ACKNOWLEDGMENTS

This work was partly supported by the Ministry of Education, Culture, Sports, Science and Technology of Japan (Grants-in-Aid for Young Scientists (Start-up)) (20890295) to H.F.).

INTRODUCTION

Psychopathy

Psychopathy is a developmental disorder that involves emotional dysfunction and is characterized by reduced guilt, empathy, and attachment to significant others, and antisocial behavior, including impulsivity and poor behavioral control. Psychopathic criminals commit a disproportionate number of crimes, habitually fail to fulfill societal obligations, appear to lack a sense of loyalty, and are unperturbed when confronted with the destructive nature of their behavior (Hare, 1991). This definition is not equivalent to that of the *Diagnostic and Statistical Manual of Mental of Disorders*, 4th edition, in which psychiatric diagnoses of conduct and antisocial personality disorders (APD) focus only on the presence of antisocial behavior rather than on forms of functional impairment that might be causally related to the emergence of such disorders.

"Acquired sociopathy" and decision making in an Iowa Gambling Task

The Iowa Gambling Task (IGT) has been used previously in studies concerning lesions, especially to detect lesions in the ventromedial prefrontal cortex (vmPFC) (Bechara, Damasio, Damasio, & Anderson., 1994). Patients with vmPFC damage commonly display a syndrome that includes poor judgment, socially inappropriate behavior, and impulsivity (Damasio, 1994). Their behavior is driven by the desire for short-term benefits without regard for long-term negative consequences— a profile labeled "myopia for the future" (Bechara et al., 1994; Bechara, Tranel, & Damasio, 2000). Such patients often exhibit behavioral problems that are similar to those found in individuals with psychopathy. Damasio and colleagues anticipated that vmPFC dysfunctions will not only explain behavior changes resulting from lesions (what Damasio [1994] calls "acquired sociopathy") but also should prove to be relevant for "developmental" or "true" psychopathy (Damasio, 1994; Damasio, Tranel, & Damasio, 1990).

As far as we know, six studies have used the IGT to investigate the relationship between decision making and psychopathy. Blair, Colledge, and Mitchell (2001) showed that boys with emotional and behavioral difficulties who exhibited psychopathic tendencies made more risky decisions in the IGT than did boys in the nonpsychopathic control group. Michell, Colledge, Leonard, and Blair (2001) reported that psychopathic inmates in high-security prisons had poorer IGT performance than nonpsychopathic inmates did. Van Honk, Hermans, Putman, Montagne, and Schutter (2002) reported that the sub-clinical psychopathy group ($n = 16$) showed more impaired IGT performance than nonpsychopathy group (n = 16). Vassileva et al. (2007) compared psychopathic heroin addicts with non-psychopathic heroin addicts. Psychopathic heroin addicts showed more disadvantageous decisions on IGT than non-psychopathic heroin addicts. In contrast, Schmitt, Brinkley, and Newman (1999) applied the Psychopathy Checklist-Revised (PCL-R) to allocate prison inmates to a psychopathic group, a middle group, and a control group. However, these 3 groups did not differ in their IGT performance. In Lösel and Schmucker's (2004) study assessing male prison inmates with PCL-R, there was no general relation between psychopathy and IGT performance. Thus, the results in these studies regarding the association between psychopathy and the IGT are inconsistent.

Delay and probability discounting as decision making in behavioral and neural economics

In behavioral and neural economics, decision making is discussed in terms of which alternative an individual would select when choosing between a smaller, more certain reward and a larger, less certain reward (risky choice) or between a smaller, more immediate reward and a larger but more delayed reward (intertemporal choice). Choices involving delayed and probabilistic outcomes are viewed from the perspective of discounting. This perspective assumes that the subjective value of a reward is increasingly discounted from its nominal amount as the delay increases or until the odds against receiving the reward increase, and that individuals choose the reward with the higher (discounted) subjective value (Rachlin, 1989). The discounting approach has been applied to topics of general psychological and clinical concern, such as self-control, impulsivity, and risk taking (Rachlin. 1995).

People prefer an immediate reward to a delayed one (referred to as "delay discounting"). Psychopharmacological and neuroeconomic studies have demonstrated that smoking and drug dependence are associated with greater delay discounting (referred to as "impulsivity" in intertemporal choice) (Bickel & Marsch, 2001; Bickel, Odum, & Madden, 1999; Kirby, Pet, & Bickel, 1999; Ohmura, Takahashi, & Kitamura, 2005; Petry, 2001; Reynolds, Patak, & Shroff, 2007; Vuchinich & Simpson, 1998; Wittmann, Leland, Churan, & Paulus, 2007). Standard economic theory assumes that a discount rate is independent of dynamic consistency (*D*), which yields the exponential discount function (Frederick, Lowenstein, & O'Donoghue, 2002). However, empirical studies in humans and non-human animals have reported that delay discounting is better described by a hyperbolic function (Bickel & Marsch, 2001; Bickel et al., 1999; Kirby et al., 1999; Ohmura et al., 2005; Petry, 2001; Reynolds et al., 2007; Vuchinich & Simpson, 1998; Wittmann et al., 2007). The hyperbolic delay-discounting function is as follows:

$V_D = A / (1 + k_d D)$,

where V_D is the subjectively discounted value of the reward at delay D, A is the undiscounted value of the reward = V_D (D = 0), D is the delay to the receipt of the reward, and k_d is a free parameter (Frederick et al, 2002). The larger the k_d, the more rapidly a subject discounts the delayed reward (more impulsive intertemporal choice). In hyperbolic discounting, subjects underestimate their future impulsivity, resulting in preference reversal as time passes (Frederick et al, 2002; Takahashi, 2005).

On the other hand, subjects discount the value of uncertain rewards as the probability of receiving the rewards decreases (Rachlin, Raineri, & Cross, 1991; Yi, de la Piedad, & Bickel, 2006a). This behavioral tendency has been referred to as "probability discounting" (in psychology, it is also referred to as "uncertainty aversion"). Rachlin et al. (1991) proposed the following exponential and hyperbolic probability-discounting functions. Several studies found that a hyperbolic probability-discounting function fits the behavioral data better than the exponential discount function (Ohmura et al., 2005; Rachlin et al., 1991; Yi et al., 2006a). The hyperbolic probability-discounting function is as follows:

$V_p = A / (1 + k_p O)$,

where V_p is the subjective discounted value of a probabilistic reward, A is the value when p = 1, O is the odds against and $O = (1/p) - 1$ (proportional to an average waiting time in repeated gambling), and k_p is the probability discount rate. k_p indicates the degree to which one discounts the uncertain reward. We, therefore, adopted k_p as the subject's uncertainty aversion parameter (note that a larger k_p corresponds to a strong uncertainty aversion). It must be noted that for probabilistic gains (A > 0), a larger k_p indicates the underestimation of the reward value of uncertain gains, and for probabilistic losses (A < 0), a larger k_p indicates the underestimation of the risk of uncertain losses.

There are two studies relative to ours. One study examined the relationship between APD and discounting of delayed rewards, investigating substance (e.g. alcohol, marijuana, cocaine, sedatives, or heroine) abusers with APD (n = 58), substance abusers without APD (n = 75), and non-substance-abusing controls (n = 33) who were required from local substance abuse treatment programs, low-income housing projects, and social service agencies. The study assessed delay discounting of rewards with question-based measures. Substance abusers discounted delayed rewards at greater rates than controls, and substance abusers with APD discounted delayed rewards at higher rates than non-APD substance abusers (Petry, 2002). Melanko, Leraas, Collins, Fields, & Reynolds

(2009) focused on psychopathic trait estimated by a self-report measure, Youth Psychopathic Traits Inventry (YPI; Andershed, Hodgins, & Tengström, 2007). The YPI has good convergent validity with PCL youth version. This study compared delay discounting behavior for rewards in community adolescent nonsmokers with low psychopathy (n = 25), smokers with low (n = 25) and high (n = 25) psychopathy, using two delay discounting tasks. These assessments included question-based and real-time measures of delay discounting of rewards. Low psychopathy smokers more discounted than low psychopathy nonsmokers. In smokers, surprisingly, low psychopathy significantly more discounted than high psychopathy on question-based measure. On real-time measures, the result was similar to the question-based measure without mentioning statistical significance. The researchers argued that these results indicated that elevated but still subclinical level of antisociality are associated with more optimal decision-making.

The samples in these two studies were APD or psychopathy combined with substance abuse or smoking. Previous studies have demonstrated that smoking and drug dependence are associated with greater delay discounting (Bickel & Marsch, 2001; Bickel et al., 1999; Kirby et al., 1999; Ohmura et al., 2005; Petry, 2001; Reynolds et al., 2007; Vuchinich & Simpson, 1998; Wittmann et al., 2007). These two studies assessed delay discounting of only rewards, but not losses. These also estimated delay discounting, but not probability discounting.

Objectives of the present study

The subjects of previous studies on psychopathy were often clinical or incarcerated individuals, which introduces potentially confounding variables (e.g., severe substance use) that can complicate interpretations (Lilienfeld & Andrews, 1996). The present study investigated non-clinical individuals to minimize these effects. This selection approach has been verified by recent statistical analyses, demonstrating that scores on psychopathy measures are underpinned by a latent dimension rather than a latent taxon (Edens, Marcus, Lilienfeld, & Poythress, 2006). This study is the first to investigate the relationship between psychopathic traits and the IGT with individuals in a community. The goals of the present study are to estimate the relationship between psychopathic traits and the tendency towards four behavioral economic types of decision making (i.e., discounting of delayed and uncertain monetary gains and losses), as well as IGT performance, and to demonstrate their cognitive mechanisms by elucidating the difference between the IGT and behavioral economic types of decision making.

MATERIALS AND METHODS

Participants

Forty-one undergraduate and postgraduate students (21 men and 20 women) between 20 and 34 years of age (mean ± SD = 23.33 ± 3.19) from Japanese universities participated in this study, after the individuals with substance abuse (e.g., alcohol, nicotine, marijuana, cocaine, and heroine) were excluded by a psychiatrist, based on DSM-IV. The subjects of this study did not also have either a history of psychiatric or neurological disorders, and serious physical illnesses, or any within-second-degree relatives with a history of major psychiatric disorders.

In accordance with the Helsinki Declaration of Human Rights (1975), after complete description of the study to the subjects, written informed consent was obtained. The study protocol was approved by the local ethics committee.

Psychopathic Personality Inventory-Revised

The Psychopathic Personality Inventory-Revised (PPI-R; Lilienfeld & Widows, 2005) is a 154-item measure that assesses psychopathic traits by self-report using a 4-point response scale. The internal consistency reliability in noninstitutionalized samples has been found to be 0.92, with good test-retest reliability (r = 0.93) over a period of 19.9 days. The PPI-R includes eight content scales, seven of which form two higher order factors. The fearless dominance (FD) factor is the sum of the scores for social influence, fearlessness, and stress immunity scales. The self-centered impulsivity (SCI) factor is the sum of the scores for Machiavellian egocentricity, rebellious nonconformity, blame externalization, and carefree nonplanfulness scale scores. The eighth content scale, coldheartedness (C), does not load on either factor. The Japanese version of the PPI-R was translated by authors, using a forward-backward method. The Japanese version was approved by Psychological Assessment Resources, Inc. In our sample, internal consistency has found to be 0.77.

Iowa Gambling Task

The IGT was described in detail in a previous study (Bechara et al., 1994). Briefly, the task goal is to maximize the profit from a loan granted in play money. The subjects are required to make a series of 100-card selections from 1 of 4 card decks (A, B, C, and D). Each selection is followed by a showdown of a reward and a penalty. The reward/penalty schedules are predetermined: Decks A and B yield high immediate rewards but carry the risk of much higher long-term penalties, which will result in total loss in the long run (disadvantageous decks). Decks C and D yield low immediate rewards but smaller long-term penalties, which will result in long-term gain (advantageous decks). We developed a computerized version of the IGT in strict compliance with the original version (Fukui, Murai, Fukuyama, Hayashi, & Hanakawa, 2005). The difference from the original task was that the play money was converted from U.S. dollars to Japanese yen. After they completed the task, the subjects were asked about the decks that they thought were advantageous.

IGT performance was characterized by a net score calculated by subtracting the number of cards selected from the 2 disadvantageous decks (A + B) from the number selected from the 2 advantageous decks (C + D) (Bechara et al., 1994). Higher scores reflected more advantageous decision-making performance on the task.

Delay and probability discounting tasks

It must be noted that we previously developed the Japanese version of the discounting task (Takahashi, 2007) and utilized exactly the same discounting task in this study. The paper-and-pencil discounting tasks that were used were originally developed by Bickel's group (Yi, de la Piedad, & Bickel, 2006b). These tasks are not systematically different in discount rate was observed in response to real and hypothetical choices (Johnson & Bickel, 2002). The procedure comprised four different types of discounting (i.e., delayed gain, delayed loss, uncertain gain, and uncertain loss).

The participants were requested to choose alternatives solely on the basis of their free will, as though their choices involved real money (Takahashi, 2007; Yi et al., 2006b), and then answer a questionnaire. The questions were categorized according to the temporal distance of delay (1 week, 2 weeks, 1 month, 6 months, 1 year, 5 years, and 25 years; each page included each delay, in this order) in the delay condition and the probability of an uncertain reward (95, 90, 70, 50, 30, 10, and 5%; each page included each probability, in this order) in the probability condition. Two columns of hypothetical amounts of money were listed below the instructions. For the discounting of gains, the money was indicated as a reward; on the other hand, for the discounting of losses, the money was indicated as a payment. The right-hand column (standard amount) contained 40 rows of a fixed amount of money (100,000 yen). The left-hand column (adjusting amount) listed ascending or descending amounts of money in 2.5% increments (100,000 yen × 0.025 = 2500 yen) of the alternative in the right-hand column. The participants were instructed to choose between the two alternatives in each row of the questionnaire. Furthermore, as the discounting task of the Bickel and colleagues, the participants were directed to refer to the directions at the top of each page (containing each delay or probability) of the questionnaire, as the temporal distance would change over the course of the experiment. Thus, the subjects chose between a delayed-standard amount and an immediate-adjusted amount of money in the delay condition and between an uncertain-standard amount and a certain-adjusted amount of money in the probability condition. The order of the descending and ascending conditions was counterbalanced.

The indifference points of delay and the probability tasks were defined as the means of the largest adjusting values in which the standard alternative was preferred and the smallest adjusting values in which the adjusting alternative was preferred. Next, the mean of the indifference point in the ascending and descending adjusting amounts was calculated for the delay and probability conditions for each participant.

The indifference points for the individual and group median data were obtained in order to compare the goodness-of-fit between the exponential and hyperbolic models in delay and probability discounting and to estimate the discounting parameters by utilizing nonlinear curve fitting procedures (for details, see [Takahashi, 2007]). After confirming that the hyperbolic models better fit the data than the exponential models for all behavioral data, we examined the relationship between the k parameters in the hyperbolic models (not in the exponential models). The hyperbolic discounting parameters (i.e., k_d, and k_p) were logged because of the skewed distributions, following the standard analytical strategy in previous studies (Kirby et al., 1999; Reynolds, Richards, Horns, & Karraker, 2004). All statistical and nonlinear curve fitting procedures were conducted with R statistical language. The alpha level was set at 0.05 throughout.

RESULTS

The means and standard deviations of all the obtained variables (i.e., PPI-R scores, IGT net score, and each of the logged k parameters) are shown in Table 1.

First, we investigated the relationship between the psychopathic traits and IGT performance by calculating the Pearson product-moment correlation between the PPI-R total score and the IGT net score. The correlational analysis revealed no relationship among these scores ($r = -0.02$, p = 0.93) (see Figure 1, Table 2).

Second, we calculated the correlations among each of the four types of (logged) discounting k parameters. The significant correlations between the delay discounting of gain and loss ($r = 0.62$, $p < 0.01$) and between the probability discounting of gain and loss ($r = -0.42$, $p < 0.01$) were observed, indicating that subjects who overestimate the reward value of an uncertain reward tend to also underestimate the risk of an uncertain loss. There were no significant correlations between the delay and probability discounting parameters under both gain and loss conditions (see Table 2).

Third, to examine the relationship between the psychopathic traits and discounting behavior, the correlations between the PPI-R total score and each of the four types of discounting (logged k parameters) were calculated. The correlations between the PPI-R total score and delay discounting of gain and between the PPI-R total score and delay discounting of loss were not significant. However, significant correlations between the PPI-R total score and probability discounting of both gain and loss were observed (gain: $r = -0.38$, $p < 0.05$; loss: $r = 0.43$, $p < 0.01$) (see Table 2, Figure 2). This indicates that the subjects with a high PPI-R total score overestimated the reward value of uncertain gains and underestimated the risk of uncertain losses. Furthermore, we investigated the PPI-R factors (i.e., SCI, FD, and C) and probability discounting k parameters. Considering only FD without the other two factors, significant correlations with both gain ($r = 0.35$, $p < 0.05$) and loss ($r = 0.41$, $p < 0.01$) were observed (see Table 3).

DISCUSSION

This study obtained three main findings. First, there was no significant correlation between the PPI-R total score and the IGT net score. Second, there were significant correlations between the delay discounting of gain and loss and between the probability discounting of gain and loss. In contrast, there were no significant correlations between the delay discounting and probability discounting parameters (for both gains and losses). Third, significant correlations between the PPI-R scores and probability discounting parameters were observed, instead of delay discounting parameters. In particular, the FD of PPI-R was correlated with the probability discounting parameters.

The first finding suggests that psychopathic traits are not associated with decision making involving the IGT. Recent studies have investigated the association between psychopathy and IGT performance (Blair et al., 2001; Lösel & Schmucker, 2004; Mitchell et al., 2002; Shimitt et al., 1999; van Honk et al., 2002). Although three of these studies reported that psychopath groups showed impaired IGT performance as compared to nonpsychopath groups (Blair et al., 2001; Mitchell et al., 2002; van Honk et al., 2002), two studies showed no differences between psychopath and nonpsychopath (Lösel & Schmucker, 2004; Shimitt et al., 1999). Our result is in accordance with the last two studies. However, individuals in the same community participated in this study; thus, the population differed from the previous studies, which obtained their samples from clinical or subclinical populations. The findings of these studies are inconsistent, and the causes of the inconsistency are unclear.

The second finding suggests that the association between the tendency to discount rewards and the tendency to discount losses was positive for delay discounting, but negative for probability discounting. The positive association between the gain and loss of delay discounting suggests that the more aversive an individual is to the delay of rewards the easier it is for that individual to delay payment. Regarding the association between the probability discounting of rewards and losses, individuals who subjectively overestimate the value of uncertain rewards underestimate the seriousness of possible danger (Shead & Hodgins, 2009). This study additionally suggests that delay discounting behaviors and probability discounting behaviors are dissociated. Previous studies have proposed that two functions, intertemporal choice and risky choice, utilize the same psychological mechanism (Rachlin, Logue, Gibbon, & Frankel, 1986). However, other behavioral evidence argues against this view. Some studies have found correlations between delay and probability discounting to be weak or absent (Ohmura et al., 2005; Reynolds et al., 2004; Shead & Hodgins, 2009). Furthermore, changes in payout amounts have opposite effects in risky and intertemporal choice; in other words, decision makers are more willing to wait for large outcomes than for small ones, but they are less willing to take risks for large outcomes than for small ones (Chapman & Webster, 2006; Rachlin, Brown, & Cross, 2000). The only fMRI study on the delay and probability discounting tasks reported that intertemporal and probability choices invoked different patterns of neural activation (Webster & Huettel, 2008). This evidence indicates that the two types of decision making differ with respect to both psychological and neural mechanisms. Our study also suggests that the mechanisms of delay and probability discounting behaviors are different.

Comparing the two sets of decision making in behavioral economics tasks with gambling performance measured by IGT, the latter shows decision making under ambiguity (i.e., without explicit probability distributions of outcomes), as is the case in real-life problems (Bechara et al., 1994; Bechara et al., 2000). In ambiguous decision making, the outcome delays and outcome probabilities are either unknown or must be estimated. As players begin the IGT, the contingencies of the four decks are unspecified, and as the task progresses, the trial-by-trial outcomes enable the estimation of outcome probabilities. This task also places demands on stimulus-reinforcement learning, reversal learning

(Follows & Farah, 2005), and working memory (Hinson, Jameson, & Whitney, 2002). These findings suggest that poor decision making in the IGT arises via multiple routes, that the IGT is an implicit or complex task, and that the IGT has various components. Ambiguous decision making such as that in the IGT may include components of delay discounting (intertemporal) and probability discounting (risky). On the other hand, the delay and probability discounting tasks are simpler and more explicit and demand more basic decision making than those in the IGT. In comparison to the IGT, delay discounting tasks are more explicit for intertemporal impulsivity or the preference for short-term benefits, whereas probability discounting tasks are also more explicit with respect to risk taking in uncertain conditions.

The third finding suggests that psychopathic traits are related to risk-taking decisions under uncertain choices, while psychopathic traits are unrelated to impulsivity in intertemporal choice. Individuals with psychopathic traits are not impulsive in intertemporal choice or they do not prefer short-term benefits; however, they do prefer rewards to a large extent, regardless of the uncertainty, and do not take uncertain losses seriously, resulting in risky decisions. Therefore, it is conceivable that individuals with strong psychopathic traits may have a tendency to exhibit risky behavior in daily life. The present study indicates that the fearless dominance of psychopathic traits in particular is associated with risky behavior. The fear state tells us what is safe and what is dangerous and how to respond in appropriate ways to environmental threats. Fear is also a key determinant in the motivational balance between sensitivity to punishment and reward. Fear is an indispensible emotional state that enables animals to adapt to dangerous situations (Ledoux, 1998). Therefore, individuals with psychopathic traits are not motivated to avoid possible punishment, especially when a reward is pending.

In characterizing the nature of specific psychopathic episodes, Blair et al. (2005) argued that it was important to distinguish between reactive and instrumental aggression and that psychopathy is unique in that it is a disorder associated with elevated levels of instrumental aggression. In real-world decision making, uncertainty is present when an outcome occurs with some probability as well as when an outcome occurs after some delay. In either case, a decision-maker must consider the possibility that the outcome may not be realized. In the present experiment, we propose risky and intertemporal choice to be distinct categories, and psychopathic traits are unique in that they are related to risk-taking decisions under uncertain choices rather than "myopia for the future." Future studies should estimate the biological and environmental contributions to the above psychopathic behavior since it is considered to be mediated by separable neurocognitive systems.

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Table 1

Means and Standard Deviations for Obtained Variables

	mean	SD
PPI-R total	287.85	24.26
- SCI [a]	148.22	14.27
- FD	106.63	15.17
- C	33.00	5.38
IGT net score [b]	22.43	23.06
DD of gain *k* [c]	-7.71	2.05
DD of loss *k*	-7.50	2.41
PD of gain *k*	0.37	1.25
PD of loss *k*	-0.15	0.75

Notes. [a] SCI = self-centered impulsivity; FD = fearless dominance; C = coldheartedness.

[b] The larger the IGT net score is, the more advantageous the IGT performance is.

[c] For discounting parameters, the natural logarithm (ln) of the *k* parameters was calculated. A larger ln *k* corresponds to greater discounting. DD = delay discounting; PD = probability discounting.

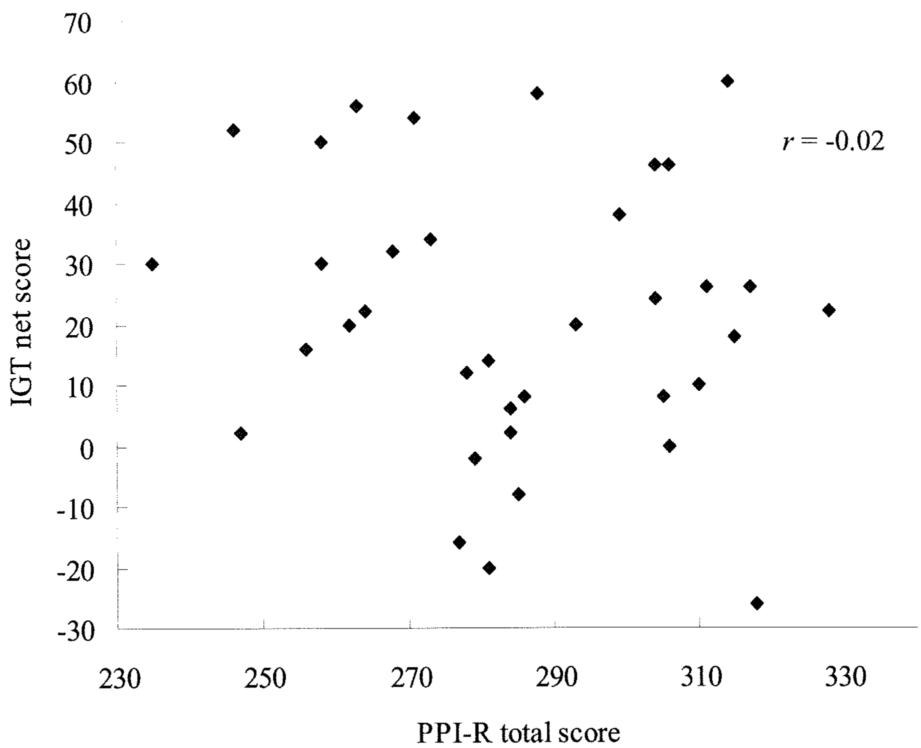

Figure 1. Scatter Plot of the PPI-R Total Score and the IGT Net Score. No correlation was observed (p = 0.93).

Table 2

Correlations Among PPI-R Total Score, IGT Net Score, and Discounting Parameters

	PPI-R	IGT	DD of gain *k*	DD of loss *k*	PD of gain *k*	PD of loss *k*
PPI-R	—	-0.02	0.05	0.15	-0.38*	0.43**
IGT net score		—	-0.09	-0.02	0.10	0.07
DD of gain *k*			—	0.62**	0.09	0.08
DD of loss *k*				—	-0.15	0.21
PD of gain *k*					—	-0.42**
PD of loss *k*						—

Notes. Larger *k* (ln *k*) values correspond to stronger discounting. DD = delay discounting; PD=probability discounting.

$^{*}p < 0.05$, $^{**}p < 0.01$.

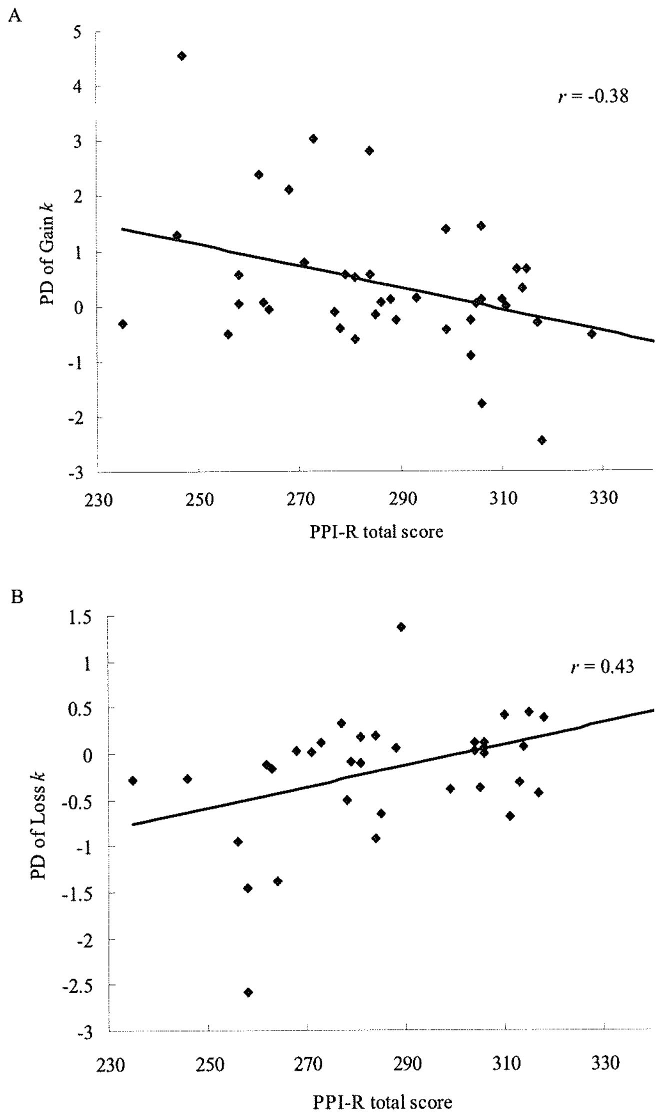

Figure 2. Scatter Plot of the PPI-R Total Score and the *k* (ln *k*) of the Probability Discounting.Panel A, the probability discounting of monetary gains; a significant correlation was observed ($p < 0.05$). A larger *k* (ln *k*) indicates a higher degree of probability discounting of uncertain gains. Panel B, the probability discounting of monetary losses; a significant correlation was observed ($p < 0.01$). A larger *k* indicates a higher degree of probability discounting of uncertain losses.