PSYCHOPHYSIOLOGICAL ANALYSIS FROM HEART RATE RESPONSES TO MENTAL TASK UNDER VARIOUS THERMAL CONDITIONS

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INTRODUCTION

This study investigates on the psychophysiological effects of a mental factor (mental task) and an environmental factor (ambient temperature) in humans. The correlation between physiological indices and subjective responses has recently become a highly attractive theme. Although physiological indices, such as electrocardiogram (ECG), electromyogram (EMG), and electroencephalogram (EEG), can be monitored continuously, subjective responses can only be elicited intermittently. In this study, relations between a continuously monitored physiological index (heart rate: HR) and subjective responses (measured at the end of each experiment) were correlated.

Regarding the thermal effect on HR responses, Hasebe et al. (1995) have reported contrasting responses, increased and decreased HR corresponding to vasodilatation and vasoconstriction in a hot (30C) and a cool (20C) environment, respectively. However, Freyshuss et al. (1988) have demonstrated that mental tasks accelerate HR through neurogenic mechanisms, and peripheral vasodilatation is achieved through the concerted actions of reduced vasoconstrictor activity and elevated circulating adrenaline. Therefore, it would be interesting to investigate the combined effect of thermal and mental factors on HR.

The implementation requirements needed to measure HR are particularly lower than the other physiological indices, and HR has often been used as a noninvasive index in assessing physical loads. However, as both the sympathetic and vagal nerves innervate the heart, the mean HR is ambiguous with regard to its autonomic mode (Berntson et al., 1993). In this regard, heart rate variability (HRV) can be divided into two major components reflecting the relative sympathetic and parasympathetic nervous activities (Pomeranz et al., 1985; Pagani et al., 1986). However, the respiratory sinus arrhythmia (RSA) component in HRV, reflect the parasympathetic nervous activity, is factor that affected by respiratory alterations that include not only tidal volume and respiratory cycle (Hirsch and Bishop, 1981; Kobayashi, 1997) but also respiratory pattern (Ishibashi et al., 1997b). Because of these respiratory effects on the RSA component, some have recommended control of the respiration of subject in a certain form (Grossman et al., 1991; Kobayashi, 1998), although the subject might experience difficulties in respiratory control while performing another task. Therefore, in this study, the respiratory coefficient of variation of heart rate (CV_{RESP}), which has previously been proposed by Taniguchi et al (1995), was used to assess HRV during task operation. This index, estimated by evaluating the cross-correlation function of two-time series data (heart period and respiratory curve), is useful in assessing the respiration-regulated parasympathetic nervous activity under various respiratory conditions.

In view of these, we focused on the effects of mental work on cardiac autonomic control under different ambient temperatures, a parameter that has proved to be most reliable in our previous experimental conditions (Ishibashi, 1997a), using the CV_{RESP} response.

METHODS

Subjects. Seven healthy male young adults (21 - 25 yr of age) consented and participated. Mean anthropometric data for the subjects were 23.1 (S.D. 1.25) years of age, 170.4 (S.D. 4.42) m tall, and weighted 57.7 (S.D. 4.56) kg. All subjects were clothed in T-shirts and shorts with underwear. Total thermal resistance from the skin to the outer surface of clothing was 0.18 clo. Subjects were asked to abstain from eating, drinking, smoking and exercise for at least 2 hr before the experiment.

Procedures. The experiments were performed in two climatic chambers at our university. Subjects accommodated in a quiet room with a constant room temperature of 28C (RH: 50%) remained in a sitting position for at least 30 min before the experiment. They were then moved to the experimental room previously designated with a certain environmental condition. The environmental condition consisted of three different ambient temperatures (21, 28 and 35℃; RH: 50%), three color temperatures (3000, 5000 and 7500K; 700lx) and three background acoustic levels (background noise plus 0, 5, and 10 dB of white noise) as described in our previous study (Ishibashi et al., 1997a). Every subject was tested under each of the 27 conditions in an order that virtually counterbalanced cross-effects on the subjects. The mental tasks consisted of distinctive reaction-time tasks, and the subjects were encouraged to engage in the tasks fullest possible.

The respiratory curve was measured by a hot-wire spirometer (MINATO Medical instruments, RF-2) attached to a mask worn by the subject. ECG and the respiratory curve were monitored simultaneously. Measurements were taken in the last 5 min of a 13-min rest interval before initiating the task for 20 min. During the task period, measurements were recorded at 6, 12 and 18 min after task initiation as well as during a 5-min post task interval. In order to measure conventional HRV, the subjects had to control their breathing (respiratory cycle = 4 sec, tidal volume = 20% vital capacity of subject) during the resting period. The procedures for this respiratory control were similar to those described by Kobayashi (1996).

The scales for assessing subjective responses (thermal sensation, fatigue sensation and the degree of concentration on task performance) are summarized in Table 1, and the responses were obtained at the end of experiments.

Data analysis. The heart period sequences, obtained by detecting the peak of R wave in ECG, were converted into beats/min and interpolated into 10-Hz equidistant data.

Based on the work of Taniguchi et al. (1995), CV_{RESP} was derived as a noninvasive index of the respiration-regulated parasympathetic activity. In order to derive CV_{RESP}, the coefficient of variation of interpolated heart rate (CV_{IHR}) and the maximal value of cross-correlation function between interpolated HR and respiratory curve (r-RESP) were calculated. The product of CV_{IHR} and r-RESP yields CV_{RESP} (i.e., $CV_{IHR} \times$ r-RESP = CV_{RESP}).

Table 1 Scales of subjective responses

Thermal sensation		Fatigue sensation		Degree of concentration on task performance	
1	very cold	1	absolutely no fatigue sensation	1	better concentrated
2	cold	2	no fatigue sensation	2	well concentrated
3	cool	3	slight fatigue sensation	3	concentrated
4	slightly cool	4	light but apparent fatigue sensation	4	less concentrated
5	neutral	5	apparent fatigue sensation	5	little concentrated
6	slightly warm				
1	warm				
2	hot				
3	very hot				

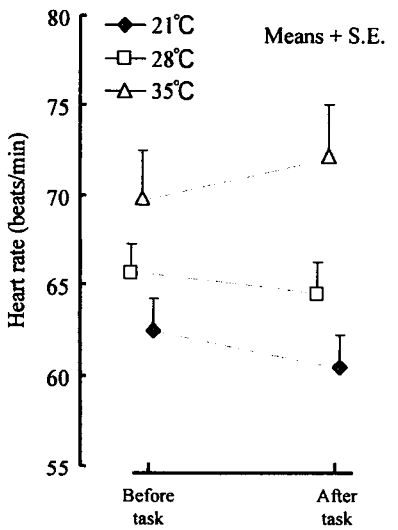

Figure 1 Interaction between ambient temperature and time-block on the heart rate during the rest

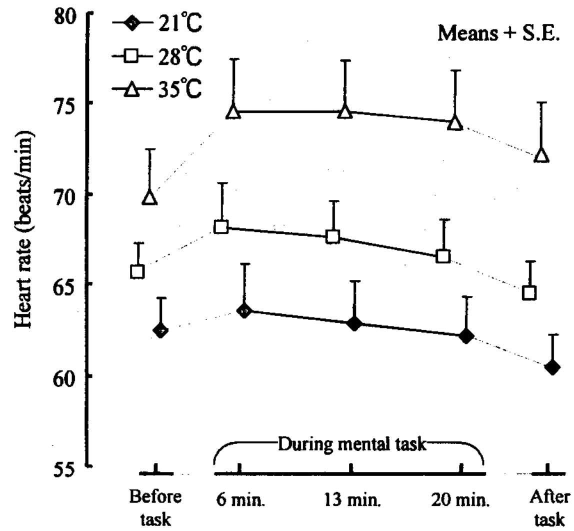

Figure 2 Interaction between ambient temperature and time block on the heart rate all throughout the experiment

The RSA component was analyzed only before and after performing the mental task where the subjects were required to control their breathing. In order to derive the RSA component, power spectra were derived from same interpolated heart rate using fast Fourier transform (FFT) processing. The RSA component is an integration of the power spectra from 0.165 to 0.332 Hz.

In this study, the number of data required to estimate CV was 512 (interpolated at 10Hz), although Taniguchi et al (1995) have applied 256 points (interpolated at 2.5 Hz). The value of CV_{RESP} was however similar in each study.

Statistical analysis Results were presented as the mean + S.E. Five-way (ambient temperature, color temperature, background noise and time blocks were of 3 levels each while, subject were of 7 levels) ANOVA was used for verification of statistical significance. Differences with a probability value of less than 0.05 were considered significant.

RESULTS

Analysis of variance revealed a

significant interaction between ambient temperature and time-block on the HR during resting, i.e., before and after performing the mental task ($F[2, 12] = 32.85$, $p < 0.0001$; Fig. 1). Analyses of variance on HR of all time blocks through the mental tasks revealed significant effects were elicited by ambient temperature ($F[2, 12] = 38.38$, $p < 0.0001$), time-block ($F[4, 24] = 8.55$, $p < 0.001$) and ambient temperature/time block interaction on HR ($F[8, 48] = 6.40$, $p < 0.0001$; Fig. 2).

From the changes in value of each coefficient of variation on time blocks at each thermal condition (Fig. 3), analyses of variance revealed significant effects of ambient temperature ($F[2, 12] = 7.06$, $p < 0.01$) and time block ($F[2, 12] = 9.48$, $p < 0.01$) on CV_{IHR} (Fig. 3A). The time blocks did not affect the CV_{RESP}, whereas the thermal effect was significant ($F[2, 12] = 18.25$, $p < 0.001$; Fig. 3B). However, the difference between CV_{IHR} and CV_{RESP} was significantly affected only by the time block ($F[2, 12] = 44.17$, $p < 0.0001$; Fig. 3C).

In the present study, the physiological effects elicited three temporal changes: (i) a change induced on initiation of the mental task; (ii) a change induced on termination of the mental task stopped, and (iii) a change elicited during exposure to ambient temperature between the resting periods. Table 2 shows correlation coefficients of the relationship between the subjective responses and the HR responses in temporal changes. With respect to thermal sensation, a closer correlation was obtained in HR changes effected during mental task performance between the resting periods compared with those induced during performance of the mental task. In aspects relating to fatigue and concentration scores, however, closer correlation coefficients were derived in conditions reversed to those described in the case of thermal sensation.

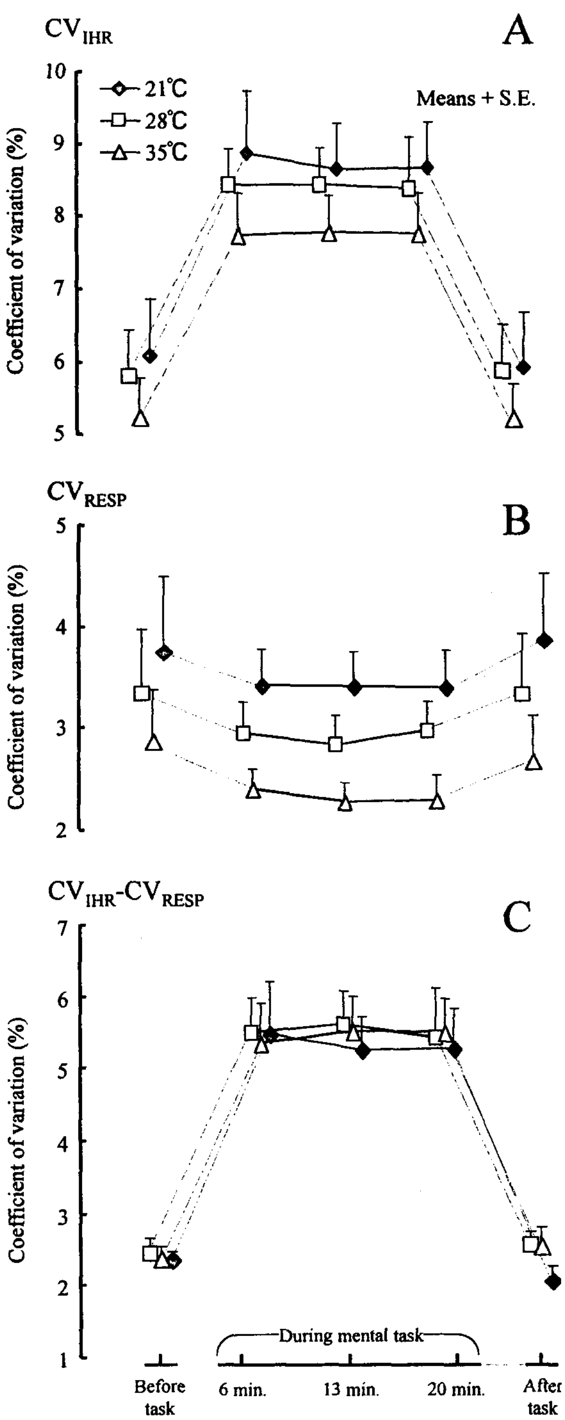

Figure 3 Changes in coefficient of variation of each component of heart rate variability over mental task at each thermal condition

DISCUSSION

Increases in HR during mental task performance observed in the present study were consistent with previous studies (Freyschuss et al., 1988; Jrgensen et al., 1990; Cacioppo et al., 1995) employing mental concentration and stress. CV_{RESP} responses induced by the mental task did not particularly contribute to the HR responses. Considering the induction mechanisms of respiratory fluctuations in HRV and findings of a decline in baroreceptor reflex sensitivity during mental stress (Robbe et al., 1987; Bernson et al, 1993), it may be concluded that the respiratory component of HRV could have decreased in mental task performance, although the decrease in CV_{RESP} due to mental task was not affected significantly in the present study. However, the correlation between RSA component and CV_{RESP} (inter-individual correlation, r = 0.54-0.91; Table 3) validated CV_{RESP} as an index of cardiac parasympathetic nervous activities.

In contrast, the increases in CV_{IHR}-CV_{RESP} (i.e., the difference between CV_{IHR} and CV_{RESP}) which are other components of HRV, were in general accord with the pattern of HR responses during performance of mental tasks. CV_{IHR}-CV_{RESP} might include the Mayer wave related sinus arrhythmia (MWSA) component, which is a principal component of HRV with exception of the respiratory component. The inhibition on MWSA during mental stress has often been observed (e.g., Aasman et al., 1987; Vicente et al, 1987). However, according to Pagani et al. (1989), the activated MWSA during mental stress is neurogenically mediated via increased sympathetic nervous activities. Findings in the present study were consistent with those of Pagani et al. (1989) in that activation of the non-respiratory

component in HRV was persistently maintained throughout the mental task performance. Furthermore, consistent activation of the sympathetic nerves has also been reported in a study using an invasive index with mental tasks (Freyshuss et al., 1988). As such, it might be suggested that CV_{IHR}-CV_{RESP} reflected the cardiac sympathetic nervous activity.

The responses of HR to varied ambient temperatures observed in the present study were characterized by activation and inhibition of HR in hot (35C) and cool (21C) conditions, respectively. These responses correlated with other findings on HR responses to the thermal factor (Hasebe et al., 1995; Nishikawa et al., 1997). In our results on HRV, responses in HR appeared in CV_{RESP} indicated the significant effect of ambient temperature, reflecting withdrawal of CV_{RESP} in a hot environment. HR responses appeared to react to thermal conditions only 10 min after thermal exposure (i.e., before mental task). These responses were enhanced after the mental task (Fig. 1). However, it is not clear from the HR responses if the enhanced HR responses were due to the temporal summation of thermal effects or the residual effect of mental tasks. In contrast, observations on HRV implicated that the main effects of ambient temperature and time blocks in CV_{IHR} were divided between the former effect in CV_{RESP} and the latter in CV_{IHR}-CV_{RESP}. These observations might interpret that respiration-regulated parasympathetic activities mainly controlled the basal effect of ambient temperature while the other components (including sympathetic activities) contributed to the HR responses to mental stress. As showed by Berntson et al. (1994) in their shown pharmacological study, these results suggest that parasympathetic activities modulate HR responses to the basal environmental factor to induce sympathetic activities when subjected with a strained environmental factor.

Table 2 Correlation coefficients of the relationship between HR responses and subjective responses (n = 189)

HR changes - Difference of each time blocks -	Thermal sensation	Fatigue sensation	Degree of concentration on task performance
Diff. before task and after task	r = 0.44 **	r = 0.15 *	N.S.
Diff. before task and 1st task period	r = 0.33 **	r = 0.16 *	r = 0.20 **
Diff. 3rd task period and after task	N.S.	r = 0.19**	r = 0.15*

N.S. : not significant, * : $p < 0.05$, ** : $p < 0.01$

Table 3 Inter individual correlation coefficient between RSA components and CV_{RESP} (n = 54).

Subj.	A	B	C	D	E	F	G
r value	0.89 **	0.90 **	0.84 **	0.54 **	0.89 **	0.79 **	0.91 **

** $p < 0.01$

The correlation between HR responses and subjective responses unfolded intriguing result. In the various factors incorporated into the subjective responses measured at the end of experiments, task-related subjective responses were more closely correlated with task-induced HR responses. However, with respect to thermal sensation, a closer correlation was obtained in HR changes induced during mental task performance in between the rest periods compared with the changes due to the mental task. These results suggest that the best avenue to relate responses in the physiological index with self-evaluation of mental effects by subjective responses depends on the property of those factors.

In summary, the present study therefore clarified the HR responses to mental tasks under various ambient temperatures. In short, sympathetic activation of the HR due to mental tasks and parasympathetic modulation were influenced closely by the ambient temperature.

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