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Interactive Effects of Task Difficulty and Personality on Mood and Heart Rate Variability

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Abstract Susceptibility to stress would presumably be different from person to person and be affected by the cause of the given stress. The purpose of this study was to investigate the interactive effects of task difficulty and subject's personality on mood and autonomic nervous function when stress was induced experimentally by tasks involving 3 degrees of difficulty: easy (Task A), difficult but controllable (Task B), and very difficult and uncontrollable (Task C). Twelve healthy female subjects volunteered for the experiment. We assessed their personalities using the Minnesota Multiphasic Personality Inventory (MMPI) questionnaire. Mood states were evaluated by a profile of mood states and a frontal alpha laterality ratio (FALR). Autonomic nervous function was estimated by a spectral analysis of heart rate variability (HRV). Repeated measures analysis of variance applied to two groups (low- and high-) divided by a median split of MMPI clinical scales, revealed significant interactions of time course × task difficulty × Hs (hypochondriasis) in FALR and time course × task difficulty × Pt (psychasthenia) in a low-frequency component and in a high-frequency component of HRV, and in FALR. The differences between low- and high-Hs, and low- and high-Pt were more obvious in Task B session. High-Hs group, whose members tend to place overemphasis on existing physical disorders, showed more negative FALR throughout the session, which would indicate prolonged negative mood possibly due to the task. High-Pt group, whose members tend to be susceptible to stress, showed sympathetic predominance during task period and parasympathetic predominance after task period, which would imply a tendency to overreact. These results suggest that task difficulties would affect mood states assessed by FALR and/or autonomic nervous function differently depending on the subject's personality, especially on Hs and Pt. *J Physiol Anthropol Appl Human Sci 23 (3): 81–91, 2004* http://www.jstage.jst.go.jp/browse/jpa

Keywords: MMPI, task difficulty, POMS, FALR, heart rate variability

Introduction

Numerous studies have demonstrated that the autonomic nervous function is modulated by various factors such as exercise (Yamamoto et al., 1991; Sun et al., 1993), postural change (Montano et al., 1994; Ishibashi et al., 1999), emotion (Lang et al., 1990; McCraty et al., 1995), and mental load (Langewitz et al., 1991; Pagani et al., 1991). Moreover, different modes of mental load are known to exert different influences on the autonomic nervous system. As previously reported, mental arithmetic is associated with a reciprocal pattern of sympathetic activation and vagal withdrawal, whereas illusion tasks induce vagal activation in the absence of sympathetic change (Berntson et al., 1996). A different mode of mental task would require different brain functions and trigger different emotional changes, which may result in different patterns of the autonomic response. However, it is difficult to distinguish the responses induced by emotional changes from those induced by cognitive processes or task-related physical movements. Therefore, we developed a joystick apparatus in order to regulate the level of task difficulty while requiring similar cognitive processes or physical movements. Differences in task difficulty would induce different autonomic responses, which would be attributable mainly to emotional changes. Consequently, the joystick apparatus would allow us to identify the responses induced by emotional changes.

In contrast, similar stress tasks were thought to yield consistently similar patterns of the autonomic response (Berntson et al., 1996). However, it is still controversial whether similar tasks with different degrees of difficulty would also cause similar patterns of the autonomic response. Moreover, it is well known that cardiovascular reactivity to mental load differs between subjects displaying different personalities such as type A and type B (Muranaka et al., 1988; Morell 1989; Kamada et al., 1992; Sato et al., 1998). However, the possible relationship between the autonomic response and personality is not yet fully understood. There might be some individual differences in the response pattern to similar tasks, which might have been obscured by analyzing the data from individuals with different personalities together.

Several studies have reported the differences in cardiovascular reactivity to mental load between subjects displaying type A and those showing type B behavior patterns (Muranaka et al., 1988; Morell 1989; Kamada et al., 1992; Sato et al., 1998). However, the classification of type A and B behavior is basically dependent on the risk of coronary heart disease in the US. Behaviors shown in a high-risk group for coronary heart disease are characterized as type A. Whether this classification is similarly applicable to a Japanese population, however, remains controversial. The Minnesota Multiphasic Personality Inventory (MMPI) is designed to provide an objective assessment of some of the major personality characteristics that affect personal and social adjustment (Dahlstrom and Welsh, 1960). Therefore, we thought there might be some correlations between stress susceptibility and MMPI scales, and used MMPI to classify the subject's personality.

Numerous studies have indicated that a spectral analysis of heart rate variability (HRV) is a powerful tool for evaluating the autonomic nervous functions non-invasively (Akselrod et al., 1985; Langewitz et al., 1991; Montano et al., 1994; Pagani et al., 1986; Pagani et al., 1991; Pomeranz et al., 1985). HRV can be divided into two main components by spectral analysis, i.e., a high-frequency component (HF) which corresponds to respiratory sinus arrhythmia (RSA) and reflects parasympathetic nerve activity, and a low-frequency component (LF) which corresponds to Mayer wave related sinus arrhythmia and relates to both sympathetic and parasympathetic nerve activities (Akselrod et al., 1985; Berger et al., 1989; Pomeranz et al., 1985; Pagani et al., 1986; Montano et al., 1994).

The right cerebral hemisphere is thought to play a major role in processing emotional information (Lang et al., 1990; Spence et al., 1996). Negative emotion was reported to be associated with right-sided activation in the frontal regions that causes a reduction in right frontal alpha power (Davidson et al., 1990). Consequently, the frontal alpha laterality ratio (FALR) is thought to be helpful in assessing the emotional state (Field et al., 1998). A more positive ratio is thought to indicate a more relaxed state, while a more negative one a more stressed state. The profile of mood states (POMS) is also a useful tool in periodically estimating mood states.

Therefore, we classified the subject's personality by MMPI, and measured the autonomic nervous functions by a spectral analysis of HRV and mood states by FALR and POMS, in response to tasks with three different degrees of difficulty. The data were analyzed in relation to the subject's personality and the level of task difficulty.

Methods

Subjects

Twelve healthy female college students aged from 20 to 22 participated in this experiment after providing written informed consent. The subjects were asked to abstain from eating, drinking and smoking for at least three hours before the experiment, and to retire no later than midnight of the previous day.

Joystick apparatus

The study apparatus we designed consists of a joystick, a notebook computer equipped with an output for error signals and self-programmed software, which can produce similar tasks involving different levels of difficulty. A task provided by the apparatus is to control a target with the joystick to stay within a track displayed on the notebook computer. Velocity, direction and delay of the target motion relative to the joystick movement are adjustable. When the velocity and direction of the target motion are the same as those of the joystick movement and the delay is close to zero, the task is easy. When the velocity and direction of the target motion are quite different from those of the joystick movement and the delay is great, the task is very difficult. By adjusting the velocity, direction and delay of the target in the way mentioned above, it was expected that the apparatus would create tasks requiring a similar cognitive process or movement while presenting mental loads with different levels of difficulty.

We employed three experimental settings in this study to provide mental loads with three different levels of difficulty: easy (Task A), difficult but controllable (Task B), and very difficult and uncontrollable (Task C).

Procedures

The experiments involved three sessions, one for each of the above 3 task levels (Task A session, Task B session and Task C session). Each session consisted of five parts: a pre-task POMS period of several minutes; another pre-task period of 10 minutes; a 19-minute task period for performing a given task (five 3-minute trials divided by 4 one-minute intervals); a post-task POMS period of 5 minutes, and another post-task period of 15 minutes. The three sessions were performed at about the same time on three consecutive days to minimize any circadian rhythm effect (Malliani et al., 1991). The order of the sessions was counterbalanced to avoid the effect of adaptation.

Having previously completed MMPI questionnaires to evaluate their personality characteristics, the subjects entered the room and were asked to fill out POMS questionnaires to ascertain their current mood for an evaluation of their basal mood state. Each subject sat upright on a chair in front of the joystick task apparatus. Disc electrodes were attached for chest electrocardiograms (ECG) with CM5 leads and for electroencephalograms (EEG) at F3, F4 of the 10/20 system with corresponding earlobe references. A thermistor for detecting respiration was also attached just under one nostril. ECG, EEG and respiration curves were recorded during the 10-minute pre-task period, the 19-minute task period including inter-trial intervals of 4 minutes and the 15-minute post-task period. Error signals were also recorded during the task period. Data were stored on a DAT recorder (TEAC RD-111T, Tokyo, Japan). Subjects were asked to keep quiet, avoiding any disruptive movements of their heads or hands throughout the experiments. They were also asked to keep their eyes closed but not to fall asleep during the pre-task period, the inter-trial intervals, and the post-task period for EEG recording. Just after accomplishing each task, they were asked to fill out POMS questionnaires describing their mood while performing the tasks for an evaluation of whatever mood states were induced by the task (post-task POMS period).

Data analysis

MMPI data were manually scored with hand-scoring stencils and summed for ten clinical scales: Hs (hypochondriasis), D (depression), Hy (hysteria), Pd (psychopathic deviate), Mf (masculinity-femininity), Pa (paranoia), Pt (psychasthenia), Sc (schizophrenia), Ma (hypomania) and Si (social introversion) (Dahlstrom and Welsh, 1960). These raw scores were converted into T-scores according to a new Japanese version of the MMPI manual (Tanaka et al., 1993) for parametric statistical analysis.

POMS data were summed to generate six sub-scales: T-A (tension and anxiety), D (depression and dejection), A-H (anger and hostility), V (vigor), F (fatigue) and C (confusion). These summed raw scores were converted into T-scores for parametric statistical analysis according to the POMS manual (Yokoyama and Araki, 1994). We also calculated negative mood score (NMS) by averaging T-A, D, A-H, F, C scores, and stress index (SI) by subtracting the Vigor score from NMS.

Error signals were recorded when the target was off the track. Error scores were manually calculated by adding up points when the target ran off the track, and when it lasted more then a second we added one more point for every second beyond the first. For example, if the target left the track and stayed off for 0.5 second, we scored it 1 point; and when it stayed off for 1.5 seconds we scored it 2 points, and 3 points for 2.5 seconds. DAT-tapes were played back offline, and ECG data were digitized at a sampling frequency of 1 kHz on a personal computer equipped with a 12-bit analog-digital converter (ADTM-98, Canopus, Kobe, Japan). After detecting every R-wave peak, consecutive R-R intervals on the ECG were calculated, excluding ectopic beats and abrupt discharges in R-R intervals. Spectral analysis was applied to the time series data of R-R intervals for each minute, using the maximum-entropy method (MemCalc Version 2.5, Suwa Trust) (Ohtomo et al., 1994). Although more than three minutes of data would be required for a fast Fourier transform (FFT), one minute of data sufficed for the maximum-entropy method used in the present study. After calculating the power-spectral density, the magnitude of the power for HRV was obtained by measuring the areas under the spectral density curves. The values were divided into two major bands, LF (0.04–0.15 Hz) and HF (0.15–0.4 Hz) domains. In addition, normalized units were obtained by dividing the power of a given component by the total power (from which a very low-frequency component had been subtracted) and multiplying by 100. The normalized units could emphasize the controlled and balanced behavior of the two branches of the autonomic nervous system (Pagani et al., 1986; Malliani et al., 1991). The normalization has been demonstrated to minimize the effect of the changes in total power on the values of LF and HF components (Malliani et al., 1991; Pagani et al., 1986; Montano et al., 1994; Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996). We considered HF as an index of parasympathetic nervous function and LF as a marker of sympathetic modulation (Malliani et al., 1991; Pagani et al., 1986). These HRV indices were represented in normalized units in the present study.

EEG data were digitized at a sampling frequency of 200 Hz on the personal computer and spectrally analyzed for 40.96 seconds of every minute using FFT with a Hanning window. The alpha band was defined as 8 to 12 Hz. Frontal alpha laterality ratios (FALR) were calculated by dividing the difference between right and left frontal alpha powers by the sum of these powers (F4−F3/F4+F3). The EEG data during trials were excluded from the analysis because of the large noise caused by performing tasks with eyes open.

Five-minute data just prior to the task period were averaged and used to establish pre-task basal activity (pre). Three-minute data during each trial were also averaged and represented as trial 1, 2, 3, 4 and 5. Data for the inter-trial intervals were represented as int 1, 2, 3 and 4. Fifteen-minute data for the post-task period were grouped into 5 three-minute segments, averaged, and represented as post 1, 2, 3, 4 and 5.

Statistical analysis

The subjects were divided into two groups by a median split according to the scores of MMPI clinical scales. Effects of task and task × MMPI scales were examined using time (pre, during and/or post task period) and time × group (low and high groups of given MMPI clinical scales) repeated measures analysis of variance (repeated measures ANOVA) for each session (Task A, B and C session). To clarify the interaction between task difficulty and personality on the time course of the indices, task (Task A, B and C) × time and task × time × group repeated measures ANOVA were conducted, thereafter. We also calculated Pearson's correlation coefficients among the HRV indices, FALR and POMS scores to assess the relationships among them. Statistical analysis was performed on a personal computer using Statview Ver. 5.0 (HULINKS), and differences with a probability value of less than 0.05 were considered significant.

Results

Error scores

Figure 1 shows error scores per trial. Task A produced only a few error scores throughout the task, whereas Task B caused more error scores which became lower with the progress of the trial, and Task C caused the most scores which remained fairly

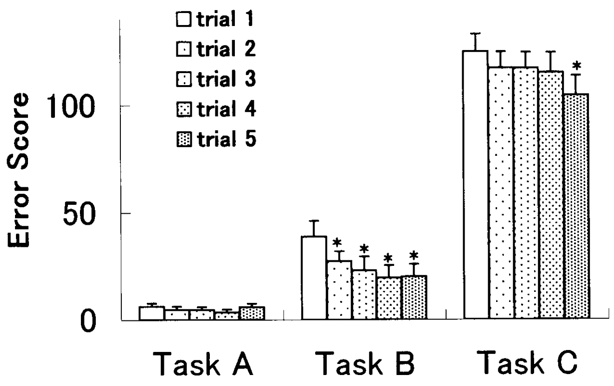

Fig. 1 Error scores during each trial of Tasks A, B and C. All values are represented as mean + S.E. (n=12). Task A shows low error scores, whereas Task B shows moderately higher scores, and Task C shows the highest scores throughout the task period. * denotes significant difference from trial 1 (p<0.05).

consistent throughout the task except for trial 5 during which a significant decrease in error scores occurred compared with trial 1.

Effects of task, task difficulty and personality on POMS

Table 1 shows the effects of time and task × time interactions on POMS scores revealed by repeated measures ANOVA. No significant time main effect was observed for T-A, A-H and C across the three task sessions (Task A, B and C sessions). In Task A session, significant time effects were observed for D (F(1,11)=6.254, p=0.0295), V (F(1,11)=4.87, p=0.0496) and SI (F(1,11)=4.963, p=0.0477). In Task B session, significant time effects were observed for NMS (F(1,11)=5.299, p=0.0419) and SI (F(1,11)=6.040, p=0.0318). In Task C session, significant time effects were observed for F (F(1,11)=5.324, p=0.0415). No task × time interactions were observed for any POMS scores. That is, the observed time effects were not significantly different among the three task sessions.

Table 1 also shows the interactions of time × group and task × time × group on POMS scores. In Task A session, significant time × group interactions were observed for T-A when subjects were divided into low and high groups by Mf score (F(1,10)=6.467, p=0.0292), for V when divided by Pa score (F(1,10)=6.710, p=0.0269), for F when divided by Hs score (F(1,10)=7.811, p=0.0190) and by Pa score (F(1,10)=9.856, p=0.0105), and for SI when divided by Pa score (F(1,10)=6.641, p=0.0276). In Task B session, significant time × group interactions were observed for T-A when divided by Hs score (F(1,10)=7.840, p=0.0188), by Mf score (F(1,10)=13.474, p=0.0043), and by Sc score (F(1,10)=6.101, p=0.0331). In Task C session, significant time × group interactions were observed for V when divided by Pa score (F(1,10)=9.050, p=0.0132) and for SI when divided by Pa score (F(1,10)=5.050, p=0.0484). Significant task × time × group interactions were not observed for any POMS scores. That is, the observed time × group interactions were not significantly different among the three task sessions.

Effects of task, task difficulty and personality on physiological indices

Table 2 shows the effects of time and task × time interactions on physiological indices (HRV and FALR) revealed by repeated measures ANOVA. No significant time main effect was observed for FALR across the three task sessions. In Task A session, significant time effects were observed for LF (F(14,154)=2.661, p=0.0017) and for HF (F(14,154)=3.428, p<0.0001). In Task B session, no significant time effects were observed for any indices. In Task C session, significant time effects were observed for LF (F(14,154)=3.661, p<0.0001). Significant task × time interactions were observed for LF (F(28,308)=2.743, p<0.0001) and for HF (F(28,308)=1.741, p=0.0133), but not for FALR. Thus, the observed time effects were significantly different for LF and HF, but not for FALR among the three task sessions. Figure 2 shows the time courses of LF, HF and FALR. Task-trials generally evoked LF increase and/or HF decrease. Differences of these HRV indices among Task A, B and C sessions appear larger during inter-trial intervals than during the actual trials.

Table 2 also shows the interactions of time × group and task × time× group on physiological indices. In Task A session, significant time× group interactions were observed for LF when subjects were divided into low and high groups by D score (F(14,140)=2.324, p=0.0066) and by Si score (F(14,140)=2.170, p=0.0117), for HF when divided by D score (F(14,140)=2.325, p=0.0065) and by Si score (F(14,140)=2.269, p=0.0081). In Task B session, significant time× group interactions were observed for LF when divided by Hs score (F(14,140)=1.967, p=0.0245), for HF when divided by Hs score (F(14,140)=2.216, p=0.0099) and by Pt score (F(14,140)=2.681, p=0.0017), and for FALR when divided by Hs score (F(14,140)=2.376, p=0.0194) and by Pt score (F(14,140)=2.883, p=0.0053). In Task C session, significant time× group interactions were observed for FALR when divided by Pt score (F(14,140)=2.052, p=0.0423). Significant task× time× group interactions were observed for LF when divided by Pt score (F(28,280)= 1.854, p=0.0068), for HF when divided by Pt score (F(28,280)=1.659, p=0.0224), for FALR when divided by Hs score (F(18,180)= 2.282, p=0.0035) and by Pt score (F(18,180)= 1.811, p=0.0277), but not when divided by D score and by Si score. Therefore, the observed time× group interactions were significantly different for LF, HF and FALR among the three task sessions when divided by Pt, and for FALR when divided by Hs score. The other clinical scales showed neither significant time × group interactions nor significant task × time × group interactions.

Differences between low and high groups of Hs

Figure 3 shows the time courses of LF, HF and FALR of the

Table 1 Effects of time, time × group, task × time and task × time × group on POMS (Profile of Mood States) scores

		POMS scores							
		T-A	**D**	**A-H**	**V**	**F**	**C**	**NMS**	**SI**
Task A	Time	n.s.	(p=0.0295)	n.s.	(p=0.0496)	n.s.	n.s.	n.s.	(p=0.0477)
	Time × group	×Mf (p=0.0292)	n.s.	n.s.	×Pa (p=0.0269)	×Hs (p=0.0190) ×Pa (p=0.0105)	n.s.	n.s.	×Pa (p=0.0276)
Task B	Time	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	(p=0.0419)	(p=0.0318)
	Time × group	×Hs (p=0.0188) ×Mf (p=0.0043) ×Sc (p=0.0331)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Task C	Time	n.s.	n.s.	n.s.	n.s.	(p=0.0415)	n.s.	n.s	n.s
	Time × group	n.s.	n.s.	n.s.	×Pa (p=0.0132)	n.s.	n.s.	n.s.	×Pa (p=0.0484)
Task × time		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Task × time × group		n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

Time, group and task indicate a time course (a change from pre- to post-task) of each score, low and high groups divided by MMPI clinical scales, and Task A, B and C sessions, respectively. T-A: Tension-Anxiety; D: Depression-Dejection; A-H: Anger-Hostility; V: Vigor; F: Fatigue; C: Confusion; NMS: negative mood score; SI: stress index; n.s.: not significant. Only scales that had significant effects, and probability values are shown where significant ($p<0.05$).

Table 2 Effects of time, time × group, task × time and task × time × group on physiological indices (HRV, FALR)

		Physiological indices		
		LF	HF	FALR
Task A	Time	(p=0.0017)	(p<0.0001)	n.s.
	Time × group	× D (p=0.0066) × Si (p=0.0117)	× D (p=0.0065) × Si (p=0.0081)	n.s.
Task B	Time	n.s.	n.s.	n.s.
	Time × group	× Hs (p=0.0245)	× Hs (p=0.0099) × Pt (p=0.0017)	× Hs (P=0.0194) × Pt (p=0.0053)
Task C	Time	(p<0.0001)	n.s.	n.s.
	Time × group	n.s.	n.s.	× Pt (p=0.0423)
Task × time		(p<0.0001)	(p=0.0133)	n.s.
Task × time × group		× Pt (p=0.0068)	× Pt (p=0.0224)	× Hs (p=0.0035) × Pt (p=0.0277)

Time, group and task indicate a time course of each index, low and high groups divided by MMPI clinical scales, and Task A, B and C sessions, respectively. n.s.: not significant. Only scales that had significant effects, and probability values are shown where significant ($p < 0.05$).

low- and high-Hs groups. In Task A session, LF showed a trend to increase, while HF to decrease during the task period, and there was little difference in the time courses of LF and HF between the low- and high-Hs groups. FALR changed little in both groups. In Task B session, LF of high-Hs group showed a gradually increasing trend, whereas that of low-Hs group showed a trend to decrease, during the post-task period. Trends of HF in both groups were almost the opposite of those of LF. High-Hs group showed a consistently lower FALR than low-Hs group throughout the session except for int 3. In Task C session, trends of LF in both groups fluctuated during the task period, and almost returned to the basal level after task. HF showed decreasing trends during the task period, thereafter, almost returned to the basal level after task in both groups. FALR did not show obvious changes in either group. The differences in LF, HF and FALR between both groups were clearly larger in Task B session as revealed statistically by repeated measures ANOVA.

Differences between low and high groups of Pt

Figure 4 shows the time courses of LF, HF and FALR of the low- and high-Pt groups. In Task A session, LF showed a trend to increase, while HF to decrease during the task period in both groups. FALR changed little throughout Task A session in both groups. In Task B session, LF of high-Pt showed an increasing trend during the 2nd half of the task period and a decreasing trend after task, whereas that of low-Pt showed an increasing trend during the post-task period. However, the repeated measures ANOVA showed no significant difference in their trends. HF of high-Pt displayed a decreasing trend during the 2nd half of the task period and an increasing trend after task, whereas that of low-Pt showed a trend to increase during the task period and to decrease after task. FALR of high-Pt showed a trend to increase during the post-task period, whereas that of low-Pt remained almost stable. In Task C session, LF and HF fluctuated during the task period, and returned to the basal level after task in both groups. FALR remained almost stable throughout the session in both groups with a slight but statistically significant difference in the repeated measures ANOVA as shown in Table 2. Briefly, high-Pt exhibited increased LF with decreased HF during the 2nd half of the task period and decreased LF with increased HF and FALR during the post-task period, in Task B session. The differences of these indices between low- and high-Hs were less in Task A and C sessions.

Correlation of HRV, FALR and POMS

LF was not significantly correlated with any sub-scales of POMS. In contrast, HF was negatively correlated with T-A, D, A-H and NMS ($r=-0.28$, $p<0.05$; $r=-0.27$, $p<0.05$; $r=-0.29$, $p<0.05$ and $r=-0.25$, $p<0.05$, respectively). HF also showed a significant positive correlation with FALR ($r=0.19$, $p<0.01$). There was no significant correlation between FALR and POMS sub-scales.

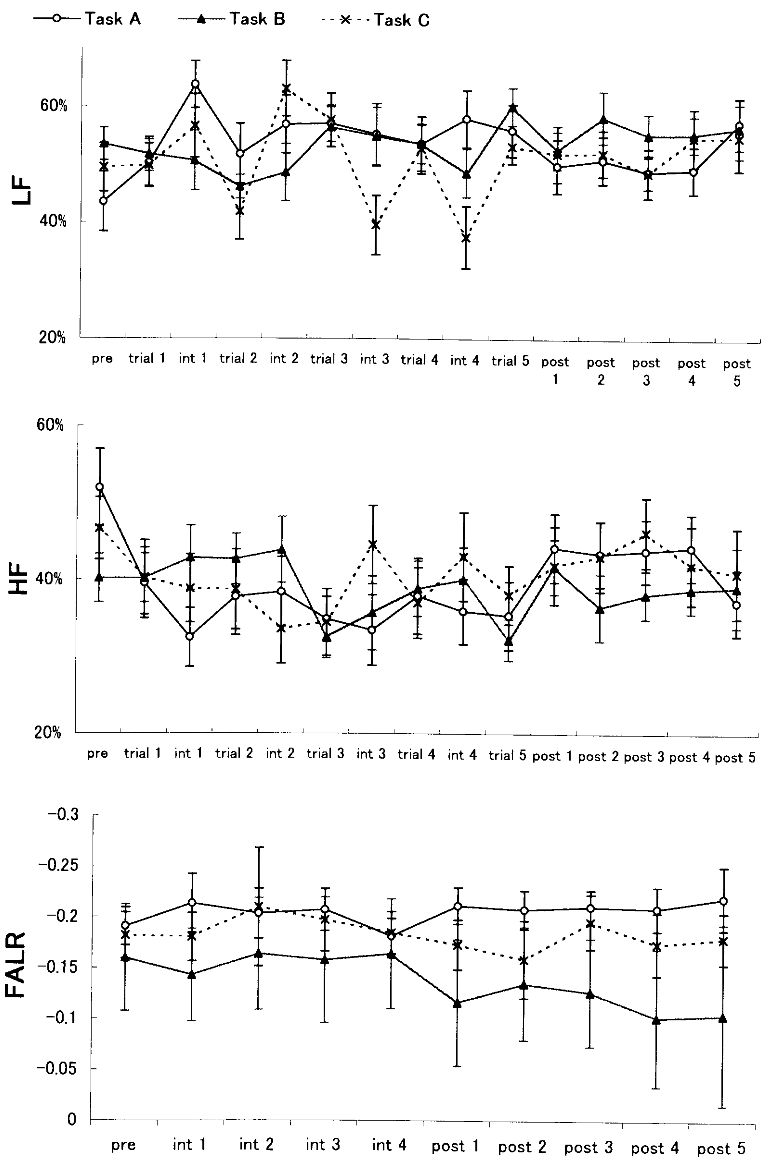

Fig. 2 Low-frequency component (LF), High-frequency component (HF), and frontal alpha laterality ratio (FALR) during the sessions. LF and HF components are represented in normalized units. pre: pre-task period (for 5 min just prior to task); trials 1, 2, 3, 4, 5: each 3-min trial during task period; int 1, 2, 3, 4: 1st, 2nd, 3rd and 4th inter-trial intervals; and post 1, 2, 3, 4, 5: each 3-min segment during post-task period. All values are represented as mean±S.E. (n=12).

Respiratory frequencies

Respiratory frequencies of all subjects were over 10 cycles per minute (i.e., over 0.15 Hz) throughout the experiments. Therefore, the respiratory frequencies did not overlap with the frequency domains of LF component. Those frequencies significantly increased during trials, but were not different among the tasks, as shown in Fig. 5.

Discussion

Validity of task difficulty setting

People usually suffer much stress when encountering great difficulties and feel them manageable only with maximum effort. On the contrary, the stress would be reduced, if they felt that they were powerless to overcome the difficulties even with maximum effort and instead had to accept the situation. In the present study, we had expected Task B to be an instance of the former and Task C of the latter. Error scores clearly revealed the discriminative difficulties of Task A, B and C. Task A would be readily achieved with a slight expenditure of the effort and attention since error scores were lower then those of the other two tasks. Task B would have required a greater expenditure of the effort and attention but proved to be achievable when those requirements were met. Error scores in Task B showed the gradual improvement of skill to indicate controllability with effort. Task C turned out to be difficult and fairly uncontrollable, because of much higher error scores than in the other two tasks, although a significant decrease in error

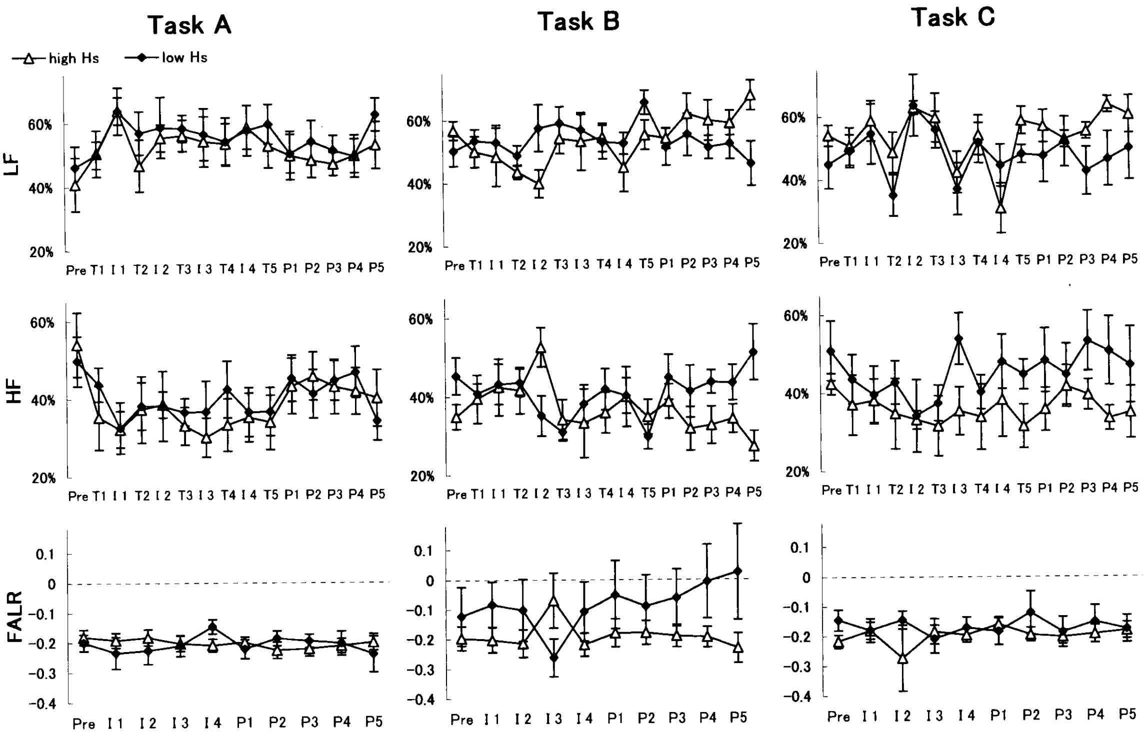

Fig. 3 LF, HF and FALR of low- and high-Hs groups during each session. All values are represented as mean ± S.E. (n=6). The differences of LF, HF and FALR between low- and high-Hs groups are clearly larger in Task B session. T1, 2, 3, 4, 5: trial 1, 2, 3, 4, 5; I1, 2, 3, 4: int 1, 2, 3, 4; and P1, 2, 3, 4, 5: post 1, 2, 3, 4, 5. See text for details.

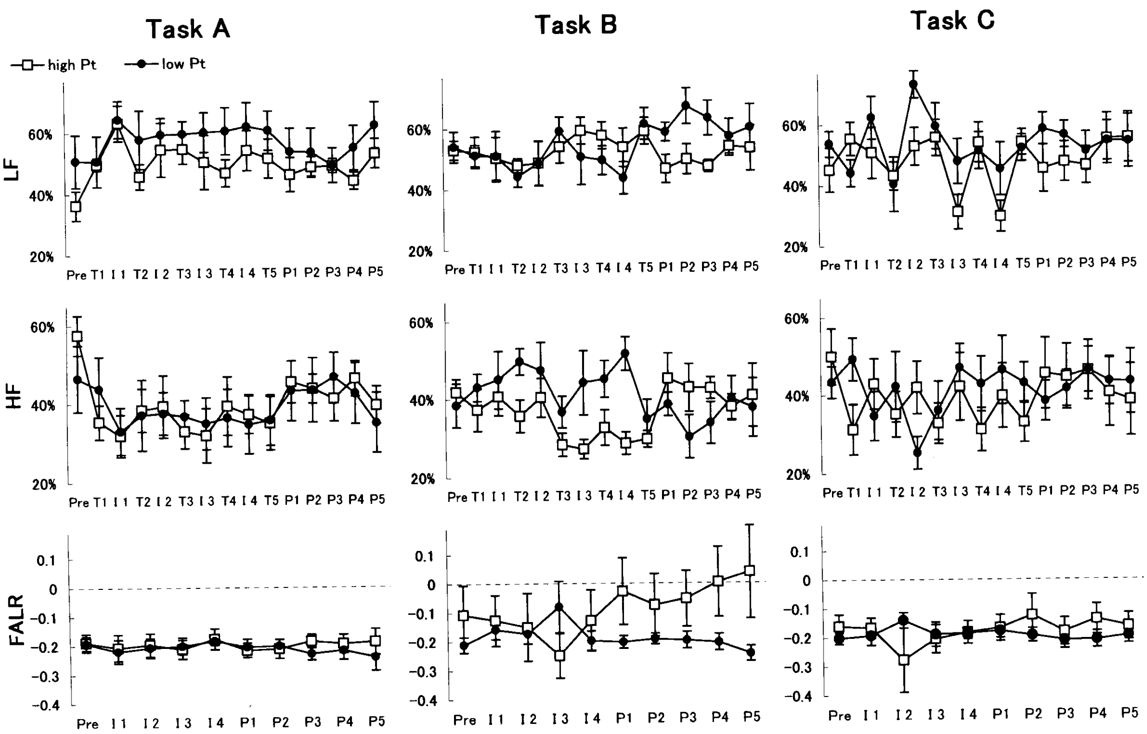

Fig. 4 LF, HF and FALR of low-and high-Pt groups during each session. All values are represented as mean±S.E. (n=6). The differences of these indices between low- and high-Pt groups are less in Task A and C sessions. T1, 2, 3, 4, 5: trial 1, 2, 3, 4, 5; I1, 2, 3, 4: int 1, 2, 3, 4; and P1, 2, 3, 4, 5: post 1, 2, 3, 4, 5. See text for details.

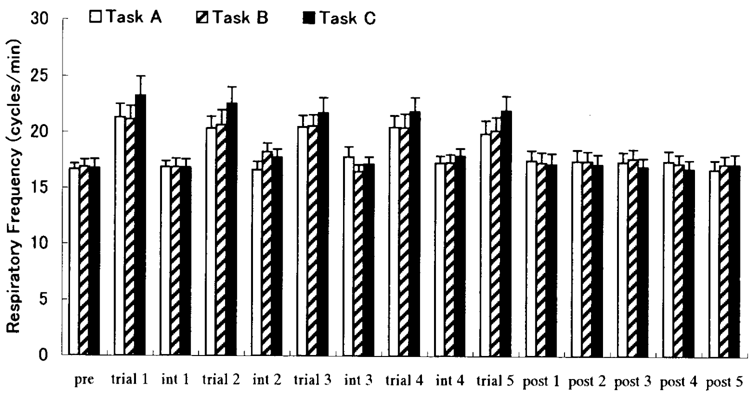

Fig. 5 Respiratory frequency during each session. Each value is represented in terms of cycles per minute. pre: pre-task period (for 5 min just prior to task); trials 1, 2, 3, 4, 5: each 3-min trial during task period; int 1, 2, 3, 4: 1st, 2nd, 3rd and 4th inter-trial intervals, respectively. post 1, 2, 3, 4, 5: each 3-min segment during post-task period. All values are represented as mean + S.E. (n=12). Respiration during each trial is significantly more frequent compared to other segments in each session.

scores was seen in trial 5. Thus, we considered that we could apply the tasks with three different levels of difficulty to the subjects.

Usefulness of joystick apparatus

We introduced the joystick apparatus to provide mental workloads with different levels of difficulty, by changing the system parameters. The autonomic nervous system can be modulated by various factors, such as the cognitive process, motor activity and mental state. The cognitive process or task-related motion per se seems to have some effects on autonomic functions. Stress or tension is thought to induce sympathetic activation and/or parasympathetic withdrawal, which corresponds to LF increase and/or HF decrease. Therefore, the HRV responses during trials would be modulated by a task-related cognitive process, physical activity and associated mental state, whereas those during inter-trial intervals would reflect the mental state. Respiratory frequency is also known to have a considerable effect on HF (Kageyama et al., 1996; Kobayashi, 1998). The frequency increase sometimes causes a decrease in tidal volume, which would consequently result in a reduction in HF power. Since the respiratory frequencies during trials in the present study were significantly higher than those during the pre-task, inter-trial intervals and post-task periods, the HF during each trial could have been confounded by the effects of respiration as well as by those of task-related movements. The smaller differences of LF and HF among Tasks A, B and C during trials would imply that each task would require a nearly equivalent cognitive process and motor activity and that the influence was considerably larger than that of the mental state. This may be supported by the fact that the increases in the respiratory frequency during trials did not differ in relation to task difficulty. In contrast, larger differences of the HRV indices during inter-trial intervals might mean that the joystick apparatus could possibly induce different emotional states. Consequently, the apparatus appears suitable for simulating some stress conditions, minimizing interferences that would be induced by the task performance itself.

Correlations among HRV, FALR and POMS

Mood states were evaluated by both POMS and FALR in the present study. POMS would be suitable to know the contents of mood, whereas FALR would be suitable to assess instantaneous mood states as a numerical value. In the present study, HF showed significant negative correlations with T-A, D, A-H and NMS. Moreover, HF also showed a significant positive correlation with FALR. These results suggest that a negative mood would induce parasympathetic withdrawal, while a positive mood would induce parasympathetic activation. Although no direct correlation was observed between FALR and POMS sub-scales, these results suggest that mood states correlate with parasympathetic function.

Interaction between task difficulty and personality on mood

The responses of some POMS scores were influenced by several MMPI clinical scales, when analyzed separately for each task session. Significant task × time × group interactions, however, were not observed by the repeated measures ANOVA when analyzed including task difficulty as a within-subject factor. Furthermore, a more effective MMPI scale seemed to be somewhat different among the POMS scores, as well as among the three task sessions. Although each scale had significant effects in each session, the effects were not significantly different among the three task sessions.

The results for FALR were fairly different from those for POMS. Responses of FALR were also influenced by several MMPI clinical scales when analyzed separately for each task session, but the scales that had significant time × group interactions were different from those for POMS except for Hs. Task × time × group interaction in the repeated measures ANOVA did not reveal any significance for POMS, but revealed significance for FALR when subjects were divided into two groups by Hs or Pt score. This discrepancy between POMS and FALR might come from the differences in their properties mentioned above. We considered Hs and Pt as the important scales in terms of task difficulty and personality interactions on mood, though it was revealed only by FALR.

Interaction between task difficulty and personality on autonomic nervous function

The autonomic nervous function was evaluated using spectral analysis of HRV. The responses of each HRV index were influenced by D and Si in Task A session, and by Hs and Pt in Task B session when analyzed separately for each task session. Task × time × group interaction in the repeated measures, ANOVA however, revealed significance only when subjects were divided into two groups by Pt score. Thus, D, Si and Hs did not have significantly different effects among the three task sessions, though they had significant effects in Task A or B sessions. Hence, we considered Pt as the important scale in terms of task difficulty and personality interactions on autonomic nervous function.

Responses of low and high groups of Hs

According to the MMPI handbook and manual, a person who scores low on scale Hs tends to be alert, quick to adjust, at ease in oral expression and out-going, whereas those who score high tend to be responsive, modest, orderly, slow to adjust, lack ease in oral expression and place overemphasis on existing physical disorders (Dahlstrom and Welsh, 1960; Tanaka et al., 1993). High-Hs subjects exhibited more sympathetic predominance than low-Hs during the post-task period in Task B session, which may suggest that the influence of the task would be delayed or prolonged in high-Hs group. The tendency to be slow to adjust might be a possible cause of this delayed or prolonged responses. More negative FALR seen throughout Task B session in high-Hs group may mean the prolonged stress condition, which might be related to the tendency to overemphasize the existing physical disorders.

Responses of low and high groups of Pt

According to the MMPI handbook and manual, a person who scores low on the Pt scale tends to be cheerful, alert, self-confident and balanced, whereas those who score high tend to be sensitive, prone to worry, emotional, high-strung and susceptible to stress (Dahlstrom and Welsh, 1960; Tanaka et al., 1993). In Task B session, high-Pt subjects showed more sympathetic predominance during the task period possibly due to high tension and more parasympathetic predominance during the post-task period possibly due to release from the task, which might mean a tendency to overreact in the high-Pt group. Fig. 4 shows a clear difference in FALR at the post-task period of Task B session between low- and high-Pt groups. Increased FALR in high-Pt group may indicate a more relaxed feeling possibly caused by their release from the demanding Task B, which would be consistent with the results of HRV. This easy susceptibility to stress revealed by physiological indices in high-Pt subjects would be consistent with their tendency to be sensitive, prone to worry and susceptible to stress indicated by MMPI.

Conclusion

We examined the acute interactive effects of task difficulty and personality on a subject's mood and autonomic nervous function. Hs and Pt had significant interactions with task difficulty on the responses induced by the tasks. These effects of Hs and Pt were more apparent when Task B, which requires a high level of attention and effort, was applied.

The high-Hs group exhibited sympathetic predominance during the post-task period and showed negative FALR throughout the session, which may suggest that the influence of the task would be delayed or prolonged. The high-Pt group showed a more sympathetic predominance during the task period and more para-sympathetic predominance after the task period with the positive FALR compared with the low-Pt group. This result may suggest a tendency to over-react in the high-Pt group, since the influence of the task was excessive and transient in this group.

Taken together, these results mentioned above suggest that task difficulties would affect mood states assessed by FALR and/or autonomic nervous function differently, depending on the subject's personality, especially on Hs and Pt. When we study the stress response using physiological indices, we should pay attention to the subjects' personality that might affect and confound the responses, as well as to what task and indices should be employed for the purpose of a study.

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