working at a VDT [3]. The tasks used involved alternating between VDT work and writing in 30 minute segments, with 90 minutes in total, or VDT working periods of 15 minutes, with nine minute breaks (96 minutes in total). Most tests have therefore studied transient or short-lived effects. In this study, we used electrocardiogram and questionnaire data to investigate subjective symptoms and clarify the relationship between the electrocardiogram data and the subjective symptoms in an extended (8 hour) study.

2. PREVIOUS RESEARCH

Martens applied the Vragenlijst Onderzoek Ervaren Gezondheid (VOEG -21) test battery, comprising 21 health-related questions [4]. Based on data from workers in Belgium, they found that the mental health of both long-term workers and short-term employees tended to deteriorate. The implication was that long-term labor negatively affects mental health. Perrucci investigated the employment environment in the United States, and concluded that longer working hours and irregular working hours are more likely to adversely affect mental health [5].

Previous research conducted in Japan has used subjective indicators and focused on the effect of long working hours. Ogura and Fujimoto used a Likert-like questionnaire to explore the determinants of work stress [6]. Controlling for the influence of factors such as sex, educational background, position, and workforce size, they concluded that there is a statistically significant relationship between long working hours and personal stress. Kamesaka and Tamura (2016) analyzed the influence of working hours on anxiety and “death from overwork” [7]. Under Heisei 24, and to explore measures for preventing death from overwork, the Cabinet Office conducted a survey on the quality of life, using individual voter data.

The goal of this research was to deepen our understanding of the relationship between long working hours and stress, and to propose the introduction of an efficient system for monitoring stress. We based our evaluation of VDT work fatigue on the R-to-R interval (RRI) analysis of electrocardiogram data, and proposed the introduction of biometric measurement software

3. INDICATIVE EXPLANATION AND HYPOTHESIS

3.1 Physiological index

In this study, electrocardiogram data were used to construct a physiological index. In the RRI model shown in Figure 1, the cardiac cycle is derived from the interval between the R waves and the RR interval, and from the standard deviations SD 1 (T) and SD 2 (L) / T Indicator, LF / HF. This can be used to evaluate relaxation, tension, and stress. As it is a time domain analysis, RRI is generally amplified by the heart rate. Stress is experienced when the RRI is shortened, and this has been used as an index of stress in many studies [8]. The L / T index becomes L / T at rest, and L / T decreases as stress / tension becomes more stable [9].

LF / HF generally increases when the sympathetic nervous system is excited, suggesting that stress is being experienced, and falls when the parasympathetic nervous system is elevated. These three indicators can be used to evaluate stress and tension. We also analyzed any change

Figure 1: RRI Model

in RRI when the subject was working at a VDT. We then correlated the results from the subjective self-reporting of symptoms (the questionnaire) and the electrocardiogram data [10].

We conducted a fatigue examination task, using Fitts's law as the indicator. Fitts's law models the act of pointing, either by physically touching an object with the finger, or virtually by pointing at a computer display using an input device such as a mouse. It is calculated using the following formula.

$$T = a + b \log_2(D/W + 1)$$

where T is the average time taken to move the pointer to the target, D is the distance between the starting point and target, W is the width of the target measured along the axis of motion, a is the start / stop time of pointer movement, and b is the speed of the pointer.

In this research, we developed the pointing task created by authors. Two rectangles, one yellow and the other blue, were displayed on the screen at the start of the task. Participants were asked to click on the yellow rectangle quickly and accurately, which caused the rectangles to exchange their colors. Participants were then asked to click the yellow rectangle again. In a single task this operation was repeated 40 times.

Assuming that the task followed Fitts's law, its difficulty would be inversely proportional to the short side (W) of the object and proportional to the distance (D) between the objects. D/W was therefore used as the measure of task difficulty. Tasks at four difficulty levels were prepared.

The output screen is shown in Figure 2. The leftmost column is the response time (in seconds), the next column shows the difficulty level, and the number of missed clicks is shown at the upper right. We hypothesized that,

Figure 2: Output screen

as the VDT working time lengthens, physical evidence of fatigue will appear and the task performance will fall.

4. EXPERIMENT

4.1 VDT work

VDT work refers to any work involving a VDT, which most frequently means work using a computer. The Ministry of Health, Labor, and Welfare has published “Guidelines for Occupational Health Environmental Management in VDT Work”. Much VDT work involves data input and document creation, but in our experiment an urban development simulation computer game (Sim City) was used.

4.2 Experimental procedure

In the experiment, as shown in Figure 3, participants worked at the VDT for 40 minutes. The fatigue examination was performed immediately afterwards, and the questionnaire administered after five minutes of rest. This was repeated at hourly intervals over a period of eight hours, giving eight measurement sets. The experimental environment was a laboratory, and the participants were five healthy students aged 21 and 22 years. Data was captured using a PC (IBM ThinkPad), Vital Recorder, Electrocardiographic Respiration Sensor (DL - 320), Biological Amplifier (DL - 720), Disposable Electrode, and PC (GALLERIA).

4.3 Measurements

The electrocardiogram measurements were taken for 10 min in total, comprising 5 min of the end of the work period and 5 min in the rest state. Measurement chart of electrocardiogram is shown as Figure 4.

Figure 3: Experimental procedure

Figure 4: Measurement chart of electrocardiogram

5. ANALYSIS METHOD

5.1 RRI, variance analysis, correlation

① RRI

The data output from the VitalRecorder was filtered by Vimtas with a band stop filter between 40 and 60 Hz to eliminate power supply noise (50 Hz) [14]. The L / T index and LF / HF were analyzed from the RRI, and SD1 (T) and SD2 (L), respectively.

② analysis of variance

Distributed analysis was used to determine the factors and the effects of interaction after resolving fluctuations in the observed data into variations caused by error and fluctuations caused by interactions between the factors. One-way analysis of variance was performed for RRI at rest and during VDT work, using Excel.

③ Correlations

The correlations between five factors reported in the questionnaire: sleepiness, uneasiness, discomfort, feeling of sagging, blurred feeling and the RRI, L / T index, and LF / HF from the electrocardiogram were examined for each subject And the ANOVA was used to identify correlations between VDT work time and RRI.

6. EXPERIMENTAL RESULTS

6.1 Results

The RRIs while working of all participants are shown in Figure 5. The graph represents the average RRI from each set. While the numerical values for each participant were different, the shapes of the graphs were similar. A significant difference was observed ($p < 0.05$) between variance of RRI and working time for each participant. The RRI changed as the working time increased. Comparing the dispersion of the RRI results in the first hour and the eighth hour, the number rose for four participants and fell for one. The RRI of most participants showed the influence of VDT work. While resting, most of the participants showed a decreasing numerical value, though it can be seen from the RRI graph that fatigue from VDT work persisted even at rest periods.

Figure 5(a)-(e) shows the relationship between the self-reported symptoms from the questionnaire results and the RRI over time. As can be seen, the questionnaire results diverged before the numerical value of RRI reached a lowest value of about 60 to 40, which is less than half the maximum score of 125, although there were individual differences between participants. The initial electrocardiogram data and self-reported symptoms appeared to be inversely proportional to each other.

Figure 5: RRI and subjective fatigue questionnaire

The same relationship between the questionnaire results and the RRI reaching the lowest value was observed for all participants. Participant 1 showed a match between the two after 4 h (3a), with r values for sleepiness, feeling of dullness, and blurred feeling in the range 0.5 to 0.6. Results for Participant 2 matched after 7 h (3b), with r values for the feeling of sagging and blurred feeling again approximately 0.5 to 0.6. Participant 3 reported lower values in the questionnaire (3c), but the reported symptoms began to coincide with the RRI from about the fourth hour onward. Both Participant 4 and Participant 5 matched from hour 6 (3d and 3e).

At the early period of VDT work, an inverse relationship was found between the RRI and the questionnaire results. However, when the RRI reached its minimum value, the two became proportional to each other. This suggested that agreement appeared between the electrocardiogram data and the subjective symptoms reported by the participants at the lowest RRI value. There was no relationship between L / T and HF / LF .

6.2 Results of RRI

6.2.1 Fatigue questionnaire

In the fatigue examination task, the reaction time became faster for all participants with increased time. This was considered to reflect growing familiarity with the task. There was no relationship found between the electrocardiogram data and the fatigue examination task.

6.2.2 Questionnaire

Although individual differences were found, the scores from the questionnaire increased as the VDT working time increased, suggesting that participants were aware of fatigue. Participant 3 had the lowest score. We believe that this reflects differences in the character and environment of the participants.

7. DISCUSSION AND FUTURE WORK

Our experimental results suggest the importance of introducing mechanisms to monitor biological signals of stress, in situations where it is difficult for the worker to detect that they are under stress. The significance of this research is that it is the first to apply biometric measurement to long-term working and developed a new evaluation system.

The regulations mandate that stress checks be applied at least once a year. Most companies have implemented this, and use the results in their workplace analysis. This workplace analysis sums up and analyzes the stress check results for each group on a given scale (such as by department or division). However, although stress checks are conducted, it is not always the case that the workplace analysis is used to improve working environment.

If employees become aware of their health status, this will be a catalyst for improving the workplace by conducting organizational diagnosis. In the unlikely event that an employee launches a civil lawsuit against a manager of the company, this may help avoid the company being accused of violations of safety obligations. Social cost benefit analysis may reveal additional benefits, such as reduction in the cost and time of civil trials, government expenditure on additional measures, or unquantified psychological losses.

In this research, we studied about the introduction of the stress check system. At that time, the simultaneous introduction of biometric measurement software was examined based on the evaluation result of VDT work fatigue by RRI analysis of electrocardiograms. In this experiment, we aimed to clarify the relationship between

electrocardiograms and the subjective symptoms in a long time experiment (8 hours) and comprehensively perform representative electrocardiogram analysis (RRI, L / T, LF / HF). As a result, it turned out that there was a change in RRI. Further, the relationship between RRI and the subjective symptoms was inversely proportional to the questionnaire before RRI reached the lowest value.

However, after RRI reached its lowest value, it turned out that there was a proportional relationship with the questionnaire [Note 4]. Although there are individual differences, this is considered to be a point where biological information and subjective symptoms coincide. There were individual differences in the L / T index and LF / HF, so it was not possible to say definitely, and it turned out that RRI was useful. As a future subject, L / T index and LF / HF have been regarded as effective as a transient physiological index. Therefore, we think that it is necessary to investigate whether it is effective as a long-term physiological index.

The results from our experiments highlight the use of biological signals in situations where it is difficult for an individual to gain awareness that an abnormality in the body has been caused by stress. The main contribution of the current research is that biometric measurement of long-term work has not previously been undertaken. As future development, we can expect to establish objective indicators and rationalize diagnosis from this experiment result. Therefore, we would like to suggest the simultaneous introduction of biometric measurement software in addition to the stress check system. Moreover, we although this study uses an electrocardiogram, the application value of this paper is high because essentially the same evaluation can be made with pulse wave measurement using a smart watch etc.

As a concrete proposal, we aim to build a notification system, and we believe it will be possible to reflect more on-site conditions in the system. Concrete activities in the workplace include “counseling and use of support.” Therefore, in the future, by collaborating with mental health counselors, it will be useful to implement mental health measures at actual sites

To provide a foundation for policy decisions, welfare economics, legal studies, and economics require further development. It should be possible to reduce externalities by seeking the cooperation of the private sector. The conventional analysis of welfare can also be extended by incorporating the dual process theory of biometrics and behavioral economics.

NOTES

1. Ministry of Health, Labor and Welfare, Labor and Bureau Administration, Notification from the Ministry of Health, Labor and Welfare, by the director.
https://www.mhlw.go.jp/file/05-Shingikai-11201000-Roudoukijunkyoku-Soumuka/8_sankou4.pdf (accessed 2019.04.01).
2. Industrial Safety and Health Act (No. 57 of 1972) Article 6 (Formulation of occupational accident prevention plan)
3. Industrial Safety and Health Act (No. 57 of 1972) Health Education, etc. Article 69-70-2.
Guidelines for maintaining and improving workers' mental health, Ninomiya and Higuchi; Individual Difference Analysis of Fashion Image Shapes, Ningen-Kougaku, 24(1), pp.43-51, 1988.
4. We interpreted the experimental results using the dual process theory proposed by Kahneman et al. [11-13]. Kahneman's hypothesis is that humans have two behavioral systems, which they use in combination. System 1 works automatically, whereas System 2 requires conscious effort. In the working tasks used in this experiment, and assuming that System 1 is mainly used, the following interpretation emerges. In the early stages of the experiment, the actions are performed by System 2 and are not perceived as being tiring. Over time, the work is shifted to System 1. In other words, although fatigue is a biological reaction, a difference is perceived when switching between Systems 1 and 2. The experimental task was based on the assumption that physical fatigue appears as the VDT working time increases, and that performance on the fatigue examination task will decline. No relationship was seen between the electrocardiogram and the fatigue examination task.

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