Variations of heart rate variability under varied physical environmental factors

Keita Ishibashi, Akira Yasukouchi

Department of Physiological Anthropology, Kyushu Institute of Design

Abstract

In this study, we estimated the behavior of the diversity of physiological responses under varied physical environmental factors by measuring variations of heart rate variability (HRV), an index of activity of cardiac autonomic control. Seven healthy young male adults consented and participated in the study. The environmental conditions consisted of thermal, lighting, and acoustic conditions. Two components of HRV were measured. One was the low frequency (LF) component of HRV, which provided a quantitative index of the sympathetic and parasympathetic (vagal) activities controlling the heart rate (HR). The other component measured was the high frequency (HF) component, which provided an index of the vagal tone. The percent contributions of the diversity of physiological responses in the HRV indices were calculated by ANOVA. The contribution of physical environmental factors to the variations in HR was higher than the contribution to HF and LF. However, the contribution of these factors was lower than the contribution related with individual difference in all indices. This result showed that the individual diversity of physiological responses is not a negligible quantity.

Keyword : Variation, Error, Physiological Anthropology, Heart rate variability, Human

1. Introduction

Numerous studies have reported the reliability of heart rate variability (HRV) as a noninvasive index of cardiac autonomic activities (Sayers, 1973; Pomeranz et al., 1985; Pagani et al., 1986). HRV encompasses two main components; high frequency (HF) and low frequency (LF) bands in the spectrum, which are called the HF and LF components, respectively. The HF component in the power spectrum relates to parasympathetic activity, while the LF component is associated with both parasympathetic and sympathetic activities (Pomeranz et al., 1985). The implementation requirements needed to measure the heart rate (HR) and its variability are much lower than other physiological measures (e.g., electroencephalogram, continuous arterial blood pressure, and electrodermal activity), which is an advantage for researchers, because it enables them to assess the actual living environment of human beings using physiological insights. However, it is commonly understood that there are larger amounts of variation in physiological measurements (such as the EEG, EMG, ECG, etc), than in measurements of subjective responses. Of course, an index which is obtained by any kind of measurement will include some degree of variation, because not only true value is also understood. However, in some experiments, most of the variations in some of the physiological indexes are unrelated to experimental conditions. These variations often are considered to be an error (measurement error, individual difference, inappropriate experimental conditions, etc). Above all, these errors are considered the “enemy” of "a significant difference" in the statistical analysis of measurements.

However, population thinking, developed largely by Darwin, considers variation not to be an error, but, as the great evolutionist Ernst Mayr put it, to be real (Mayr, 1982). In population thinking, certainly, individual variance in a population is the source of diversity upon which natural selection acts to produce different kinds of organism. This thinking might not be irrelevant to some research fields which address physiological measurements, including psychophysiology, ergonomics, and physiological anthropology, because the diversity of physiological responses in many kinds of research might not be a negligible quantity, or, rather, would be essential to the measurements. It is reasonable to assume that a methodology that considers variation not to be an error but to be real is indispensable in these kinds of disciplines.

In recent applications to evaluate the changes in autonomic activities, HRV has been employed in the physiological and objective assessment of respective physical environmental factors such as thermal temperatures, lighting, and acoustic factors (Nishikawa et al., 1997; Mukae and Sato, 1992; Miyake and Kumashiro, 1991). In an actual environment, however, there are multiple physical environmental factors, and these factors are combined. Therefore, we need to investigate the combined effects on human responses to physical environments consisting of a variety of factors. Moreover, there is little basic data available upon which to base a discussion on the diversity of physiological responses to actual environmental stimuli. In this study, therefore, we used combined environmental factors, consisting of thermal, lighting, and acoustic factors, as the physical environmental factors upon which to base our discussion on the diversity of physiological responses.

2. Materials and Methods

Subjects: Seven healthy young male adults (21 - 25 yrs of age) consented and participated in the study. The mean anthropometric data for the subjects was 23.1 (S.D. 1.25) years of age, 170.4 (S.D. 4.42) cm tall, and weighing 57.7 (S.D. 4.56) kg. All subjects were clothed in T-shirts and shorts with underwear underneath. Total thermal resistance from the skin to the outer surface of the clothing was 0.18 clo. The subjects were asked to abstain from eating, drinking, smoking, and exercise for at least two hours before the experiment.

Procedures: The experiments were performed in two climatic chambers at our university. The subjects were kept in a quiet room with a constant room temperature of 28°C (RH: 50%), and remained in a sitting position for at least 30 min prior to the experiment. They were then moved to the experimental chamber, which had been set up before their entrance with the following environmental conditions. These conditions consisted of three different ambient temperatures (21, 28 and 35°C; RH: 50%), three color temperatures from light sources (3000, 5000 and 7500K; 700lx) and three acoustic levels (background noise plus 0, 5, and 10 dB(A) of white noise). Every subject was tested under each of the 27 conditions in an order that virtually counterbalanced the cross-effects on the subjects. At the midpoint of their exposure period in the climactic chamber, the subjects engaged in mental tasks consisting of selective reaction-time tasks measured by a contingent negative variation (CNV) measurement. The subjects were instructed to press a key as fast as possible, and to stare at a fixation point, making an effort to reduce eye movement. Subjective responses were obtained at the end of the experiments. The experimental protocol is given in Figure 1.

Data analysis: The respiratory curve was measured by a hot-wire spirometer (MINATO Medical Instruments, RF-2) attached to a mask worn by the subject. The ECG (electrocardiogram) and respiratory curve were monitored simultaneously. Measurements were taken in the last 5 min of a 13 min rest period, and the task was then initiated and performed within a 20 min period, followed by a 5 min post-task period. In order to measure HRV, the subjects were required to control their breathing (respiratory cycle − 4 sec, tidal volume − 20% vital capacity of each subject). The procedures for this respiratory control were similar to those described by Kobayashi (1996).

Data was analyzed online with a personal computer that had an analog-to-digital conversion rate of 250Hz per channel by a 12-bit converter. The heart period sequences, obtained by detecting the peak of the R wave in the ECG, were converted into beats/min and interpolated into 10 Hz equidistant data. In order to derive the components, power spectra were derived from the interpolated HR using fast Fourier transform (FFT) processing.

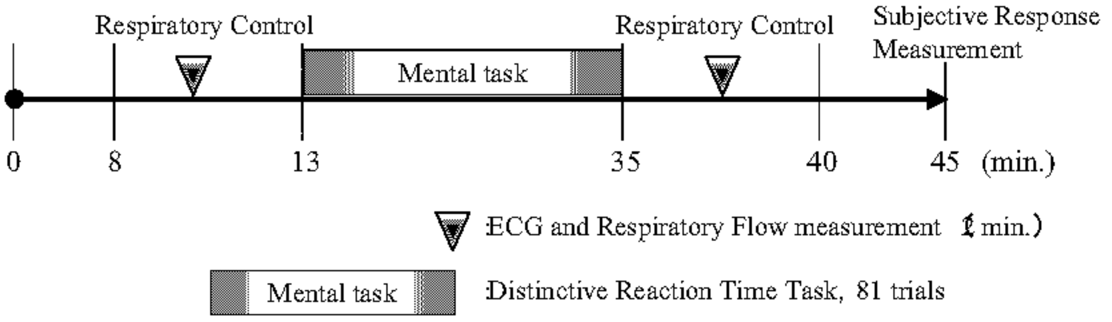

Figure. 1. Experimental protocol.

Table 1. The percent contributions of each factor on heart rate and HRV indices.

		HR	HF	LF	LF/HF
Main effect	Ambient temperature	19.9	2.1	8.8	13.3
	Color temperature	0.0	0.0	0.1	0.2
	Noise level	0.1	0.5	0.2	0.0
	Time block	0.0	0.0	0.0	0.1
	Subject	29.4	71.3	23.2	32.5
Interaction	Sum of interactions between subject and other factors	38.5	17.3	20.3	12.4
	Sum of interactions except interactions of subject	7.8	1.7	0.6	1.1
	Error	4.3	7.1	46.8	40.4
	Total	100.0	100.0	100.0	100.0

The HF and LF components were analyzed only before and after the mental task in which the subjects were required to control their breathing was performed. The HF and LF components were integrated from 0.176 to 0.332 Hz and from 0.059 to 0.137 Hz of the power spectra, respectively.

3. Results

To discuss the diversity of physiological responses, we estimated the percent contribution of each experimental factor. The percent contribution was determined by comparing their relative variances. Therefore, the technique, popularly known as the analysis of variance (ANOVA) was used for this purpose. Five-way ANOVA was used for an estimation of the percent contribution of each of these factors: (three levels of ambient temperatures (21, 28, and 35°C), three levels of color temperatures (3000, 5000, and 7500K), three noise levels (background noise plus 0, 5, and 10 dB of white noise), two levels of time blocks (before task and after task), and seven levels of subjects. The percent contribution of the interaction between the subject and other factors (38.5%), and the main effect of the subject (29.4%), which are both related to individual differences, were larger than the other contributions to the HR. In the results obtained for the HF component, the distribution ratio of the percent contributions was similar to the HR results, however, the largest percentage was for the factor for the subject (71.3%). The percent contributions of error in HR and HF were relatively lower. However, the results of LF and LF/HF indicated that the percent contribution of error, which is not related to any explanatory variables, was larger than the other contributions. These results are given in Table 1.

Table 2 shows the result of the percent contributions in each subject on the HR, as estimated by four-way ANOVA. The ratio of the percent contributions of environmental factors was relatively higher than the ratio shown in Table 1. The percent contributions of ambient temperature in each subject varied individually (3.1-48.7%), while the value in all subjects was 19.9% (Table 1). This variation was similar to the result obtained on the percent contributions of interactions between ambient temperature and other factors. The percent contributions of the factors, except for ambient temperature, were consistently lower in the results obtained for all of the subjects (Table 1). However, the contributions of color temperature or noise level in subjects E and F were relatively higher.

4. Discussion

In order to discuss the diversity of physiological responses, we estimated the percent contribution of each experimental factor. The percent contribution of the physical environmental factors in variation in HR was higher than in the HRV indices. It is commonly understood that there are larger amounts of variation in the HRV indices than in the HR indices. The percent contributions, however, were lower than the contributions related with individual differences in all indices. These variations are often considered to be errors in statistical analysis. Above all, this variation affects "the significant difference" in statistical analysis. We have often shown that the result of statistical significant in alteration of HR whereas the result of HRV is not. However, the variation of each index of HRV differed in the contribution of experimental factors. There was a large amount of individual differences in HF, while the result of LF indicated that most of the variation was not related to any explanatory variables (Table 1). Both of these variations are considered to be an error. However, the modality of the variance was not the same.

It is also understood that the HRV measurement includes some variations that should be considered an error, not real. One of these variations is the measurement error, caused by the

Table 2. The percent contributions of each factor of each subject on heart rate.

		Sub.A	Sub.B	Sub.C	Sub.D	Sub.E	Sub.F	Sub.G
Main effect	Ambient temperature	24.1	48.7	34.8	48.7	38.9	3.1	27.6
	Color temperature	3.3	0.9	0.4	3.1	6.5	16.2	4.6
	Noise level	3.4	0.8	3.5	1.5	16.1	6.0	2.0
	Time block	0.0	1.1	0.0	0.2	0.0	1.6	0.1
Interaction	Sum of interactions between ambient temperature and other factors	49.8	36.8	50.2	29.3	22.4	42.4	44.5
	Sum of interactions except interactions of ambient temperature	9.2	1.4	3.3	14.6	9.1	20.8	19.3
	Error	10.2	10.3	7.8	2.6	7.0	9.9	1.9
	Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0

slow sampling rates when digitizing the analog ECG. Because the HRV data is based on the timing of the R-wave peak, the accuracy of the amplitude of the HRV depends on the sampling rate. Less accurate detection of the R-wave contributes to additional uncontrolled variance to the HRV amplitude, as discussed in detail by Riniolo and Porges (1997), who provided a guideline which stated that the sampling rate needed to be as fast as the lowest amplitude of the HRV oscillation in milliseconds. The sampling rate in this study was 250 Hz, indicating the possible lowest amplitude detection was 4 msec of HRV oscillation, which might be related to the results of the percent contribution of error in the HRV indices being larger than that in the HR indices. Another variation concerned with error is based on physiological factors caused by an alteration in the breathing pattern. Because RSA (respiratory sinus arrhythmia), which causes the main fluctuation of the HF component, displays rhythmical fluctuations in the heart periods that coincide with respiratory frequency, a comparison between the HF component of the HRV, which is measured during a different breathing pattern, is a comparison between components with different physiological origins (Berntson et al., 1993). To study the effect of breathing on HRV, we measured HRV when the subjects were engaged in breath control. Through the measuring method used, we were able to control not only the respiratory cycle, but also the tidal volume. The results we obtained, which showed a small percent contribution of error in the HF component, could be due to the precise breathing control executed by the subjects. This small contribution might have provided a large amount of the percent contribution of the subject, indicating intra-subject repeatability of the HF component. It might be reasonable to investigate another explanatory variable or parameter to explain the individual variation of the HF component in terms of its larger contribution to the experimental conditions, which would provide "a significant difference. "

The results of this study show that there was a consistently higher percent contribution of ambient temperature in each index. This might be related to the fact that the degree of experimental stimulus variation of the ambient temperature (21 – 35 °C) was larger than the other environmental factors (color temperature: 3000 – 7500 K, noise level: +0 - 10 dB(A)). In the results obtained on the inter-individual variations of HR, however, the percent contributions of environmental factors varied individually. Moreover, the percent contributions of the noise level in each subject (0.8-16.1%, in Table 2) were clearly higher than the results of all the subjects (0.1%, in Table 1). These results might show that there was constantly the way of responses to noise level in intra-subject and also the way might differ in each subject. It might be reasonable to say that the diversity of physiological responses is not a negligible quantity, or, rather, that it is the essential quantity in all of the measurements. Therefore, we need to investigate the diversity of the responses in each subject, which may not be related to "a significant difference." This idea is connected to the methodology that considers variation not to be an error, but, rather, to be real.

References

[1] Sayers BM: Analysis of heart rate variability. Ergonomics, 16(1), 17-32, 1973

[2] Pagani M, Lombardi F, Guzzetti S, Rimoldi O, Furlen R, Pizzinelli P, Sandrone G, Malfatto G, 'Orto SD, Piccaluga E, Turiel M, Baselli G, Cerutti S, Malliani A: Power spectral analysis of heart rate and arterial pressure variabilities as a maker of sympatho-vagal interaction in man and conscious dog, Circ Res, 59(2), 171-192, 1986

[3] Pomeranz B, Macaulay RJB, Caudill MA ,Kutz I, Adam D, Gordon D, Kilborn KM, Barger AC, Shannon DC, Cohen RJ, Benson H: Assessment

of autonomic function in humans by heart rate spectral analysis, Am J Physiol, 248, H151-H153, 1985
[4] Mayr, E: The growth of biological thought. Harvard University Press, 1982
[5] Miyake S, Kumashiro M: Comfortableness of 1/f fluctuations – the effects of the pseud-airconditioner noise with 1/f fluctuation of sound pressure level -, Jpn J Ergonomics, 27 (1), 1-8, 1991 (in Japanese with English abstract)
[6] Mukae H, Sato M: The effect of color temperature of lighting sources on the autonomic nervous functions, Ann Physiol Anthropol, 11 (5), 533-538, 1992
[7] Nishikawa K, Hirasawa Y, Nagamachi M: Influence of thermal environment on heart rate variability, Jpn J Ergonomics, 33 (2), 105-112, 1997 (in Japanese with English abstract)
[8] Kobayashi H: Postural effect on respiratory sinus arrhythmia with various respiratory frequencies, Appl Human Sci, 15 (2), 87-91, 1996
[9] Riniolo T, Porges SW: Inferential and descriptive influences on measures of respiratory sinus arrhythmia: sampling rate, R-wave trigger accuracy, and variance estimates, Psychophysiology, 34(5), 613-21, 1997
[10] Berntson GG, Cacioppo JT, Quigley KS: Respiratory sinus arrhythmia: autonomic origins, physiological mechanisms, and psychophysiological implications, Psychophysiology, 30, 183-196, 1993