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Effects of Reward and Punishment on Task Performance, Mood and Autonomic Nervous Function, and the Interaction with Personality

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Abstract The effects of reward and punishment are different, and there are individual differences in sensitivity to reward and punishment. The purpose of this study was to investigate the effects of reward and punishment on task performance, mood, and autonomic nervous function, along with the interaction with personality. Twenty-one healthy female subjects volunteered for the experiment. The task performance was evaluated by required time and total errors while performing a Wisconsin Card Sorting Test. We assessed their personalities using the Minnesota Multiphasic Personality Inventory (MMPI) questionnaire, and mood states by a profile of mood states. Autonomic nervous function was estimated by a spectral analysis of heart rate variability, baroreflex sensitivity, and blood pressure. Repeated measures analysis of variance (ANOVA) revealed significant interaction of condition×time course on mood and autonomic nervous activity, which would indicate a less stressed state under the rewarding condition, but revealed no significant interaction of condition×time course on the task performance. The interactions with personality were further analyzed by repeated measures ANOVA applying the clinical scales of MMPI as independent variables, and significant interactions of condition×time course×Pt (psychasthenia) on task performance, mood, and blood pressure, were revealed. That is, the high Pt group, whose members tend to be sensitive and prone to worry, showed gradual improvement of task performance under the punishing situation with slight increase in systolic blood pressure, while showed no improvement under the rewarding situation with fatigue sense attenuation. In contrast, the low Pt group, whose members tend to be adaptive and self-confident, showed gradual improvement under the rewarding situation. Therefore, we should carefully choose the strategy of reward or punishment, considering the interaction with personality as well as the context in which it is given. *J Physiol Anthropol 28(4): 181–190, 2009* http://www.jstage.jst.go.jp/browse/jpa2
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Introduction

Reward and punishment systems in the brain are known to motivate most behaviors of an animal, including human beings. An animal generally learns and behaves to gain reward or to avoid punishment. The effects of reward and punishment, however, vary depending on the situation under which it is given, on the mood at the given moment and on the personality characteristic of the person (or animal) who receives it, or the interaction among them. Dikman and Allen (2000) indicated that a low socialization person would be more sensitive to reward than to punishment, using error-related negativity generated in response to error monitoring. Matthys et al. (2004) suggested through the measurement of performance in a door-opening task that boys with oppositional defiant disorder are related to low punishment sensitivity. Boksem et al. (2006b) found that persons scoring high on the behavioral inhibition system scale displayed larger error-related negativity amplitudes, while persons scoring high on the behavioral activation system scale displayed larger error positivity amplitudes, which reflects individual differences in reward and punishment sensitivity. Thus, there are individual differences in sensitivity to reward and/or punishment. In the field of teachers and schools, it is frequently an issue whether praising (rewarding strategy) or reproving children (punishing strategy) is better for students' development. The strategy should be adequately chosen according to the context in which it is taken or to the personality characteristic of each student. However, there are as yet not enough studies about interaction with personality.

Reward- and/or punishment-related information is considered to be processed in the prefrontal-striatal loop, including the dorsal anterior cingulate cortex, cingulate motor area, orbital and ventral prefrontal cortices, dorsolateral prefrontal cortex, ventral striatum, and so on (Shidara and Richmond, 2002; O'Doherty et al., 2003; Bishop et al., 2004; Tanaka et al., 2004). The Wisconsin Card Sorting Test (WCST) is a test widely used to assess executive function or cognitive flexibility and is believed to be processed mainly in the dorsolateral prefrontal cortex (Heaton et al., 1993; Nagahama et al., 1996; Mansouri et al., 2006). Reward/punishment processing and the WCST, then, may share some subdivisions of the prefrontal cortex, and reward and punishment may be expected to have some influence on WCST performance. We therefore used the WCST, which provided an objective assessment of dorsolateral prefrontal cortex function, as an experimental task.

Monetary gains and losses are often used for an emotion study because they are believed to effectively activate reward and punishment systems (Gehring and Willoughby, 2002; Matthys et al., 2004; Boksem et al., 2006a). We therefore, adopted monetary gain and loss combined with words of praise and reproof as rewarding and punishing stimuli, respectively.

Emotions induced by reward- or punishment-related stimuli would involve autonomic nervous system activation (Yang et al., 2007; Bradley et al., 1996). The profile of mood states (POMS) is a well-known useful tool to estimate mood states repeatedly. A spectral analysis of heart rate variability (HRV) is indicated to be a powerful tool for evaluating autonomic nervous functions noninvasively (Akselrod et al., 1985; Langewitz et al., 1991; Montano et al., 1994; Pagani et al., 1986; Pagani et al., 1991; Pomeranz et al., 1985). Baroreflex sensitivity as well as blood pressure is also known to vary depending on mental state (Steptoe and Sawada, 1989). The Minnesota Multiphasic Personality Inventory (MMPI) questionnaire 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 classified the subject's personality by MMPI, and measured autonomic nervous function by a spectral analysis of HRV, baroreflex sensitivity, and blood pressure (BP), and mood states by POMS, along with task performance, in response to the rewarding and punishing stimuli while performing WCST. Thus, we tried to elucidate some correlations between reward-penalty susceptibility and personality factors.

Methods

Participants

Twenty-one healthy female college students aged 20 to 22 participated in this experiment after providing written informed consent. They 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. Strenuous exercise and heavy drink on the previous day were also prohibited. They were paid 700 yen/hr (standard wage) for their participation on the whole, regardless of their task performance.

Task and stimuli

We used the WCST to evaluate prefrontal cortex function. The WCST was performed 5 times, including a practical trial preceded by an instruction under each condition. The rewarding stimulus was to inform a subject that her performance was very good, and she would be paid an extra wage of 300 yen/hr (the standard wage of 700 yen/hr plus the extra wage resulted in 1000 yen/hr), if she kept performing like this, while the punishing stimulus was to inform a subject that her performance was very bad, and that her wage would be cut by 300 yen/hr (resulting in 400 yen/hr) unless her performance improved greatly. Each stimulus was given repeatedly just prior to each WCST trial (1st, 2nd, 3rd, and 4th trial) under each condition regardless of their actual performance (see Fig. 1).

Procedures

The experiments were carried out under rewarding and punishing conditions. Each experiment consisted of five parts: a pre-task POMS period of around 5 minutes; pre-task basal recording of 5 minutes; a series of instruction or stimulus and trial of WCST (five 2 to 4-minute trials each preceded by around 45 sec instruction or stimulus); a post-task POMS period of 5 minutes, and another post-task period of 30 minutes, which were divided into six 5-minute periods for later analysis. The whole sequence of each experiment is shown in Fig. 1. The two experiments were performed at about the same time on the same day of the week to minimize any circadian rhythm effect (Malliani et al., 1991), and in their follicular phase to diminish the effects of the menstrual cycle. The order of the experiments was counterbalanced to avoid the effect of adaptation, that is, 10 out of 21 subjects performed the rewarding experiment first and the punishing experiment second, and the other 11 subjects performed the punishing experiment first and the rewarding experiment second.

Having previously completed MMPI questionnaires to evaluate their personality characteristics, the subjects entered the room and were asked to fill out POMS questionnaires for an evaluation of their basal mood state. Each subject sat upright on a chair while disc electrodes were attached for chest electrocardiograms (ECG) with CM5 leads, and a thermistor was attached just under one nostril for detecting respiration. Blood pressure (BP) was measured with the tonometric method (Colin Japan). ECG, BP and respiration curves were recorded during the 5-minute pre-task period, the task period

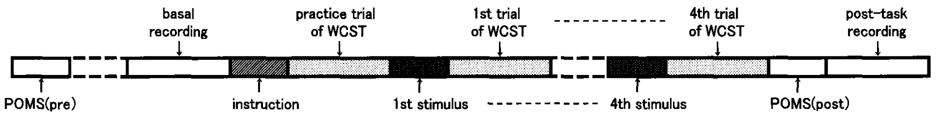

Fig. 1 Sequence of experimental procedures. Instruction was the same under both conditions, while the stimuli were rewarding in a rewarding experiment and punishing in a punishing experiment.

including inter-trial stimulation phase, and the 30-minute post-task period. Indices of WCST were also recorded during the task period. Data were stored on a personal computer equipped with a 12-bit analog-digital converter (ADTM-98, Canopus, Kobe, Japan) for subsequent offline analysis.

Subjects were asked to keep quiet, avoiding any disruptive movements of their heads or hands throughout the experiments. We asked them to perform the task as fast and accurately as possible. They were also asked to keep their eyes closed but not to fall asleep during the pre-task period, the inter-trial stimulation phase and the post-task period. Just after accomplishing the 4th trial of the task they were asked to fill out POMS questionnaires for an evaluation of whatever mood states were induced by the stimuli and task trials (post-task POMS period).

Data analysis

WCST indices were recorded on a notebook PC when performing the task. The WCST was considered to be useful for an objective assessment of prefrontal cortex function especially in the diagnosis of dementia (Heaton et al., 1993; Nagahama et al., 1996; Mansouri et al., 2006). When the WCST was applied to young healthy subjects, very few remarkable findings were observed. We decided, therefore, that only two indices out of 10 WCST indices, required time and total errors, would be useful to evaluate task performance of healthy participants in this study, and these two indices were used for later 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) to assign participants into low- (T-score <50) and high-score groups (T-score >50).

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 by averaging T–A, D, A–H, F, C scores, and stress index by subtracting the V score from the negative mood score.

ECG data were digitized at a sampling frequency of 1 kHz on a personal computer. 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 5 min, using the maximum-entropy method (MemCalc Version 2.5, Suwa Trust) (Ohtomo et al., 1994). After calculating the power-spectral density, the magnitude of the power for HRV was obtained by measuring areas under the spectral density curves. The values were divided into two major bands, a low-frequency component (LF; 0.04–0.15 Hz) and a high-frequency component (HF; 0.15–0.4 Hz). Thereafter, the amplitude of each frequency band was calculated as twice the power magnitude and the square root thereof. It is known that the HF corresponds to respiratory sinus arrhythmia (RSA) and reflects parasympathetic nerve activity, and the LF 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). Then we considered HF amplitude (HF) as an index of parasympathetic nervous function and LF/HF amplitude (LF/HF) as a marker of relative sympathetic activity (Pagani et al., 1986; Malliani et al., 1991).

BP wave forms were digitized at a sampling frequency of 1 kHz on a personal computer. Beat-to-beat systolic and diastolic peaks of the BP wave were detected and stored as time series data of systolic (SBP) and diastolic blood pressure (DBP), respectively. Spectral analysis was applied to the time series data of SBP for each 5 min, then LF and HF amplitudes of SBP variability were obtained in the same way as the spectral analysis of HRV. Thereafter, baroreflex sensitivity was calculated as the ratio of LF amplitude of HRV to LF amplitude of SBP variability. Mean SBP and DBP were also calculated for every 5 min.

For physiological data analysis, five-minute data just prior to the task period were used to establish pre-task basal activity (basal), and thirty-minute data for the post-task period were divided into 6 five-minute segments and represented as after 1, 2, 3, 4, 5 and 6. We excluded the data during the task period from the analysis, since it seemed difficult to distinguish the responses induced by emotional changes from those induced by cognitive processes or task-related physical movements. Thus, we concentrated on the aftereffects induced by rewarding and punishing stimuli in the present experiment.

Statistical analysis

To clarify the effects of reward and punishment on task performance, mood and autonomic nervous function, interactions between condition (rewarding and punishing) and time course were examined by repeated measures analysis of variance (repeated measures ANOVA). Furthermore, to clarify the interaction with personality, repeated measures ANOVA were applied to the subjects who were divided into two groups, low- and high-groups, by a T-score of each MMPI clinical scale (those with a score higher than 50 were assigned to the high group, and the others to the low group). To elucidate the correlation of the stimuli-related changes, we calculated the delta values of task performance (required time and delta total errors; change from the value of the practical trial to the averaged value of the 1st to 4th trials), POMS scores (change from the basal value to the post-stimulus value) and autonomic indices (HRV, baroreflex sensitivity, systolic BP, diastolic BP; change from the basal value to the value of after 1, 2, 3, 4, 5 and 6, and named as 1st Δ baroreflex sensitivity, 2nd Δ baroreflex sensitivity, 3rd Δ baroreflex sensitivity, etc), and computed Pearson's correlation coefficients between them. Statistical analysis was performed on a personal computer using Statview Ver. 5.0 (HULINKS) along with effect size calculations (Faul et al., 2007; Mizumoto and Takeuchi, 2008), and differences with a probability value of less than 0.05, and correlation coefficients (absolute value) of more than 0.5 were considered significant. The data were analyzed in relation to the stimulus condition and subject's personality.

Results

Task performance

Figure 2 shows the changes in task performance assessed by required time and total errors per trial. Although there seems to be some shortening of required time under the punishing condition, the repeated measures ANOVA revealed no significant interaction between condition (rewarding and punishing) and time course in both required time and total errors.

Mood

Figure 3 shows the changes in POMS scores under each condition. The repeated measures ANOVA revealed significant condition (rewarding and punishing)×time course (pre- and post-task) interaction in T–A ($F(1,20)=4.536$, $p<0.05$, partial $\eta^2=0.185$), V ($F(1,20)=8.181$, $p<0.01$, partial $\eta^2=0.290$), F scores ($F(1,20)=8.832$, $p<0.01$, partial $\eta^2=0.306$), negative mood score ($F(1,20)=7.077$, $p<0.05$, partial $\eta^2=0.261$), and stress index ($F(1,20)=12.436$, $p<0.01$, partial $\eta^2=0.383$). The T–A, F and negative mood score decreased under the rewarding condition, while increased under the punishing condition. V-score reduction and stress index augmentation were less under the rewarding than the punishing condition.

Autonomic nervous function

Figure 4 shows the time course of HF amplitude, LF/HF amplitude, systolic BP, diastolic BP, and baroreflex sensitivity under each condition. The repeated measures ANOVA revealed no significant interactions of condition (rewarding and

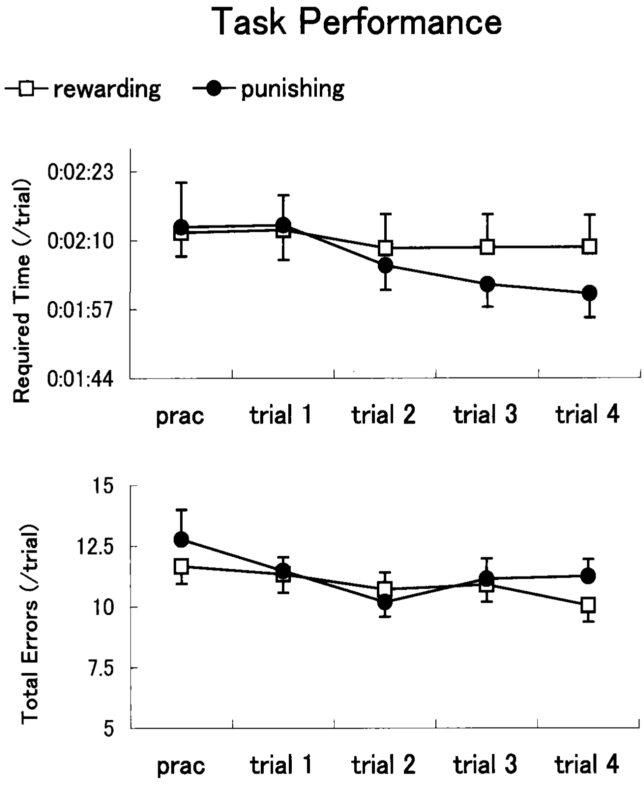

Fig. 2 Task performance indices (required time and total errors/trial) under each condition. Open square: indices under the rewarding condition, closed circle: indices under the punishing condition. No significant condition×time course interaction in both required time and total errors was shown by repeated measures ANOVA.

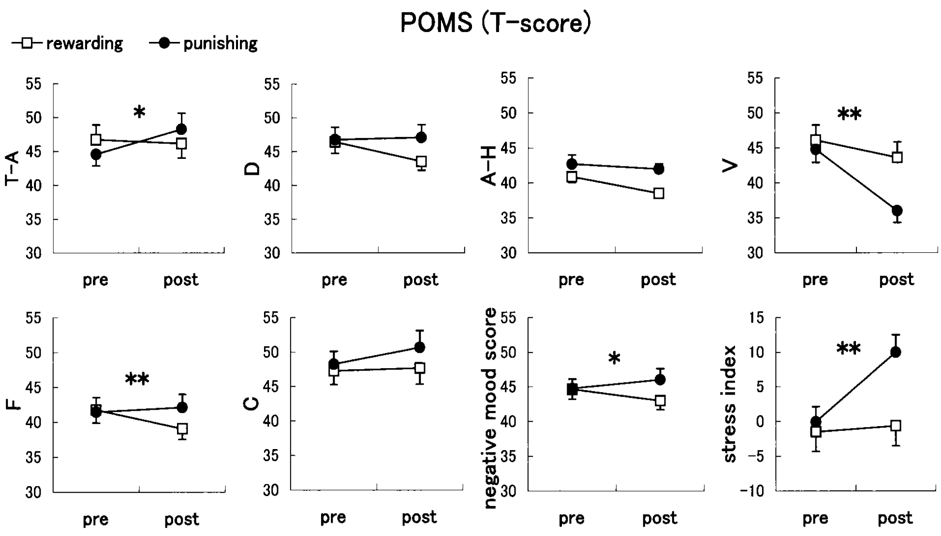

Fig. 3 POMS scores of six sub-scales, negative mood score and stress index under each condition. Open square: scores under the rewarding condition, closed circle: scores under the punishing condition. Significant condition (rewarding and punishing)×time course (pre- and post-task) interactions were shown in T–A, V, F scores, negative mood score and stress index, as indicated by asterisks. T–A: Tension–Anxiety, D: Depression-Dejection, A–H: Anger–Hostility, V: Vigor, F: Fatigue, C: Confusion. * denotes $p<0.05$, ** denotes $p<0.01$ revealed by repeated measures ANOVA.

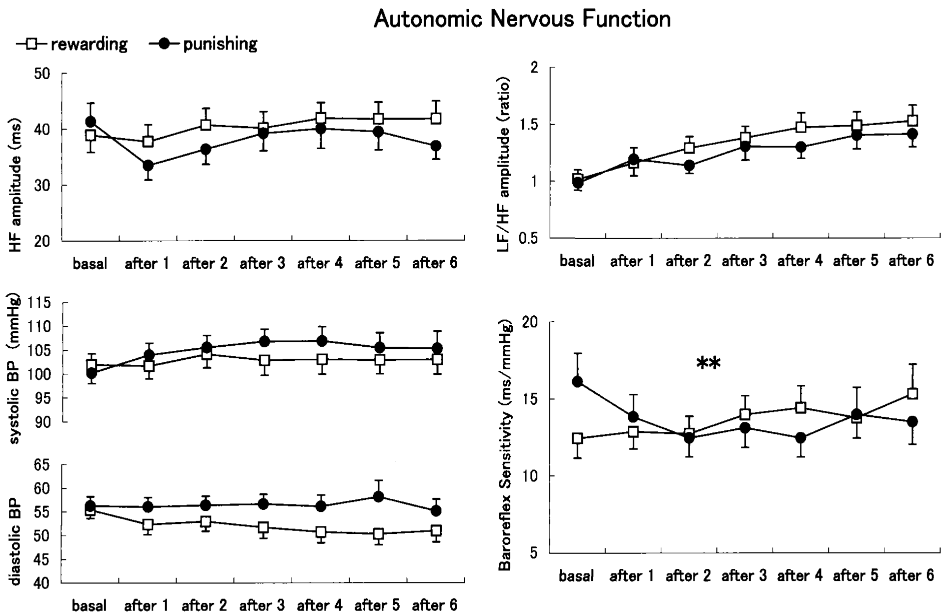

Fig. 4 Time course of autonomic indices (HF amplitude, LF/HF amplitude, systolic BP, diastolic BP and baroreflex sensitivity) under each condition. Open square: indices under the rewarding condition, closed circle: indices under the punishing condition. Significant interaction is marked by ** ($p<0.01$, by repeated measures ANOVA).

punishing)×time course (basal and after 1 to after 6) in autonomic indices except for baroreflex sensitivity ($F(6, 78)=5.137$, $p<0.001$, partial $\eta^2=0.283$). Baroreflex sensitivity gradually increased under the rewarding condition, while it gradually decreased (at least to after 4) under the punishing condition. Since there seemed some difference in the pre-stimulus basal levels of baroreflex sensitivity, we performed a paired *t*-test and found no significant difference in the pre-stimulus basal levels between the rewarding and punishing conditions ($p=0.0868$).

Interaction with personality

Means and SDs of T-score of clinical scales in MMPI in the present population were as follows: Hs (49.32±8.41), D (50.09±11.34), Hy (50.28±9.35), Pd (51.48±13.42), Mf (54.76±9.92), Pa (58.25±14.17), Pt (55.02±10.59), Sc (53.20±11.58), Ma (51.06±10.79) and Si (51.31±9.19). Subjects in the present experiment were divided into two groups by assigning those with a T-score of each MMPI clinical scale higher than 50 to the high group, and the others to the low group. Repeated measures ANOVA were applied to these two groups to further analyze interactions of condition, time course, and personality on task performance, mood, and autonomic indices. Condition and time course were used as within-subject variables and groups (personality factors) were used as between-subject variables.

Table 1 shows the interactive effects of condition×time×group on task performance, POMS, and physiological indices, along with condition×time interaction. The repeated measures ANOVA showed significant condition×time course×Pt interactions in required time ($F(4, 76)=5.485$, $p<0.001$, partial $\eta^2=0.224$) and total errors ($F(4, 76)=3.067$, $p<0.05$, partial $\eta^2=0.139$). Several factors from MMPI showed significant condition×time course×personality factor (MMPI clinical scales of Sc, D, Pt, Pa and Hs) interactions in POMS subscales of T–A, D, F along with negative mood score, and stress index (see Table 1 for details). The repeated measures ANOVA showed significant condition×time course×Hs interactions in HF amplitude, and significant condition×time course×Pt interactions in systolic BP and diastolic BP (see Table 1 in detail). The effect of condition on the task performance was significantly different between the low and high groups of Pt, but not those divided by the other factors. According to the MMPI handbook and manual, a person who scores high on the Pt scale tends to be sensitive, prone to worry, emotional, high-strung and susceptible to stress, whereas those who score low on the Pt scale tend to be cheerful, alert, self-confident and balanced (Dahlstrom and Welsh, 1960; Tanaka et al., 1993). We considered Pt, then, as the most important factor from the point of task performance, and carried out further analysis.

Differences between low and high groups of Pt

Figure 5 shows task performance (required time and total errors per trial) and POMS (F subscale) of the low and high Pt groups. Significant differences in required time and total errors per trial of the task between low and high Pt groups were revealed. That is, high Pt subjects showed no remarkable change in either required time or total errors under the rewarding condition, but clear shortening in required time and a clear decrease in total errors under the punishing condition, while the low Pt group showed clear shortening in required time and a clear decrease in total errors under the rewarding condition, but little change in either required time or total errors under the punishing condition. On the other hand, the high Pt subjects showed F (fatigue) sub-scale score reduction

Table 1 Interactive effects of condition×time and condition×time×group on task performance, POMS and physiological indices

		Condition×time	Condition×time×group
Task Performance	Time Required	n.s.	×Pt (F(4, 76)=5.485, p=0.0006, partial η^2=0.224)
	Total Errors	n.s.	×Pt (F(4, 76)=3.067, p=0.0213, partial η^2=0.139)
POMS sub-scales	T–A	(F(1, 20)=4.536, p=0.0458, partial η^2=0.185)	×Sc (F(1, 19)=5.069, p=0.0364, partial η^2=0.211)
	D	n.s.	×D (F(1, 19)=10.072, p=0.0050, partial η^2=0.346)
	A–H	n.s.	n.s.
	V	(F(1, 20)=8.181, p=0.0097, partial η^2=0.290)	n.s.
	F	(F(1, 20)=8.832, p=0.0075, partial η^2=0.306)	×D (F(1, 19)=4.924, p=0.0389, partial η^2=0.206)
			×Pt (F(1, 19)=5.760, p=0.0268, partial η^2=0.233)
	C	n.s.	n.s.
	Negative mood score	(F(1, 20)=7.077, p=0.0150, partial η^2=0.261)	×D (F(1, 19)=5.915, p=0.0251, partial η^2=0.237)
			×Pa (F(1, 19)=4.465, p=0.0481, partial η^2=0.190)
	Stress index	(F(1, 20)=12.436, p=0.0021, partial η^2=0.383)	×Hs (F(1, 19)=4.476, p=0.0478, partial η^2=0.191)
Physiological indices	HF amplitude	n.s.	×Hs (F(6, 84)=2.232, p=0.0478, partial η^2=0.137)
	LF/HF amplitude	n.s.	n.s.
	systolic BP	n.s.	×Pt (F(6, 66)=2.371, p=0.0390, partial η^2=0.177)
	diastolic BP	n.s.	×Pt (F(6, 66)=2.429, p=0.0350, partial η^2=0.181)
	Baroreflex Sensitivity	(F(6, 78)=5.137, p=0.0002, partial η^2=0.283)	n.s.

Condition, time and group indicate an experimental condition (a rewarding and a punishing condition), time course (from practice trial to 4th trial of WCST for task performance; a change from pre- to post-task for POMS sub-scales; a change from pre- to post-task period for physiological indices) of each index, and low and high groups divided by MMPI clinical scales, respectively. T–A: Tension–Anxiety; D: Depression–Dejection; A–H: Anger–Hostility; V: Vigor; F: Fatigue; C: Confusion; n.s.: not significant. Only scales that had significant effects (p<0.05) are shown with F, probability and partial η^2 values.

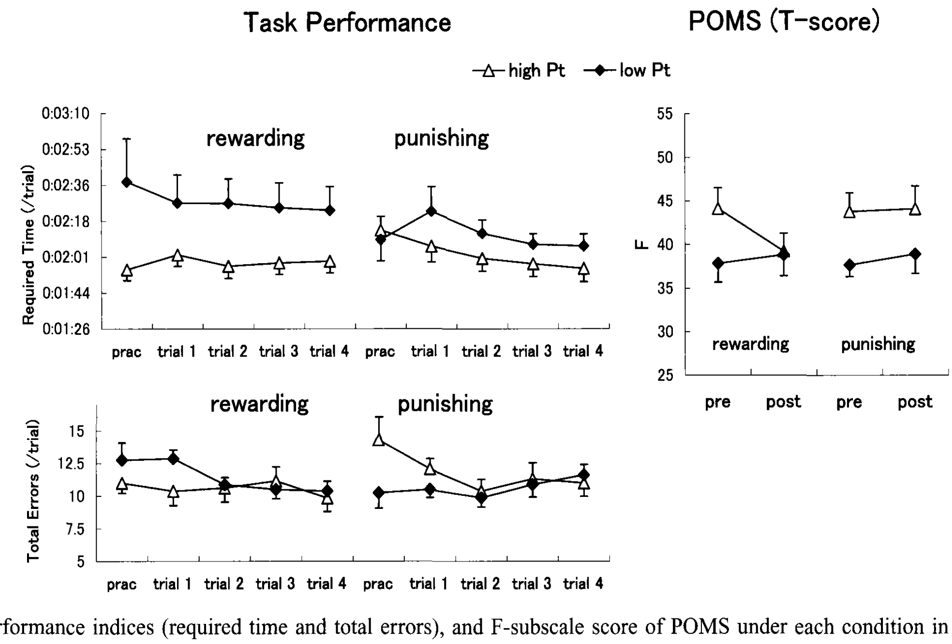

Fig. 5 Task performance indices (required time and total errors), and F-subscale score of POMS under each condition in high-Pt and low-Pt group. Open triangle: trends in high Pt, closed rhombus: trends in low Pt. Repeated measures ANOVA showed significant condition×time course×Pt interactions in required time (F(4, 76)=5.485, p<0.001, partial η^2=0.224), total errors (F(4, 76)=3.067, p<0.05, partial η^2=0.139) and F-subscale score (F(1, 19)=5.760, p<0.05, partial η^2=0.233).

after the task period under the rewarding condition but not under the punishing condition, while the low Pt group showed no remarkable change under either condition. Since there seemed some difference in pre-stimulus basal levels of task performance indices and F-subscale score of POMS, we applied a t-test to the pre-stimulus basal values and found no significant differences (p=0.0851, p=0.2419, p=0.0682 and p=0.0885 for required time in the rewarding condition, total errors in the rewarding condition, total errors in the punishing condition and the F subscale score in the rewarding condition, respectively), except for the F subscale score in the punishing condition (p<0.05, Cohen's d=0.997). Furthermore, we combined pre-stimulus F sub-scale scores in the rewarding condition and those in the punishing condition and performed a t-test to determine whether the F sub-scale score is originally different between the two groups, and found a significant

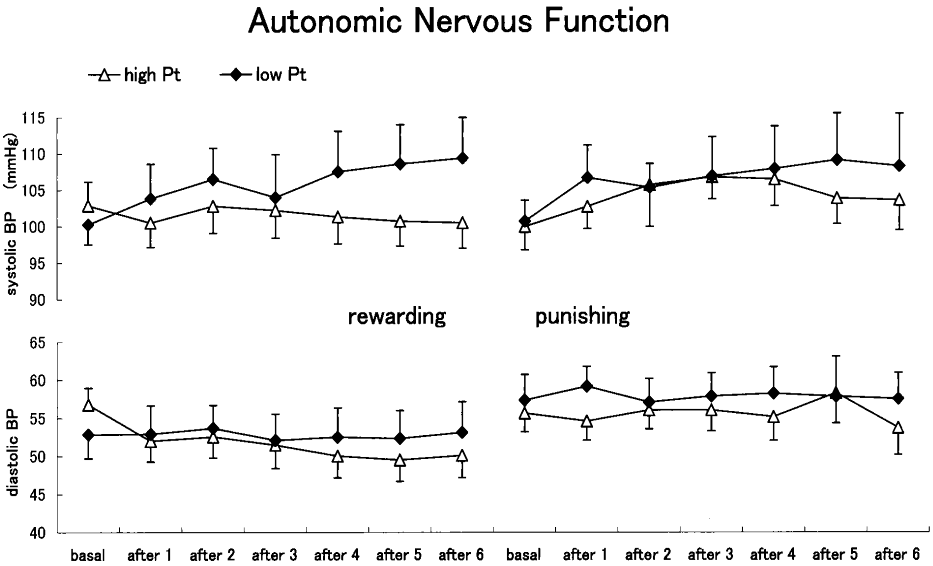

Fig. 6 Systolic and diastolic BP, under each condition in high-Pt and low-Pt group. Open triangle: trends in high Pt, closed rhombus: trends in low Pt. Repeated measures ANOVA showed significant condition×time course×Pt interactions in systolic BP ($F(6, 66)=2.371$, $p<0.05$, partial $\eta^2=0.177$) and diastolic BP ($F(6, 66)=2.429$, $p<0.05$, partial $\eta^2=0.181$).

difference ($p<0.01$, Cohen's $d=0.929$).

Figure 6 shows the systolic and diastolic BP of the low and high Pt groups. In the rewarding condition, the high Pt group showed a slight gradual decrease in both systolic and diastolic BP, while the low Pt group showed a gradual increase in systolic BP and little change in diastolic BP. In the punishing condition, the high Pt group showed an inverted U-shaped slight increase, while the low Pt group showed a gradual increase in systolic BP, and both groups showed little change in diastolic BP. The clear difference between the two groups is that the high Pt subjects showed a mild systolic BP reduction after the task period under the rewarding condition and a slight elevation under the punishing condition, while the low Pt group showed a systolic BP elevation under both conditions.

Correlation of task performance and POMS sub-scales or physiological indices

Delta required time (change from the value of the practical trial to the averaged value of the 1st, 2nd, 3rd, and 4th trials) was significantly correlated with the 2nd Δ baroreflex sensitivity (change from the basal value to that of after 2; $r=0.5044$, $p<0.01$) and the 3rd Δ baroreflex sensitivity (change from the basal value to that of after 3; $r=0.5505$, $p<0.01$). There was no significant correlation between task performance and POMS sub-scales.

Respiratory frequencies

The respiratory frequencies of all subjects were over 10 cycles per minute (i.e., over 0.15 Hz) throughout the experiments. Those frequencies significantly increased during trials, but were not different among the tasks.

Discussion

Reward and punishment is a substantial source of every behavior, and people generally act to gain reward or to avoid punishment. Whether reward or punishment is better or more beneficial may depend on the situation under which it is given or the personality characteristic of the person who receives it, or the interaction among them. People usually feel pleasure and get relaxed when encountering a reward. On the other hand, people usually feel unpleasantness and get angry, when encountering punishment. In the present study, we expected that the participants would be in a more positive mood state and perform the task better under a rewarding condition than a punishing one. This expectation was partially confirmed by the fact that a less negative mood was induced under the rewarding condition than the punishing one, although the task performance was not significantly affected by the conditions. Baroreflex sensitivity, which is known to decrease in a stressed state or tension and to increase in a relaxed situation (Steptoe and Sawada, 1989; Conway et al., 1983), gradually increased under the rewarding condition, while decreasing under the punishing condition. This physiological finding would also support the expectation mentioned above.

The fact that Δ required time was significantly correlated with Δ baroreflex sensitivity (2nd and 3rd Δ baroreflex sensitivity) may indicate that the time requirement would induce such a stressed state as to be detected by a physiological index such as baroreflex sensitivity.

Respiratory frequency was found to have a considerable effect on the high frequency component of HRV (Kageyama et al., 1996; Kobayashi, 1998). Respiratory sinus arrhythmia (RSA) usually appears in the HF band, and the central frequency of the HF band corresponds to respiratory frequency. In other words, if respiratory frequency falls below the lower limit of the HF band, RSA would appear in the LF band. Respiratory frequencies of all subjects in this study were over 10 cycles per minute (i.e., over 0.15 Hz) throughout the experiments. Therefore, respiratory frequencies did not overlap with the frequency domains of the LF component.

Numerous studies have reported 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 and is adequate to this type of study remains controversial. The Carver and White scales (Carver and White, 1994), a brief questionnaire to measure BIS (behavioral inhibition system) and BAS (behavioral activation system) sensitivities, may be more adequate to study the effects of reward and punishment however, the scales are not so popular in Japan. Therefore, we used MMPI, which is popular to assess personality characteristics in Japan as well as round the world, to classify a subject's personality.

The effects of conditions on mood and autonomic indices were significantly affected by certain personality factors, while those on task performance indices were significantly affected only by Pt. There may be some inconsistencies among task performance, mood, and physiological indices in relation to reward and/or punishment sensitivity. That is, the effects of reward and punishment may be different among mood, autonomic activity, and task performance. One possible explanation is that Pt may be related to attention and effort as we reported previously (Sakuragi and Sugiyama, 2004). In other words, low and high Pt subjects may have had different levels of attention and effort, which in turn would have induced different levels of stress, and thus caused different physiological responses under each condition. Or the motivational incentives of reward and punishment may be different between low and high Pt subjects, which would have consequently induced different responses.

There was a significant difference in pre-stimulus basal levels of the F-subscale score between the low and high Pt groups (Fig. 5), which might have some influence on its responses. Basal mood state and/or sensitivity to a novel experience (such as participating in a scientific experiment) may originally be different between the two groups. Initial differences of required time in the rewarding condition, and total errors in the rewarding and punishing conditions might also have some influence on their responses, though the differences did not reach a significant level.

It was reported that effortful and active coping for a reward (effort coping) intensifies cardiovascular responses, particularly blood pressure, whereas an avoidance strategy for threat of punishment (distress coping) would intensify skin conductance level, and effort-distress coping would intensify both (Suzuki et al., 2003). From the point of view of blood pressure responses, the punishing condition in the present study may have worked as an ambivalent stressor and induced effort-distress coping in both the low and high Pt groups, which consequently caused a gradual increase in systolic BP. The rewarding condition in the present study was expected to work as a rewarding stressor for both groups and to induce effort coping however, the condition might have worked as no stressor for the high Pt group since no increase was observed in systolic BP. The high Pt group showed gradual improvement of the task performance under the punishing situation with no remarkable mood change and with an inverted U-shaped slight increase in systolic BP, while they showed no clear improvement of the task performance under the rewarding condition with remarkable fatigue sense attenuation and with a slight gradual decrease in both systolic and diastolic BP. Persons with a high Pt score may have low sensitivity to reward and have shown little effortful performance, which may some association with fatigue sense attenuation. In contrast, the low Pt group showed a gradual improvement of task performance under the rewarding situation, with slight fatigue sense elevation and with a gradual increase in systolic BP and little change in diastolic BP, which were also seen under the punishing condition. Persons with a low Pt score may have adequate sensitivity to reward, which would induce effective effort coping to improve task performance. The punishing condition in the present study might have induced inappropriate effort-distress coping in the low Pt group, which in turn might have made the performance worse. Taken together, high Pt subjects would feel more relaxed or no tension under the rewarding condition and might have shown no clear improvement in the task performance, while they would feel more stressed or tension under the punishing condition and might have shown a clear improvement in the task performance. That is, the punishing strategy may be efficient for a high Pt person from the point of view of task efficiency however, this may not be beneficial from the point of view of mental health. In contrast, low Pt subjects would feel some tension under both conditions despite the fact that clear task performance improvement was seen only under the rewarding condition, which indicates that the rewarding strategy may be efficient for a low Pt person from the both points of view.

Standardization of a new Japanese version of MMPI was carried out based on 500 healthy male and 522 healthy female samples collected all over Japan with construction ratios close to the national census carried out in 1990, with regard to district (8 districts), age (7 divisions, older than 14 years old), occupation (5 divisions) and educational history (5 divisions) (Tanaka et al., 1993). Means of all clinical scales were in the range of mean$\pm$1SD of those in the parent population however, the means of some clinical scales (Mf, Pa, Pt and Sc) in the present population were slightly higher than those in the parent population. Therefore, whether these findings could be widely generalized is uncertain, since subjects in the present study were all female college students and seemed somewhat different from the parent population in certain respects. Further investigations in different populations are required for generalization however, when we use the strategy of reward or punishment, the interaction with personality and current goal as well as the context in which it is given, should be taken into careful consideration.

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