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ORIGINAL ARTICLE

Neuroeconomics of psychopathy: risk taking in probability discounting of gain and loss predicts psychopathy

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Abstract

BACKGROUND: This study investigated the relationships between psychopathy and impulsive and risky decision making, by utilizing intertemporal and probabilistic choices for both gain and loss, in addition to the Iowa gambling task.
METHODS: The Psychopathic Personality Inventory-Revised – a 154-item measure that assesses psychopathic traits by self-report – was used with a 4-point response scale to assess 113 undergraduate students from three Japanese universities. Participants' performance on the Iowa Gambling Task and four behavioral neuroeconomic tasks of discounting – delayed gain, delayed loss, uncertain gain, and uncertain loss – were estimated.
RESULTS: Risky decisions in probability discounting of gain and loss were associated with psychopathy. Psychopathic traits had no relationship with performance on the Iowa Gambling and were not significantly related to delay discounting.
CONCLUSIONS: Psychopathy is predicted by risky decision in probability discounting of gain and loss, but not strongly associated with future myopia. Implications of the present findings for neuroeconomics and neurolaw are discussed.

INTRODUCTION

Psychopathy is a personality 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 conduct and antisocial personality disorders (APD) in the Diagnostic and Statistical Manual of Mental of Disorders, 4th edition, in which diagnosis is focused 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 lesion studies, particularly in studying performance deficits linked to lesions in the ventromedial prefrontal cortex (vmPFC) (Bechara *et al.* 1994). Patients with vmPFC damage commonly display a syndrome that includes poor judgment, socially inappropriate behavior, and impulsivity (Damasio1994). 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; 2000). Such patients often exhibit behavioral problems that are similar to those found in individuals with psychopathy. Damasio *et al.* (1990; 1994) anticipated that vmPFC dysfunctions account for psychopathic tendency.

As far as we know, several studies have used the IGT to investigate the relationship between decision-making and psychopathy (Schmitt *et al.* 1999; Bass & Nussbaum 2010). Blair *et al.* (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 *et al.* (2002) reported that psychopathic inmates in high-security prisons had poorer IGT performance than nonpsychopathic inmates did. Van Honk *et al.* (2002) reported that the sub-clinical psychopathy group showed more impaired IGT performance than non-psychopathy group. 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 *et al.* (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 neuro- economics, decision making has been 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 *et al.* 1999; Kirby *et al.* 1999; Ohmura *et al.* 2005; Petry 2001; Reynolds *et al.* 2007; Vuchinich & Simpson 1998; Wittmann *et al.* 2007). Standard economic theory assumes that a discount rate is independent of dynamic consistency (D), which yields the exponential discount function (Frederick *et al.* 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, participants underestimate their future impulsivity, resulting in preference reversal as time passes (Frederick *et al.* 2002; Takahashi 2005).

On the other hand, participants discount the value of uncertain rewards as the probability of receiving the rewards decreases (Rachlin *et al.* 1991; Yi *et al.* 2006). 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 (OhmuraEt *al.* 2005; Rachlin *et al.* 1991; Yi *et al.* 2006). 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.

Two previous studies are related to our study. One of them examined the relationship between APD and the discounting of delayed rewards by investigating substance (e.g., alcohol, marijuana, cocaine, sedatives, or heroin) abusers with APD, substance abusers without APD, and the required non-substance-abusing controls 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. The substance abusers discounted delayed rewards at greater rates than the controls; further, the substance abusers with APD discounted delayed rewards at higher rates than the non-APD substance abusers (Petry 2002). Melanko *et al.* (2009) focused on psychopathic traits estimated by a self-report measure, namely, the Youth Psychopathic Traits Inventory (YPI; Andershed *et al.* 2007). The YPI has a good convergent validity with the PCL youth version. This study compared the delay discounting behavior for rewards in community-dwelling adolescent non-smokers with low psychopathy, smokers with low psychopathy, and those with high psychopathy by using two delay discounting tasks. These assessments included question-based and real-time measures of delay discounting of rewards. According to researchers, these results indicated that elevated but subclinical levels of antisociality are associated with more optimal decision making.

The samples in the above two studies exhibited APD or psychopathy combined with substance abuse or smoking. Previous studies have revealed 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). The above two studies only assessed the delay discounting of rewards, not that of losses. Further, they estimated delay discounting, but not probability discounting.

The participants of previous studies on psychopathy were often clinical or incarcerated individuals; this introduced potentially confounding variables (e.g., severe substance use) that could complicate the interpretations (Lilienfeld & Andrews 1996). Thus, the present study investigated non-clinical individuals to minimize these effects. This selection approach was verified by recent statistical analyses, demonstrating that the scores on psychopathy measures are underpinned by a latent dimension rather than a latent taxon (Edens 2006). The present study is the first to investigate the relationship between psychopathic traits and IGT with individuals in a community. It aims to estimate the relationship between psychopathic traits and the tendency toward four behavioral economic types of decision making (i.e., discounting of delayed and uncertain monetary gains and losses) as well as IGT performance; moreover, it aims to demonstrate their cognitive mechanisms by elucidating the difference between risky decisions in the IGT and probability discounting, in addition to impulsivity in intertemporal choice.

MATERIALS AND METHODS

Participants

The participants belonged to a larger group comprising students from three Japanese universities (Hokkaido University, The University of Tokyo and Chuo University). This study recruited 115 Japanese non-smokers who have never smoked. We screened the participants using the Mini-International Neuropsychiatric Interview (MINI), and excluded two of them because they were diagnosed with psychiatric disorders (panic disorder and eating disorder). Further, all the participants were screened by a psychiatrist on the basis of DSM-IV to check for any history of psychiatric or neurological disorders, serious physical illnesses, or within-second-degree relatives with a history of major psychiatric disorders or substance abuse (e.g., alcohol, nicotine, marijuana, cocaine, and heroin). Thus, 113 undergraduate and postgraduate students (66 men and 47 women) aged between 18 and 34 years (mean ± SD=21.18±2.71) participated in this study. In accordance with the Helsinki Declaration of Human Rights, after complete description of the study to the participants, written informed consent was obtained. The study protocol was approved by the ethics committee at Hokkaido University.

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 four-point response scale. The internal consistency reliability in non-institutionalized samples was 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 non-planfulness scale scores. The eighth content scale, coldheartedness (C), does not load on either factor. The Japanese version of the PPI-R was translated by the authors, using the forward-backward method and was approved by Psychological Assessment Resources, Inc. The internal consistency of our sample

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was found to be 0.84 for the total score (Cronbach's alpha, for subscales, SCI=0.87, FD=0.90, C=0.67).

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 participants 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 *et al.* 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 participants 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 *et al.* 2006). 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.* 2006), 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 participants 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 *et al.* 2004). All statistical and nonlinear curve fitting procedures were conducted with R statistical language. The significance 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 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=−0.15, p=0.13; see Figure 1, Table 2). Next, we examined the relationships between PPI-R factors and IGT performance. We observed no significant correlation between them (see Table 3). However, only fearlessness dominance subscale was marginaly correlated with the IGT net score (r=−0.19, p=0.052).

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=0.43, p<0.001) and between the probability discounting of gain and loss (r=−0.21, p=0.03) were observed, indicating that participants who overestimate the reward value of an uncertain reward tend to also underestimate the risk of an uncertain loss. This indicates that weak probability discounting of gain and strong probability discounting of loss corresponds to risky decision in probability discounting. While there was positively significant correlation between the delay and probability discounting of loss (r=0.19, p=0.04), there was no significant correlation between the delay and probability discounting of gain (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 (See Table 2). However, significant correlations between the PPI-R total score and probability discounting of both gain and loss were observed, in a negative and positive manner, respectively (gain: r=−0.29, p=0.002; loss: r=0.34, p=0.0003; see Table 2, Figure 2). This indicates that the participants with a high PPI-R total score overestimated the reward value of uncertain gains and underestimated the risk of uncertain losses. In other words, psychopathy was associated with more risky decision under uncertainty. Furthermore, we investigated the relationships between PPI-R factors (i.e., SCI,

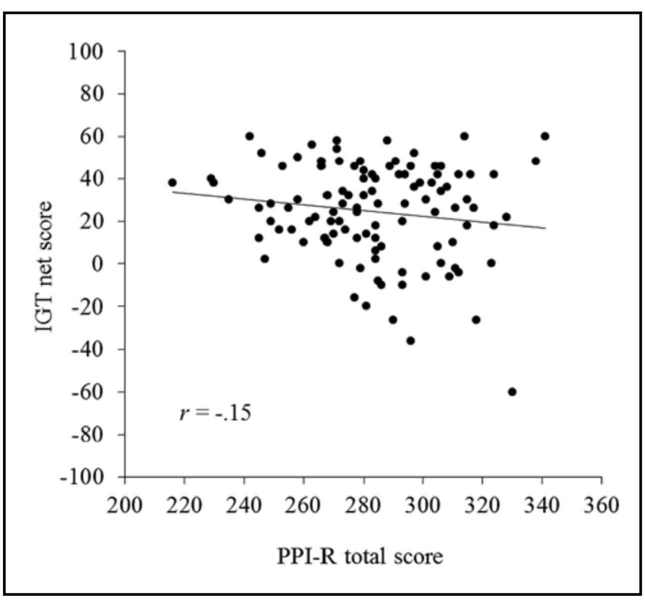

Fig. 1. Scatter Plot of the PPI-R Total Score and the IGT Net Score.

Tab. 1. Means and standard deviations for obtained variables.

	M	SD
PPI-R total	285.26	24.77
- SCI [a]	148.68	15.01
- FD	102.91	14.90
- C	33.66	5.21
IGT net score [b]	24.32	22.76
DD of gain *k* [c]	0.002422	0.009453
DD of loss *k*	0.004735	0.024612
PD of gain *k*	7.3399	20.5875
PD of loss *k*	2.1465	13.0900

[a] SCI = self-centered impulsivity; FD = fearless dominance; C = cold heartedness. [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 *k* corresponds to greater discounting. DD = delay discounting; PD = probability discounting.

Tab. 2. Correlations among PPI-R total score, IGT net score, and discounting parameters.

	1	2	3	4	5	6
1 PPI-R	-	−0.150	0.060	0.171	−0.293**	0.337***
2 IGT net score		–	−0.152	−0.133	0.151	0.033
3 DD of gain log *k*			–	0.430***	−0.002	0.239*
4 DD of loss log *k*				–	−0.004	0.194*
5 PD of gain log *k*					–	−0.211*
6 PD of loss log *k*						-

*p<0.05, **p<0.01, ***p<0.001. Larger k (ln k) values correspond to stronger discounting. DD = delay discounting; PD = probability discounting. Psychopathic tendency is related to "risky" decision under uncertainty (strong probability discounting of gain and weak probability discounting of loss; i.e., overweighting of uncertain reward and underweighting of uncertain punishment)

Tab. 3. Correlations between PPI-R factors scores and discounting parameters.

	PD of gain log *k* [a]	PD of loss log *k*	IGT net score
SCI [b]	−0.197*	0.307**	−0.058
FD	−0.245**	0.176	−0.190
C	−0.130	0.216*	0.002

*p<0.05, **p<0.01. [a] Larger k (ln k) values correspond to stronger probability discounting. PD = probability discounting.
[b] SCI = self-centered impulsivity; FD = fearless dominance; C = coldheartedness. All of psychopathic factors are associated with weak probability of gain (i.e., overweighting the value of uncertain reward) and strong probability discounting of loss (i.e., underweighting the seriousness of uncertain punishment).

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FD, and C) and probability discounting k parameters (Table 3). The score of SCI was negatively and positively correlated with probability discounting of gain and loss, respectively (r=–0.197, p=0.037, for gain; r=0.307, p=0.001, for loss). The score of FD was negatively correlated with probability discounting of gain (r=–0.245, p=0.009). The score of C was positively correlated with probability discounting of loss (r=0.216, p=0.022).

DISCUSSION

The main finding is that psychopathy is predicted by risky decision in probability discounting. 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 positive and negative correlations between the delay discounting of gain and loss and between the probability discounting of gain and loss, respectively. Delay discounting of gain was not significantly correlated with probability discounting of gain; while delay discounting of loss was positively correlated with probability discounting of loss. Third, significant correlations between the PPI-R scores and some of probability discounting parameters were observed, instead of delay 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 (Schmitt *et al.* 1999; Blair *et al.* 2001; Mitchell *et al.* 2002; Van Honk *et al.* 2002; Lösel & Schmucker 2004). 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 (Schmitt *et al.* 1999; Lösel & Schmucker 2004). 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 more tendency of procrastination the individual has. 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, at least partially, dissociated. Previous studies have proposed that two functions, intertemporal choice and risky choice, utilize the same psychological mechanism (Rachlin *et al.* 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 & Weber 2006; Rachlin *et al.* 2000). The only fMRI study on the delay and probability discounting tasks reported that intertemporal and probability choices invoked different

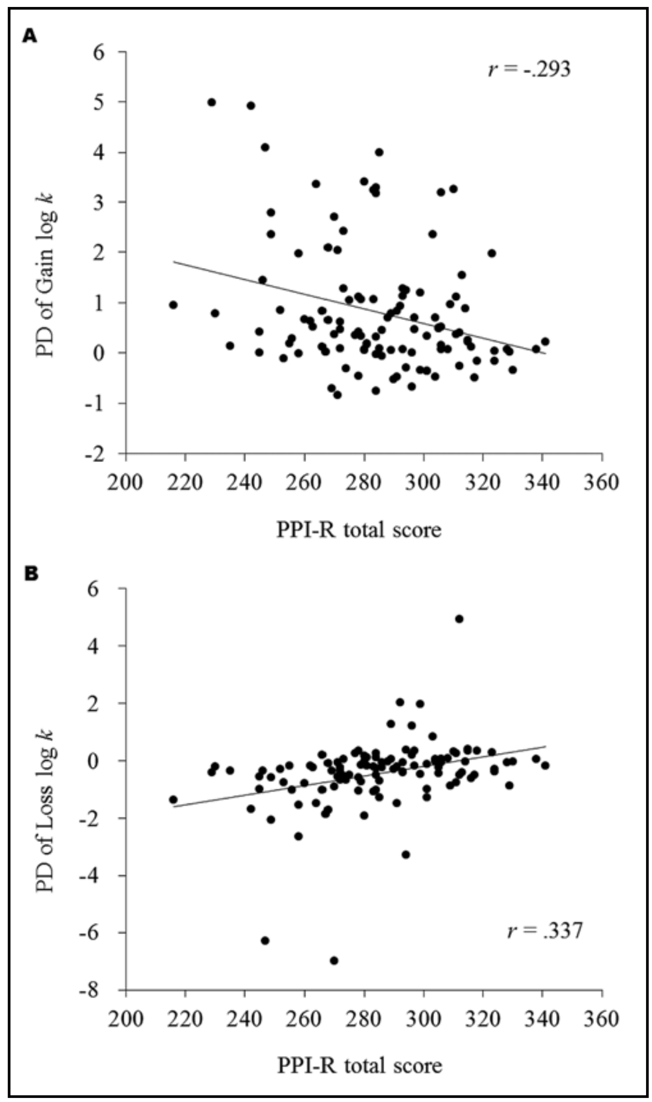

Fig. 2. Scatter Plot of the PPI-R Total Score and the k (ln k) of the Probability Discounting. Panel A, the probability discounting of monetary gains; a significant correlation was observed (p<0.01). A larger k (ln k) indicates a higher degree of probability discounting of uncertain gains. Panel B, the probability discounting of monetary losses; a significant correlation was observed (p<0.001). A larger k indicates a higher degree of probability discounting of uncertain losses.

patterns of neural activation (Weber & 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; 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 *et al.* 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 regarding expected gains and losses.

The third finding suggests that psychopathic traits are related to risk-taking decisions under uncertainty, 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 elevated psychopathic traits may have tendency to exhibit risky behavior in daily life.

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. We might 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.

In neuroeconomics of crime and punishment, molecular neurobiological machineries mediating risky decisions are supposed to be associated with criminal behavior via reduction in sensitivity to potential punishment associated with anti-social behaviors (Takahashi 2012). The present study illustrates how sensitivities to uncertain punishment and reward are related to psychopathy, by utilizing the framework of probability discounting. Future investigations in neuroeconomics of crime and punishment and neurolaw (Jones *et al.* 2013) should employ probability discounting tasks for gain and loss, to analyze decisions underlying criminal behaviors.

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Authors' contributions: HF, MT, and TT designed research; HT and HN performed research and analyzed data; HF, TT, HN and HT wrote the paper. All authors read and approved the final manuscript.

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REFERENCES

1 Andershed H, Hodgins S, Tengström A (2007) Convergent validity of the Youth Psychopathic Traits Inventory (YPI): association with the Psychopathy Checklist: Youth Version (PCL:YV). Assessment. **14**(2): 144–154.
2 Bass SLS, Nussbaum D (2010). Decision Making and Aggression in Forensic Psychiatric Inpatients. Criminal and Justice Behavior. **37**(4): 365–383.
3 Bechara A, Damasio AR, Damasio H, Anderson SW (1994). Insensitivity to future consequences following damage to human prefrontal cortex. Cognition. **50**(1–3): 7–15.
4 Bechara A, Tranel D, Damasio H (2000). Characterization of the decision-making deficit of patients with ventromedial prefrontal cortex lesions. Brain. **123**(11): 2189–2202.
5 Bickel WK, Marsch LA (2001). Toward a behavioral economic understanding of drug dependence: delay discounting processes. Addiction. **96**(1): 73–86.
6 Bickel WK, Odum AL, Madden GJ (1999). Impulsivity and cigarette smoking: delay discounting in current never and ex-smokers. Psychopharmacology (Berl). **146**(4): 447–454.
7 Blair J, Mitchell D, Blair K (2005). The Psychopath: Emotion and the Brain. Oxford, U.K: Blackwell Publishing.
8 Blair RJR, Colledge E, Mitchell DGV (2001). Somatic markers and response reversal: Is there orbitofrontal cortex dysfunction in boys with psychopathic tendencies? Journal of Abnormal Child Psychology. **29**(6): 499–511.
9 Chapman GB, Weber BJ (2006). Decision biases in intertemporal choice and choice under uncertainty: testing a common account. Memory & Cognition. **34**(3): 589–602.

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10 Damasio AR (1994). Descartes' Error: Emotion, Reason, and the Human Brain. New York: Putnam.
11 Damasio AR, Tranel D, Damasio H (1990). Individual with sociopathic behavior caused by frontal damage fail to respond autonomically to social stimuli. Behavioral Brain Research. **41**(2): 81–94.
12 Edens JF, Marcus DK, Lilienfeld SO, Poythress NG Jr (2006). Psychopathic, not psychopath: taxometric evidence for the dimensional structure of psychopathy. Journal of Abnormal Psychology. **115**(1): 131–144.
13 Follows LK, Farah MJ (2005). Different underlying impairments in decision making following ventromedial and dorsolateral frontal lobe damage in humans. Cerebral Cortex. **15**(1): 58–63.
14 Frederick S, Loewenstein G, O'Donoghue T (2002). Time discounting and time preference: a critical review. Journal of Economic Literature. **40**(2): 351–401.
15 Fukui H, Murai T, Fukuyama H, Hayashi T, Hanakawa T (2005). Functional activity related to risk anticipation during performance of the Iowa gambling task. Neuroimage. **24**(1): 253–259.
16 Gao Y, Baker LA, Raine A, Wu H, Bezdjian S (2009). Brief Report: Interaction between social class and risky decision-making in children with psychopathic tendencies. Journal of Adolescence. **32**(2): 409–414.
17 Hare RD (1991). The Hare Psychopathy Checklist-Revised. Toronto: Multi-Health Systems.
18 Hinson JM, Jameson TL, Whitney P (2002). Somatic markers, working memory, and decision making. Cognitive, Affective, & Behavioral Neuroscience. **2**(4): 341–353.
19 Johnson MK, Bickel WK (2002). Within-subject comparison of real and hypothetical money rewards in delay discounting. Journal of the Experimental Analysis of Behavior. **77**(2): 129–146.
20 Jones OD, Marois R, Farah MJ, Greely HT (2013) Law and neuroscience. J Neurosci. **33**(45): 17624–17630.
21 Kirby KN, Petry NM, Bickel WK (1999). Heroin addicts have higher discount rates for delayed rewards then non-drug-using controls. Journal of Experimental Psychology General. **128**(1): 78–87.
22 Lilienfeld SO, Andrews BP (1996). Development and preliminary validation of a self-report measure of psychopathic personality traits in noncriminal populations. Journal of Personality Assessment. **66**(3): 488–524.
23 Lilienfeld SO, Widows M (2005). Professional Manual for the Psychopathic Personality Inventory-Revised (PPI-R). Florida : Psychological Assessment Resources, Lutz.
24 Lösel F, Schmucker M (2004). Psychopathy, risk taking, and attention: a differentiated test of the somatic marker hypothesis. Journal of Abnormal Psychology. **113**(4): 522–529.
25 Mahmut MK, Homewood J, Stevenson RJ (2007). The characteristics of non-criminals with high psychopathy traits: Are they similar to criminal psychopaths? Journal of Research in Personality. **42**(3): 679–692.
26 Melanko S, Leraas K, Collins C, Fields S, Reynolds B (2009). Characteristics of psychopathy in adolescent nonsmokers and smokers: Relations to delay discounting and self-reported impulsivity. Experimental and Clinical Psychopharmacology. **17**(4): 258–265.
27 Miranda RM, MacKillop J, Justus A, Myerson L, Lovallo W (2009). Influence of Antisocial and Psychopathic Traits on Decision-Making Biases in Alcoholics. Alcoholism: Clinical and Experimental Research. **33**(5): 817–825.
28 Mitchell DGV, Colledge E, Leonard A, Blair RJR (2002). Risky decisions and response reversal: is there evidence of orbitofrontal cortex dysfunction in psychopathic individuals? Neuropsychologia. **40**(12): 2013–2022.
29 Ohmura Y, Takahashi T, Kitamura N (2005). Discounting delayed and probabilistic monetary gains and losses by smokers of cigarettes. Psychopharmacology (Berl). **182**(4): 508–515.
30 Petry NM (2001). Delay discounting of money and alcohol in actively using alcoholics, currently abstinent alcoholics, and controls. Psychopharmacology (Berl). **154**(3): 243–250.
31 Petry NM (2002). Discounting of delayed rewards in substance abusers: relationship to antisocial personality disorder. Psychopharmacology. **162**(4): 425–432.
32 Rachlin H, Brown J, Cross D (2000). Discounting in judgments of delay and probability. Journal of Behavioral Decision Making. **13**(2): 145–159.
33 Rachlin H (1995). Self-control: beyond commitment. Behavioral and Brain Sciences. **18**(1): 109–121.
34 Rachlin, H, Logue, AW, Gibbon, J, Frankel, M (1986). Cognition and behavior in studies of choice. Psychological Review. **93**(1): 33–45.
35 Rachlin, H, Raineri, A, Cross, D (1991). Subjective probability and delay. Journal of the Experimental Analysis of Behavior. **55**(2): 233–244.
36 Rachlin H (1989). Judgment, decision, and choice: a cognitive/behavioral synthesis. New York : Freeman.
37 Reynolds B, Patak M, Shroff P (2007). Adolescent smokers rate delayed rewards as less certain than adolescent nonsmokers. Drug and Alcohol Dependence. **90**(2–3): 301–301.
38 Reynolds B, Richards JB, Horns K, Karraker, K (2004). Delay discounting and probability discounting as related to cigarette smoking status in adults. Behavioral Processes. **65**(1): 35–42.
39 Schmitt WC, Brinkley CA, Newman JP (1999). Testing Damasio's somatic marker hypothesis with psychopathic individuals: risk takers or risk averse? Journal of Abnormal Psychology. **108**(3): 538–543.
40 Shead NW, Hodgins DC (2009). Probability discounting of gains and losses: Implications for risk attitudes and impulsivity. Journal of the Experimental Analysis of Behavior. **92**(1): 1–16.
41 Takahashi T (2005). Loss of self-control in intertemporal choice may be attributable to logarithmic time-perception. Medical Hypotheses. **65**(4): 691–693.
42 Takahashi T (2007). A comparison of intertemporal choices for oneself versus someone else based on Tsallis' statistics. Physica A. **385**(2): 637–644.
43 Takahashi T (2012) Molecular neuroeconomics of crime and punishment: implications for neurolaw. Neuro Endocrinol Lett. **33**(7): 667–673.
44 Van Honk J, Hermans EJ, Putman P, Montagne B, Schutter DJ (2002). Defective somatic markers in sub-clinical psychopathy. Neuroreport. **13**(8): 1025–1027.
45 Vassileva J, Petkova P, Georgiev S, Martin EM, Tersiyski R, Raycheva M, Velinov V, Marinov P (2007). Impaired decision making in psychopathic heroin addicts. Drug and Alcohol Dependence. **86**(2–3): 287–289.
46 Vuchinich RE, Simpson CA (1998). Hyperbolic temporal discounting in social drinkers and problem drinkers. Experimental & Clinical Psychopharmacology. **6**(3): 292–305.
47 Weber BJ, Huettel AA (2008). The neural substrates of probabilistic and intertemporal decision making. Brain Research. **1234**(9): 104–115.
48 Wittmann M, Leland DS, Churan J, Paulus MP (2007). Impaired time perception and motor timing in stimulant-dependent subjects. Drug and Alcohol Dependence. **90**(2–3): 183–192.
49 Yechiam E, Kanz J, Bechara A, Stout JC, Busemeyer JR, Altmaier EM, Paulsen J (2008). Neurocognitive deficits related to poor decision-making in people behind bars. Psychonomic Bulletin and Review. **15**(1): 44–51.
50 Yi R, de la Piedad X, Bickel WK (2006). Discounting of past outcomes. Experimental & Clinical Psychopharmacology. **14**(3): 311–317.
51 Yi R, de la Piedad X, Bickel WK (2006). The combined effects of delay and probability in discounting. Behavioral Processes. **73**(2): 149–155.