Assessment of Workplace Organization Environment by Wearable Biometric Sensor

Junichiro Hayano, Minoru Mitsui, Nao Ozaki, Mihoko Wakui, Katsunori Kawano, and Emi Yuda

***Abstract*—Usefulness of biometric information obtained from biosensor worn by employees for assessing organization environment in workplace was investigated. In 85 employees, heart rate variability (HRV) indices calculated from the time series of R-R intervals of electrocardiogram during work hours were compared with the responses to a questionnaire concerning job stress, communication, and physical and mental conditions and HRV indices were also compared between before and after intervention for improving workplace organization. The higher the arbitrariness in work, the smaller the SD of R-R interval and the very low frequency (VLF) and low frequency (LF) amplitude of HRV, the higher the mental frustration and fatigue, the worse the communication with the boss and colleagues, the greater the LF amplitude and SD of LF amplitude (LFsd). By factor analysis of the responses to questionnaire, three factors reflecting stress, depressiveness, and fatigue were extracted. Among the factors extracted, the LF amplitude and LFsd correlated with the degree of fatigue. The intervention activities decreased LF amplitude and LFsd among subjects who reported to have deeply participated in the activities, while these indices increased among those reported to have not participated much.**

***Index Terms*—Organization environment, job stress, depression, fatigue, wearable biometric sensor, heart rate variability.**

I. Introduction

Along with widespread use of wearable biometric sensors, it is becoming possible to grasp the biological conditions during daily activities [1]. Many companies in various industries are considering introduction of this technique to workplace [2]-[4] because it seems useful for improving work environment and productivity as well as stress and health management of workers [5]. The time series data obtained from the wearable biometric sensor, biologicals such as electrocardiogram, pulse wave, body acceleration, skin temperature, etc. form the huge amount of extensive longitudinal data. In order to utilize these data, it is necessary to convert them to usable information automatically in a physiologically supported and ethically relevant manner. Compared to the speed of the improvement of sensor performance and the development and dissemination of data communication and accumulation technology, there is much room for development of effective processing technology for accumulated data [1]. Also, it is an unknown field how to utilize this new information which could not be obtained in the past in the work environment.

In this research, we aimed at obtaining basic knowledge for developing effective processing method and application method of biological information obtained from wearable biometric sensor. For this purpose, we analyzed the relationships between biological information recorded in employees during work hours and their responses to questionnaire concerning job stress, communication, and physical and mental conditions. We also analyzed the effects of an intervention for improving workplace organization on the biological information.

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II. Methods

A. Subjects

We studied employees of Fuji Xerox Co., Ltd. who worked for the branches of the company. They were grouped into 7 job categories consisting of 3 sales divisions, engineers, and 2 staff divisions. Table I shows their characteristics by the job category.

B. Protocol

This study was a part of an investigation performed by Fuji Xerox Co., Ltd. concerning the effects of communication workshop for employees on their organization environment. To evaluate the effects of the intervention, an organization performance analysis was performed before and after the workshop at an interval of 3 months. The same protocol was repeated in each organization performance analysis. Briefly, subjects gathered at 09:00 and, following the instruction about the analysis, they wore a biometric sensor (myBeat®, Union Tool Co., Tokyo, Japan) on their upper chest wall. Between 09:30 and 09:40 they kept standing position for an autonomic function test. Between 09:40 and 10:00 they divided into small groups and performed a small group discussion as a communication task. At 10:00 they got into their normal jobs with wearing the biometric sensor until 17:00. Then, questionnaire survey was conducted.

C. Measurement

Biometric information during work hours were recorded continuously by the wearable sensor "myBeat®," which digitized electrocardiogram at 1000 Hz, tri-axial acceleration at31.25 Hz, and skin temperature at 1 Hz. These data were processed by the dedicated software attached to the biometric sensor and converted into time series of beat-to-beat R-R intervals, skin temperature, and moving averaged acceleration

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for *x*, *y*, and *z* axes.

TABLE I: CHARACTERISTICS OF SUBJECTS

Job category	Male		Female	
	N	Age, yr	N	Age, yr
Sales 1	19 (90%)	43 ±9	2 (10%)	33 ±13
Sales 2	10 (100%)	45 ±4	0 (0%)	
Sales 3	11 (85%)	48 ±6	2 (15%)	45 ±2
Engineer	25 (96%)	45 ±8	1 (4%)	19
Staff G	6 (55%)	51 ±7	5 (45%)	39 ±8
Staff S	1 (25%)	56	3 (75%)	40 ±5
Total	72	46 ±7	13	38 ±9

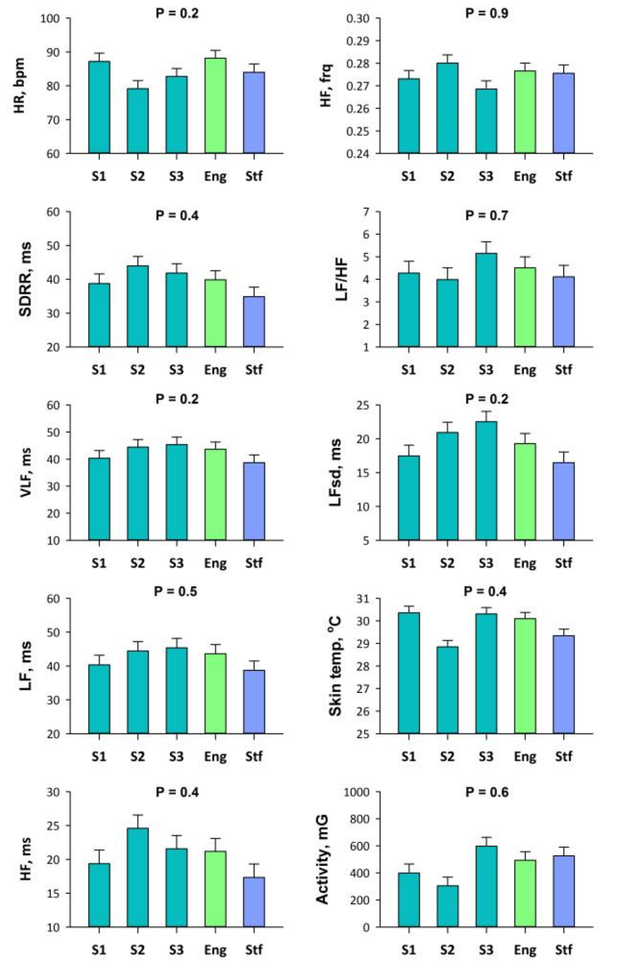

Fig. 1. Biometric information during work hours by job category S1, 2, and 3 = sales sections 1 ,2,and 3; Eng = engineering section; and Stf = staff section.

The questionnaire was consisted of 61 items of questions with 4 choices concerning job stress, physical and mental conditions, and workplace and private communication.

D. Data Analysis

R-R interval time series were analyzed by the method of complex demodulation (CDM) [6]-[8]. CDM is a time domain method for time series analysis which provides the instantaneous amplitude and frequency of fluctuation in a specified frequency band as continuous functions of time. In this study, amplitudes and frequencies of very-low frequency (VLF, 0.0033-0.04 Hz), low frequency (LF, 0.04-0.15 Hz), and high frequency (HF, 0.15-0.4 Hz) bands were demodulated. For CDM, R-R interval time series were processed for filtering "abnormal" data that were assumed as those caused by ectopic beats or noises. Then, filtered data were interpolated by a linear step function using only "normal" R-R intervals (N-N intervals), resampled at 2 Hz, and submitted to CDM procedure.

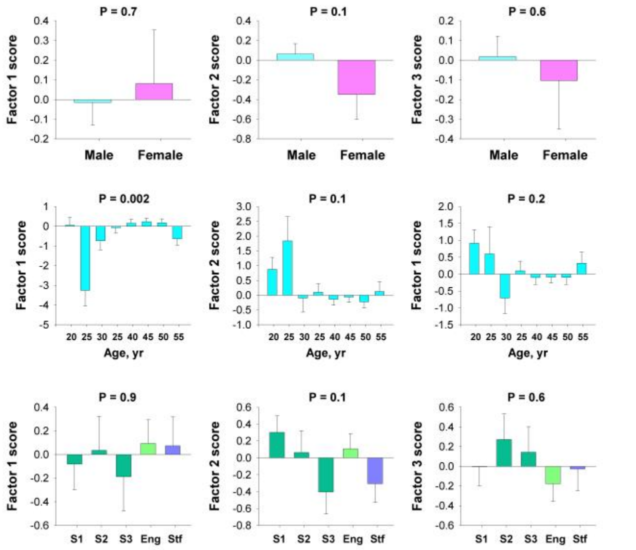

Fig. 2. Factor scores by attributes of subjects.

Continuous functions of amplitude and frequency for each frequency band were averaged over every 1 min. Mean and standard deviation of N-N interval (SDRR) and LF-to-LF ratio (LF/HF) of their power (squared ratio of the heir amplitudes) were also calculated for the same 1-min time frame.

As the index of physical activity, successive changes in the magnitude of acceleration vector (the square root of the sum of x^2, y^2, and z^2) were calculated. The physical activity at each time point was defined as the non-zero value of physical activity just before the point. The physical activity and skin temperature were averaged over the same 1-min time frame used for HRV.

To evaluate the relationships between biometric data and the responses to questionnaire, the biometric data during work hours and the response to questionnaire obtained in 85 subjects at the first organization performance analysis were used. To evaluate the effects of the intervention with a communication workshop, the biologic information obtained after the intervention was compared with that at the first organization performance analysis in 32 subjects in whom questionnaire about the degree of participation in the intervention was implemented.

E. Statistical Analysis

Statistical Analysis System program package was used. The associations between item responses to questionnaire and biometric data were analyzed with Pearson's correlation coefficient. Factor analysis was performed to delineate the features that were measured by the questionnaire. To exclude the effects caused by internal correlation between items, the items with lower variance among the two correlated (r> 0.4) item pairs were excluded from factor analysis. To exclude the effects caused by the internal correlations among items, one of the two correlated (r >0.4) items that had a lower variance was removed. This procedure was repeated until there was no pair of items that showed a correlation coefficient >0.4. Factor analysis was performed using FACTOR procedure.

Principal component analysis was used for examining eigenvalues and factors with eigenvalue ≥1 were extracted. Squared multiple correlations were used as coefficients for communality estimates and were inserted in the diagonal elements. Principal-axes factor analysis was iterated until no changes in the third decimal place of communality estimates were observed. The orthogonal factors were rotated with the varimax criterion.

TABLE II: ROTATED FACTOR PATTERN OF EXTRACTED FACTORS FOR QUESTIONNAIRE RESPONSES

Item	Questionnaire	Factor1 Stress	Factor2 Depressiveness	Factor3 Fatigue
A3	I have to work hard	-0.05	0.27	0.39
A7	Use the body very often for work	-0.14	**0.46**	0.13
A8	I can work at my own pace	-0.25	-0.16	-0.24
A10	I can reflect my opinion on the work policies of my workplace	**-0.48**	0.05	-0.02
A11	I rarely use my skills and knowledge in my workplace	0.15	0.09	0.12
A13	My department do not suite well with other departments	**0.48**	0.14	-0.08
B2	I am full of energy	-0.12	**-0.54**	-0.09
B8	I am completely tired	0.24	0.38	**0.49**
B16	I do not feel refreshed	0.26	**0.64**	0.13
B19	I fell dizzy	**0.6**	-0.01	0.04
B22	I have a stiff neck and shoulders	**0.49**	-0.01	0.24
B26	My gastrointestinal condition is poor	0.23	-0.04	**0.45**
B29	I cannot sleep well.	**0.41**	0.11	0.34
C2	I can talk with colleagues at work easily	**-0.56**	-0.04	-0.24
C3	I can talk with my spouse, family, friends, etc. easily	-0.04	-0.18	-0.33
C7	My boss will take care of my personal problems	**-0.61**	-0.21	0.11
D1	I am satisfied with my work	**-0.44**	-0.37	0.24
E3	How was your creativity today?	0.14	0.03	**-0.47**

The associations between factor scores and job category were analyzed by General Linear model and the correlations between factor scores and biometric information were evaluated by correlation coefficients.

TABLE III: CORRELATIONS OF FACTOR SCORES WITH BIOMETRIC INFORMATION DURING WORK HOURS

	Factor1	Factor2	Factor3
HR	0.06	0.14	0.03
SDRR	-0.17	0.12	0.34*
VLF amplitude	-0.15	0.09	0.30*
LF amplitude	-0.21	0.14	0.34*
HF amplitude	-0.05	0.08	0.30*
HF frequency	0.04	-0.03	0.02
LF/HF	-0.19	-0.02	-0.05
LFsd	-0.16	0.16	0.22
Skin temperature	0.13	-0.23	-0.12
Body movement	-0.05	0.01	0.07

The effects of intervention on biological information were evaluated by General Linear model with time (before and after intervention), the degree of participation to the intervention, and their interaction as independent variables.

The type I error level was set at $P < 0.05$.

III. RESULTS

The associations between job category and biometric information during work hours are presented in Fig. 1. After adjusting the effects of age and gender, none of the biometric information showed significant difference with job category.

The analysis between the responses to questionnaire and biometric information revealed that the higher the discretionarily in work, the smaller the SDRR and VLF and LF amplitude, the higher the mental frustration and fatigue, the worse the communication with the boss and colleagues, the greater the LF amplitude and LFsd.

TABLE IV: SUBJECTIVE EVALUATION OF THE DEGREE OF PARTICIPATION IN INTERVENTION

	Subject, *n*	%
Not participated at all	0	0
Little participated	5	16
Neither	12	37
Somewhat participated	10	31
Quite participated	5	16

Factor analysis of the responses to questionnaire revealed that there were three eigenvalues >0.9 and they explained 77% of variance of the responses. Table II shows the varimax rotated factor patterns of three factors. According to the pattern of items that contributed to each factor, factors 1, 2, and 3 were interpreted as reflecting “stress”, “depressiveness”, and “fatigue”, respectively.

Fig. 2 shows the relationships between subjects’ attributes and factor scores. None of the factor scores showed significant association with gender, age, or job category, except that factor 1 score differed between age groups, showing low values for age 25-29 yr and >55 yr.

Table III shows the correlations between biometric information during work hours and factor scores. Significant positive correlations were observed for the variables reflecting HRV magnitude (SDNN and VLF, LF, and HF amplitudes) with factor 3 score, while none of the biometric information correlated significantly with factor 1 or 2 scores.

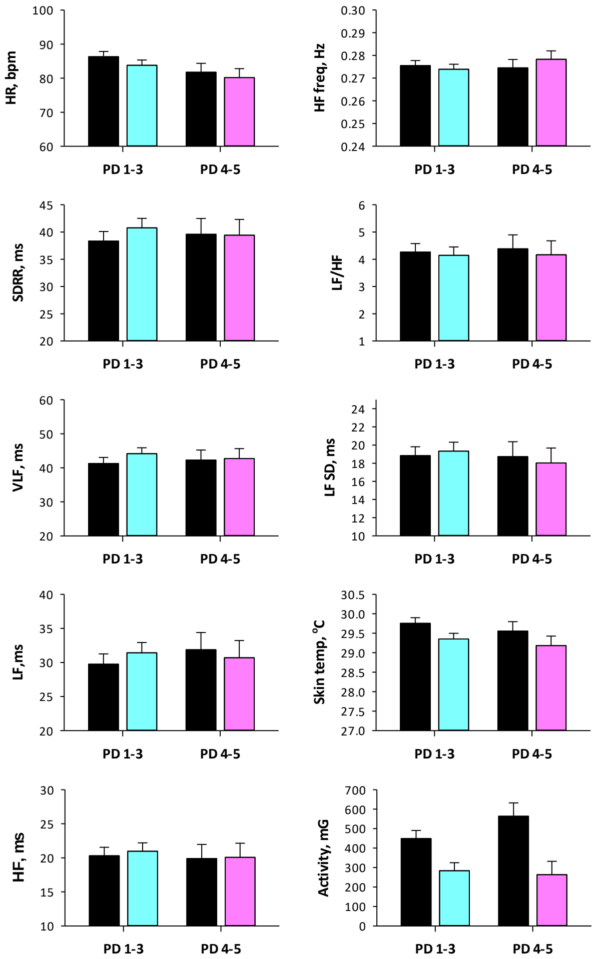

Fig. 3. Changes in biometric information during work hours with intervention (black: before; color: after) by participation degree (PD). Data are means and standard errors. Participation degree (PD) was analyzed in binary (PD 1-3: shallow and PD 4-5: deeper).

After the intervention of communication workshop, 17 (53%) of subjects reported shallow participation (little participated or neither agree nor disagree) and 15 (47%) reported deeper participation (somewhat or quite participated). All indices of HRV but LF/HF showed a significant interaction between participation degree and intervention. Particularly, while SDRR, VLF and LF amplitude, and LFsd increased after the intervention in subjects with shallow participation, these indices decreased or stayed unchanged with it in subjects with deeper participation.

IV. Discussions

To get the basic knowledge necessary to develop effective methods for data processing of biometric data collected in the workplace via wearable sensors, we examined the basic characteristics of HRV, skin temperature, and body movement during work hours in workers of sales, engineering, and staff sections. We also examined the effects of intervention by communication workshop on these biological data.

We found that biometric information showed no significant difference with job category after adjusting the effects of age and gender. The analysis of the relationship between HRV and the responses to questionnaire revealed that the higher the discretionarily in work, the smaller the SDRR and VLF and LF amplitude, the higher the mental frustration and fatigue, the worse the communication with the boss and colleagues, the greater the LF amplitude and LFsd. These suggest that the magnitudes of workers' HRV (SDRR, VLF and LF amplitude, and LFsd) during working hours are associated with work environment prone to labor dissatisfaction and fatigue.

TABLE V: Significance of the Effects of Participation Degree (PD) and Intervention on Biometric Information during Work Hours

Effect	Significance of effects (P value)		
	PD	Intervention	PD × intervention
HR	0.1	<0.0001	<0.0001
SDRR	0.9	<0.0001	<0.0001
VLF amplitude	0.9	<0.0001	<0.0001
LF amplitude	0.8	0.1	<0.0001
HF amplitude	0.7	0.0008	0.04
HF frequency	0.6	0.001	<0.0001
LF/HF	0.9	0.001	0.4
LFsd	0.6	0.2	<0.0001
Skin temperature	0.4	<0.0001	0.3
Activity	0.5	<0.0001	<0.0001

This notion is also supported by the results of factor analysis. The analysis revealed that the responses to questionnaire consisted of three factors respectively representing stress, depressiveness, and fatigue. Among these factors, factor 3 (fatigue) correlated with increases in HRV (SDRR and VLF, LF, HF amplitude) during work.

In general, HRV is reduced with physical and mental stress [9]. Thus, our observations of the association of increased SDRR and LVF and LF amplitude with higher mental frustration and fatigue may be unexpected. Schubert et al. [10], however, have reported that acute stress caused by speech task increased SDRR and LF power in 50 healthy adults. Similar observations have also been reported by Rodrigues et al. [5] in a study of 311 air traffic controllers. They observed an increase in SDRR with acute stress by the Trier Social Stress Test that was composed of speech task followed by arithmetic task. Our observations are on the same line of these earlier studies, but ours are unique from them in terms of being obtained in real work environments.

This study has limitations. We analyzed the relationships between biological measures (HRV) and the responses to questionnaire. We observed the associations of increased HRV with subjective frustration or stress. The responses to the questionnaire, however, depend on the individual perceptions about the situation. People may feel stressed for the very busy situation of work, but some may feel that it is a fulfilling and favorable situation. For the later type of people, an increase in mental and/or physical demands with busy work may cause the association between a decrease in HRV and a decrease in stress. To prevent unexpected harm to the health of workers, we must be prudent enough in the interpretation of changes in HRV.

V. Conclusion

The results of the present study suggest that analysis of

HRV, particularly increases in LF amplitude and LFsd may be associated with frustration caused by less arbitrariness of job and fatigue of workers. The mechanisms underlying this association are unclear from this study. Further studies are necessary to safely apply the results of this study to workplace.

Conflict of Interest

M. Mitsui, N. Ozaki, M. Wakui, and K. Kawano are employees of Fuji Xerox Co., Ltd. This work was performed as a collaborative study between Fuji Xerox Co., Ltd. and the Department of Medical Education, Nagoya City University Graduate School of Medical Sciences.

Author Contributions

J.H. analyzed the data and wrote the paper; M.M., N.O., M.W., and K.K. formulated the study concept, managed the experiments, and collected the data; and E.Y. conceived the study plan.

Acknowledgment

The name of wearable sensor, “myBeat” is registered trademark owned by Union Tool Co. in Japan.

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