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Effects of Mental Task on Heart Rate Variability during Graded Head-Up Tilt

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Abstract. In this study, we used spectral analysis of heart rate variability (HRV) to estimate the changes in autonomic control in response to disparate stimuli produced by mental task and graded head-up tilting. The low frequency (LF) component of HRV provided a quantitative index of the sympathetic and parasympathetic (vagal) activities controlling the heart rate (HR), while the high frequency (HF) component of HRV provided an index of the vagal tone. We studied 17 healthy male subjects (21–25 yr of age) who were placed on a tilt-table and the graded tilt-protocol involved tilted sine angles 0.0, 0.2, 0.4, 0.6, 0.8, and 1.0. These tilt-protocols were repeated with or without the mental task, which consisted of auditory distinctive reaction-time tasks. The basal autonomic mode against the graded head-up tilt was characterized by reciprocal changes in sympathetic and vagal tones. There were significant increases of HR corresponding to the mental task with lower tilt-angle, albeit the changes with higher tilt angles were not significant. Furthermore, there were increases and decreases of the LF component induced by the mental task at lower and higher tilt-angles, respectively. These results revealed that the different responses of HR and LF component against the same tasks could be derived from the alterations of autonomic mode during gradual changes in autonomic control.

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Keywords: heart rate variability, autonomic nervous system, spectral analysis, mental task, orthostatic stress

Introduction

The autonomic nervous system plays an important role in regulating homeostasis of humans, who are subjected to various multifaceted stimuli in daily life. Numerous studies have reported the reliability of heart rate variability (HRV) as a noninvasive index of cardiac autonomic activities (e.g., Pagani et al., 1986; Pomeranz et al., 1985; Sayers, 1973). HRV defines fluctuations in the heart periods that encompass two main components: RSA (respiratory sinus arrhythmia) and MWSA (Mayer wave related sinus arrhythmia). RSA displays rhythmical fluctuations in the heart periods that coincide with respiratory frequency (Berntson et al., 1993), while MWSA manifests fluctuations of the heart periods that synchronize with the baroreceptor reflex to arterial pressure Mayer waves (Madwed et al., 1989). In the spectrum analysis, RSA and MWSA appear in relatively high frequency and low frequency bands, and are called the HF and LF components, respectively. The HF component in the power spectrum relates to parasympathetic activity, while the LF component associates with both parasympathetic and sympathetic activities (Pomeranz et al., 1985). And, the LF/HF ratio was proposed as an index of sympatho-vagal balance by Pagani et al. (1986). Since sympatho-vagal firing alters spontaneous sinus node depolarization of the heart, it could alternatively be argued that heart rate (HR) reflects the said sympatho-vagal balance. However, sympathetic and parasympathetic nervous function reciprocally, independently and non-reciprocally (Berntson et al., 1994). Because of these multiple modes of autonomic control, HR is ambiguous with regard to its autonomic mode. Therefore, there are differences when indices of sympatho-vagal balances are defined by HR and HRV, which could be divided into two main components reflecting relative sympathetic and parasympathetic nervous activities (Pagani et al., 1986; Pomeranz et al., 1985).

In recent applications to evaluate the changes in autonomic activities, HRV has been employed in physiological assessment of living environmental factors such as thermal, lighting and acoustic factors (Miyake and Kumashiro, 1991; Mukae and Sato, 1992; Nishikawa et al., 1997), as well as assessment of mental factors such as the mental load and mental task (Langewitz et al., 1991; Pagani et al., 1991). It is therefore reasonable to suppose that the integrated study of these factors is needed to evaluate the living environmental assessment comprehensively. Given that the stimuli in these factors are divided into passive and active inputs, environmental and mental factors deliver passive and active stimuli to the autonomic nerves, respectively. Through investigations on the combined effects of environmental and mental factors on cardiac autonomic responses (Ishibashi and Yasukouchi, 1999), it is suggested that parasympathetic activity might control the basal effect of ambient temperature and the other components, including sympathetic activity contributing to the increase in HR due to mental tasks. A notable result was that the mental task activated HR consistently via sympathetic control as active stimuli, while the parasympathetic activity was affected gradually with alterations of the ambient temperature as passive stimuli. A number of studies have reported the sympathetic increase in HR due to mental task as active stimuli (Cacioppo et al., 1995; Freyschuss et al., 1988; Jørgensen et al., 1990). However, they provided no information about the effect of mental tasks on HR under progressive autonomic alterations by passive stimuli. Previous study (Ishibashi and Yasukouchi, 1999) has shown the effect of mental task under gradual alteration of parasympathetic activity is portrayed as passive stimuli. In this study, therefore, we investigated the effect of mental tasks on autonomic control during physiological manoeuvre, such as passive graded head-up tilting, that increases sympathetic activities (Iwase et al., 1987; Mukai and Hayano, 1995).

Methods

Subjects

Seventeen young healthy male adults (21–25 yr of age) participated in the study with prior consent. Mean anthropometric data for the subjects were 170.8 ± 5.36 cm in body height and 61.1 ± 7.68 kg in body weight. All subjects were clothed in T-shirts and shorts with underwear. 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 a climatic chamber (28°C; RH: 50%) at our university. The subjects were placed on a tilt-table and supported with a footrest. Progressive orthostatic stress was induced by graded tilting, with supine stabilization (25 min). The graded tilt-protocol involved tilted sine angle of 0.0, 0.2, 0.4, 0.6, 0.8, and 1.0 (corresponding to 0.0, 11.5, 23.6, 36.9, 53.1, and 90.0°, respectively). These tilt protocols were repeated with and without mental task on the same day, and every subject was tested under each condition in an order that virtually counterbalanced cross-effects on the subjects.

The mental task consisted of auditory distinctive reaction-time tasks. In this task, two different one-digit numbers were simultaneously presented via headphones to each ear. With one set of the two numbers randomly arranged for each presentation, the subject was instructed to press a key that indicated the higher number. The concentration required to ignore irrelevant information and to press the correct key as fast as possible resulted in subjective feelings of stress. The inter-trial interval was set at 2.0 sec, and 120 trials were performed at each tilt angle.

Each tilt angle was maintained for 6 min, and measurements were taken within 1 to 5 min. Because of respiratory effects on the HF component, some investigators have recommended controlling the subject's respiration in a certain form (Grossman et al., 1991; Kobayashi, 1998). Radaelli et al. (1994) have reported that controlled breathing does not induce important changes in autonomic modulation during tilting, and according to Ishibashi et al. (1997) HF and LF components are not influenced by respiratory control per se. Therefore, the subjects were instructed to control their respiration at 15 breaths/min (0.25 Hz) following auditory cues via the headphones during the measurement. Under the mental task condition, the cues regulated the timing of task presentation.

The respiratory curve was measured by a hot-wire spirometer (MINATO Medical Instruments, RF-2) attached to a mask worn by the subject. ECG (electrocardiogram) and the respiratory curve were monitored simultaneously.

Data analysis

Data were analyzed on-line with a personal computer with an analog-to-digital conversion rate of 1000 Hz per channel by a 12-bit converter (MICROSCIENCE, ADM-652AT). 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. At each tilt angle, average HR, HF and LF components were computed from the interpolated data within 1 to 5 min. In order to derive the power spectra of HRV, a liner least square fit was first constructed from the data. The fitted line was then subtracted from the data to delete any liner trend. The power spectra were derived from the data using fast Fourier transform (FFT) processing. The HF and LF components were integrated from 0.176 to 0.332 Hz and 0.059 to 0.137 Hz of the power spectra, respectively. In this study, the number of data applied to derive the HF and LF components were 1024 (interpolated at 10 Hz), and the time of data series was 102.4 sec. HF and LF components were computed twice at each tilt angle and the values were averaged.

In this study, we instructed subjects to control only their respiratory cycle. Therefore, HF component might have been confounded by potential alterations in tidal volume, which are known to affect the magnitude of HF (Hirsch and Bishop, 1981; Kobayashi, 1998). To normalize potential respiratory influences, we submitted the HF component based on the findings of Kobayashi (1998).

Statistical analysis

Results were presented as the mean ± S.E. Responses to the mental task procedure and effects of head-up tilt technique were evaluated by two- or three-way analyses of variance (ANOVA). Three-way ANOVA was used to analyze the HR and HRV parameters. The factors were task condition (control and mental task), tilt angle, and subject. Two-way ANOVA was used to analyze mental task performance. The factors were tilt angle and subject. Post-hoc comparisons of means were done by using the Fisher's protected least significant difference. Differences with a probability value of less than 0.05 were considered significant.

Results

Fourteen subjects completed the protocol. In 3 cases, the protocol was not applied because their respiratory cycles were not well regulated.

From the changes in HR during graded head-up tilt with or without mental task (Fig. 1), three-way ANOVA revealed significant effects of tilt angle (F [5, 65] = 139.33, p<0.0001), task condition (F [1, 13] = 9.26, p<0.01) and (tilt angle)/(task condition) interaction (F [5, 65] = 5.77, p<0.001) on HR. The HR was increased by mental tasks until a tilted sine of 0.4 (p<0.01), whereas further increase of tilt angle from 0.6 to 1.0 did not elicit any significant effects.

From the spectral analysis in HRV, although three-way ANOVA revealed significant effects of tilt angle (F [5, 65] = 12.70, p<0.0001) on HF component, task condition and (tilt angle)/(task condition) interaction were not significant (Fig. 2).

From the changes in the LF component during graded head-up tilt with or without mental task (Fig. 3), three-way ANOVA revealed significant effects of tilt angle (F [5, 65] = 24.15, p<0.0001) and (tilt angle)/(task condition) interaction (F [5, 65] = 3.77, p<0.01) on LF component. The LF component was increased by mental tasks until a tilted sine angle of 0.2 (p<0.05) followed by decreases at a tilted sine angle of 1.0 (p<0.05).

Figure 4 shows the changes in LF/HF ratio during graded head-up tilt with or without mental task. Three-way ANOVA manifested significant effects which were elicited by tilt angle (F [5, 65] = 29.91, p<0.0001) and (tilt angle)/(task condition) interaction on the LF/HF ratio (F [5, 65] = 3.11, p<0.05). The LF/HF ratio was increased by mental tasks until a tilted sine angle of 0.2 (p<0.05), whereas insignificant effects were displayed as the tilt angle increased from 0.4 to 1.0.

With regard to the reaction time (RT) data and percentage of correct responses in the mental task (Fig. 5), two-way ANOVA depicted insignificant differences in either RT (F [5, 65] = 0.54, N.S.) or percentage of correct responses (F [5, 65] = 1.28, N.S.) with the tilt angle.

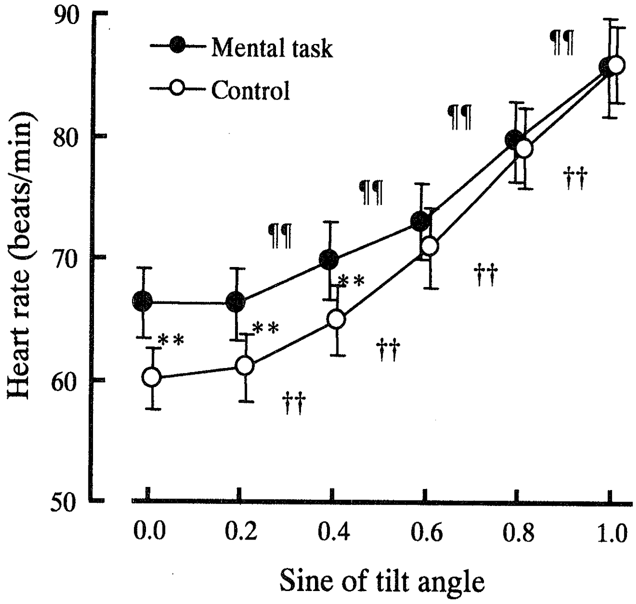

Fig. 1 The changes in heart rate during graded head-up tilt with (closed circle) and without (open circle) mental task. The tilt angle × task condition interaction was significant (p<0.001). Values are means ± S.E. ¶¶ p<0.01, ¶ p<0.05 indicate the significant difference between a values and the previous tilt angle in mental task condition. †† p<0.01, † p<0.05 indicate significant difference between a values and the previous angle in control condition. ** p<0.01, * p<0.05 indicate significant difference between a value of mental task and control condition.

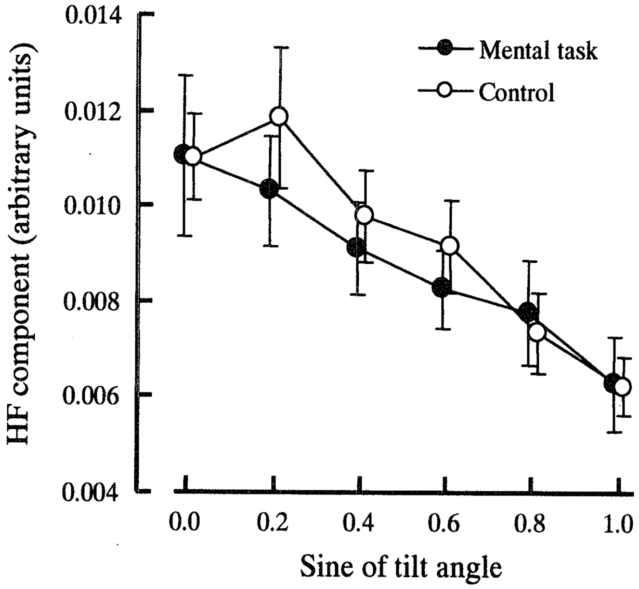

Fig. 2 The changes in high frequency (HF) component during graded head-up tilt with (closed circle) and without (open circle) mental task. Although the effect of tilt angle was significant (p<0.0001), tilt angle × task condition interaction was not. Values are means ± S.E.

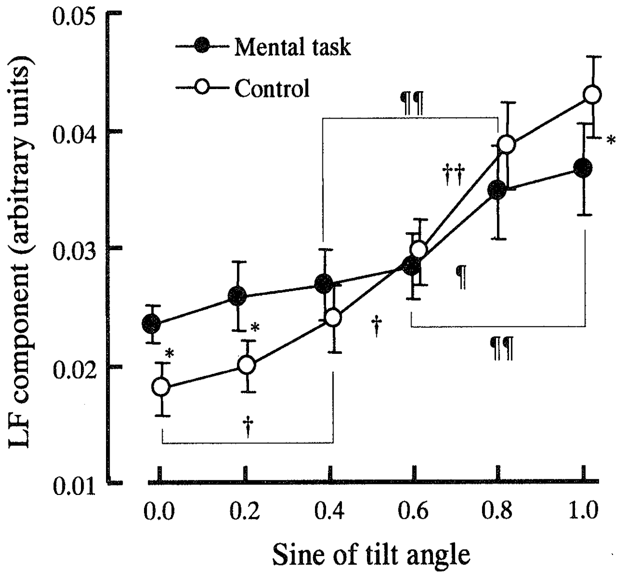

Fig. 3 The changes in low frequency (LF) component during graded head-up tilt with (closed circle) and without (open circle) mental task. Tilt angle × task condition interaction was significant (p<0.01). Values are means ± S.E. Refer to symbols indicating significant differences in Fig. 1.

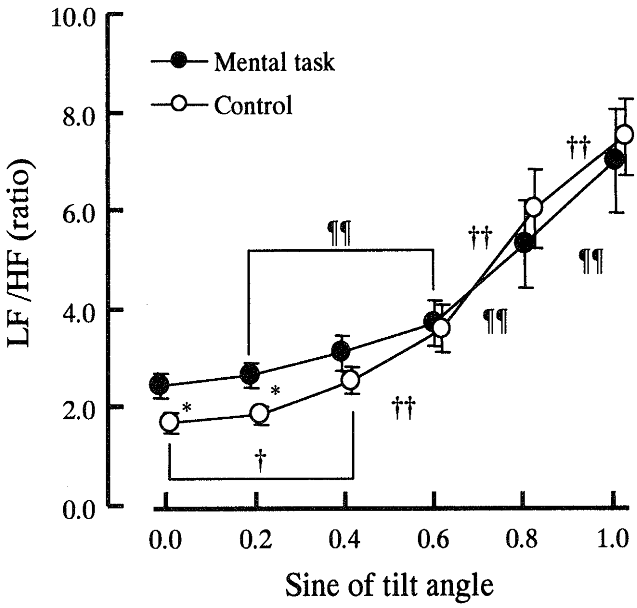

Fig. 4 The changes in LF/HF ratio during graded head-up tilt with (closed circle) and without (open circle) mental task. Tilt angle × task condition interaction was significant (p<0.05). Values are means ± S.E. Refer to symbols indicating significant differences in Fig. 1.

Discussion

In autonomic responses to orthostatic stress, gravity is an essential factor. Its effects on subjects placed on a tilt table can be divided into two components: the force acting along the body axis and another exerting against on the table. The tilted sine angle is proportional to gravity acting along the body axis. With head-up tilt devoid of mental task condition (i.e., control condition), the present study showed marked HRV responses; viz., a progressive decrease in the HF component and an increase in the LF component and LF/HF ratio with the tilted sine angle. Our present findings revealed that the basal autonomic mode against the graded head-up tilt was characterized by reciprocal changes in sympathetic and vagal tones, similar to the results of previous studies using graded head-up tilt or 90° head-up tilt (Bootsma et al., 1994; Kobayashi, 1996; Pagani et al, 1986). Although the present study manifested a progressive increase in the LF component with tilt angle, Mukai and Hayano (1995) have reported that the LF component increases with the tilt angle up to 30° (corresponding to sine of tilt angle 0.5) and decreased slightly, but not significantly, with the tilt angle from 30 to 90° (corresponding to sine of tilt angle 1.0) in graded head-up tilt experiments. It is possible that different autonomic controls to the head-up tilt caused by differences in the protocol of measuring period (Wieling, 1988) are responsible for this discrepancy. Montano et al. (1994) reported a similar result with progressive increases of the relative LF component using different tilt angles in a random order interrupted by changes in the supine position, while validation of the LF component response to graded head-up tilt was emphasized in this study.

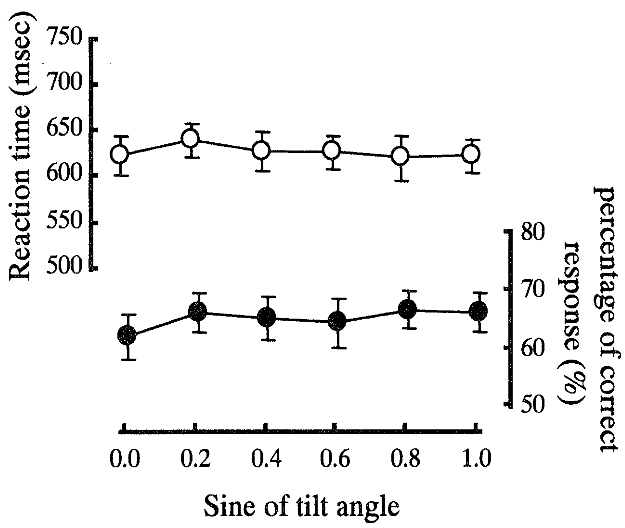

Fig. 5 Reaction time (open circle) and percentages of correct responses (closed circle) in the mental task over sine of tilt angle. Values are means ± S.E.

A linear function between the tilted sine angle and the burst rate of muscle sympathetic nerve activities during graded head-up tilting has been portrayed in a study by Iwase et al. (1987). However, Iwase et al. (1987) have also found that HR increases exponentially with graded head-up tilt (i.e., greater augmentation at higher tilt angle). Furthermore, Mukai and Hayano (1995) have also encountered this nonlinear HR response to gravity, and a similar HR response was confirmed in the present study. The augmented HR responses may reflect the arterial baroreflex, which is specifically activated by high levels of orthostatic stress, while encompass cardiovascular responses mediated consistently by the cardiopulmonary receptor reflex with head-up tilt (Smith and Ebert, 1990). In the present study, this nonlinear response to gravity was also manifested in the LF component and LF/HF ratio. These· results suggested that there were different mechanisms regulating cardiac autonomic responses between lower and higher tilt angles.

Nonetheless, since the RT and percentage of correct responses on the mental task did not change at each tilt angle, it might be implied that the mental load acting as an active stimulus on the subjects was persistently maintained. Under the control condition, the basal autonomic mode against the graded head-up tilt acting as a passive stimulus was characterized by progressive reciprocal changes in sympathetic and vagal tones. It was notable that the autonomic mode was altered by the mental task acting as an active stimulus. However, further studies to investigate the alteration of the autonomic mode against the mental task (as active stimuli) are warranted. In this study, alterations of autonomic mode due to the mental task evoked different autonomic responses at lower and higher tilt angles, respectively. Although our results indicated significant increases of HR due to the mental task at lower tilt angles (tilted sine angles of 0.0–0.4), the changes at higher tilt angles (tilted sine angles of 0.6–1.0) were otherwise. From observations on the LF/HF ratio, there was significant interaction of task condition and tilt angle, while the HF component was not significantly affected by mental task. These results suggest that the increases in HR due to the mental task at lower tilt angles might reflect sympathetic activation. A number of studies have evidenced sympathetic increase in HR due to mental tasks acting as an active stimulus (Cacioppo et al., 1995; Freyschuss et al., 1988; Jørgensen et al., 1990). The present study, however, showed that there were HR increases due to the mental task only at lower tilt angles, suggesting that the alterations of autonomic mode due to the mental task evoked a sympathetic increase in HR only at lower tilt angles.

Furthermore, the LF component depicted a marked response to the mental task, although the HF component, acting as an index of parasympathetic activity, was not affected by the mental task. Contradictory studies have documented increases and decreases of the LF component against the effects of mental task. Langewitz and Rüddel (1989) have concluded that the response of the LF component is a task-specific phenomenon. Notwithstanding the comparable results for the same mental arithmetic task, Láng et al. (1991–92) disputed the effect as an inhibition of the LF component, while Langewitz and Rüddel (1989) reported it as unchanging, and Pagani et al. (1991) as activation. The present study showed increases and decreases of the LF component due to the mental task at lower and higher tilt angles, respectively. This suggests that both changes could be caused by alterations of the autonomic mode and the increase or decrease of LF component might depend on the basal LF component, which is influenced by only passive stimuli. The LF component is a fluctuation of heart rate via the baroreceptor reflex to arterial pressure Mayer waves (Madwed et al., 1989). Since the arterial pressure Mayer waves are presumed to occur in a rhythmic fashion dependent on the sympathetic vasomotor activity (Hyndman et al., 1971; Preiss and Polosa, 1974), the effect on LF component is thought to correlate with both baroreceptor reflex sensitivity and sympathetic activity. Pagani et al. (1986) have reported that arterial pressure Mayer waves are increased by orthostatic stress. In addition, Pagani et al. (1991) have also found that the augmented arterial pressure Mayer waves are induced by mental tasks. Furthermore, a concurrent decline in the baroreceptor reflex sensitivity during mental stress has also been observed (Bernson et al, 1993; Robbe et al., 1987), although the arterial baroreflex is activated by high levels of orthostatic stress (Smith and Ebert, 1990). Therefore, it may be summated that various LF component responses are evoked by a combination of these mechanisms. The results of our experiment clearly showed that the alterations of autonomic mode due to the mental task evoked various responses in the LF component, albeit the underlying mechanisms are not clarified as yet. Furthermore, previous contradictory studies about the LF component against the effects of mental task might be clarified by the interaction of basal autonomic mode and its alteration.

In summary, the basal autonomic mode against the graded head-up tilt as a passive stimulus was characterized by reciprocal changes in sympathetic and vagal tones. Although the HF component was not affected by mental tasks, the alterations of autonomic mode due to the mental task as active stimuli evoked different responses in the LF component and LF/HF ratio at lower and higher tilt angles, as its reflected by the HR changes. All in all, this study suggests that investigations of the basal autonomic mode and relevant alterations provide useful information in physiological assessment of mental task and/or environmental factors derived from integrated assessment of the active and passive stimuli.

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