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***Chapter 11***

# HOW EXPERIENCE AND INFORMATION INFLUENCE CHOICE BEHAVIOR: A PILOT FMRI STUDY OF THE IOWA GAMBLING TASK

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## ABSTRACT

The present exploratory research extended the Iowa Gambling Task-fMRI study conducted by Lin et al. (2008a) and demonstrated how experience and information affect decision behavior and interrelated brain responses. The original Iowa Gambling Task (IGT) was designed to demonstrate choice behavior in uncertain situations, not risk situations—by providing gambling information (such as information regarding probabilities and values) to decision makers. Previously, Lin et al. (2008a) demonstrated that the activation of the basal forebrain was correlated to driving the decision and that the parietal and frontal cortex in response to the consequences evaluation under uncertainty. However, few investigations have examined changes in IGT brain maps under risk by providing gambling information (e.g., probability and value). Therefore, this study followed the paradigms established in Lin et al. (2008a), namely, using event-related fMRI and the same subjects group to identify IGT brain maps under risk (after first-run practice and after information was provided to subjects playing the game). Furthermore, we also compared brain maps under both uncertainty (Lin et al., 2008a) and risk. The behavioral results indicated that choice patterns under uncertainty and risk were markedly different for most decks. Notably, the present behavioral observations and the Soochow group's findings (Chiu et al., 2006; Lin et al., 2008b; Yen et al., 2013) have consistently demonstrated that it is possible to change decision behavior under dynamic and ambiguous situations when decision makers possess both the experience of practice and relevant gamble information. On the other hand, the basal forebrain was involved in driving the decision while the parietal and frontal lobes correlated to the consequences evaluation under not only in situations of uncertainty but also in risk situations. Remarkably, the variations in brain activation between uncertainty and risk situations may represent the changed awareness of choice consequences. Moreover, under both types of situations, we found the insula and striatum to be critical in responding to the anticipation (not outcome or reward). This finding might be valuable for clarifying certain controversial issues regarding the reward system (such as, for example, the function of the striatum; i.e., whether it is active in anticipation or reward-value representation) in dynamic choice situations. Nevertheless, the complex roles of the dorsolateral prefrontal cortex and the ventromedial prefrontal cortex in the IGT should be further elucidated. The present pilot illustration combined both the effects of practice and of providing information, so a clarifying study in which each individual factor is examined and discussed should be conducted in the future.

## ABBREVIATIONS

ACC: anterior cingulate cortex; DLPFC: dorsolateral prefrontal cortex; IFG: inferior frontal gyrus; IGT: Iowa Gambling Task; IN: insula; IPL: inferior parietal lobule; LN: lentiform nucleus; MCC: middle cingulate cortex; MFG: middle frontal gyrus; MPFC: medial prefrontal cortex; MTG: middle temporal gyrus; OFC: orbitofrontal cortex; PaL: paracentral lobule; M1: precentral gyrus; S1: somatosensory cortex (postcentral gyrus); SMH: Somatic Marker Hypothesis; S2: secondary somatosensory cortex; STG: superior temporal gyrus; SFG: superior frontal gyrus; SMA: supplementary motor area; VC: visual cortex; VMPFC: ventromedial prefrontal cortex

## INTRODUCTION

The functional differences between brain circuitry under uncertainty and under risk are not well understood, and they represent a gap in our understanding of the neuronal correlates of decision-making (Dunn et al., 2006; Krain et al., 2006). Therefore, this study sought to identify the patterns of choice behaviors and their corresponding brain maps in situations of either risk or uncertainty. More specifically, based on our own previous IGT-fMRI (Iowa gambling task combined functional Magnetic Resonance Imaging) study (Lin et al., 2008a), the study served as a pilot study to investigate the effects on choice behavior of experience and gamble information providing.

In recent decades, Damasio et al. proposed the somatic marker hypothesis (SMH) (Damasio et al., 1991; Damasio, 1994) and suggested that implicit emotional processing, executed by the somatic marker system, plays an important role in real-life decision-making under uncertainty (Damasio et al., 1996). According to the SMH, emotions play a role in rational choice behavior, particularly in highly ambiguous circumstances. The basic SMH assumes that emotion facilitates rational decisions in some uncertain situations (Damasio, 1994; Greenfield, 2001).

In traditional literature on decision-making, the definitions of "uncertainty" and "ambiguity" have overlapped in some respects. The term "uncertainty" has been defined as a risk condition that provides numerous possible consequences with distinct probabilities, while "ambiguity" has been defined as a condition in which potential outcomes and their probabilities are not clearly revealed to the decision makers (Hastie & Dawes, 2001; Plous, 1993). However, "uncertainty" as defined by the SMH is not only absent from the information on gambling probability and value provided to subjects, but also the information of the end of game in the dynamic game (Bechara et al., 1994). Furthermore, some pieces of information (e.g., the color of a card, the potential gain and loss within a trial) were presented during the IGT to distract the decision makers' logical reasoning. So, the definition of "uncertainty" employed in this manuscript primarily follows that of the SMH (basic assumption of IGT), while the concept of "risk" is primarily defined according to the specific gambles, which provide probability and gain-loss values for decision makers (Hastie & Dawes, 2001; Plous, 1993).

To verify the influence of emotions on decision-making, researchers at the University of Iowa developed the IGT to identify decision-making patterns under uncertainty (Bechara et al., 1994) and to evaluate the differences in decision-related functions between ventromedial prefrontal cortex (VMPFC)-damaged individuals and normal controls. In the IGT, players are free to choose from decks A, B, C, and D. They are told to earn as much money as possible or to lose as little as possible. However, subjects know neither the gain-loss structure of each deck nor when the game will end. Thus, subjects are placed in a context of uncertainty while playing the game, and they are forced to use their emotions to make rational decisions. Furthermore, subjects are unaware of the rules of the game when they begin to play (Bechara et al., 1999; Bechara et al., 2000). Decks A and B are bad decks with expected values (EVs) of -$250 after ten trials, whereas decks C and D are good decks with EVs of +$250 after ten trials. Bad decks A and B have a larger immediate gain-loss value than good decks C and D do. Decks A and C have a gain-loss frequency of 5 losses in 10 trials, whereas decks B and D have a gain-loss frequency of 1 large loss in 10 trials (see Supplementary Table 1). In the

original IGT, the gain-loss frequencies of the good and bad decks were equal, and the standard version involved 100 trials (Bechara et al., 1994; Bechara et al., 1997).

According to the SMH, the original IGT is a high-ambiguity game that captures real-life decision-making under uncertainty. In an uncertain situation, subjects are forced to use their emotions while making decisions because the logic system is ineffective (Damasio, 1994; Greenfield, 2001). A series of findings concerning players of the IGT support the SMH, indicating that with an intact SM system, normal decision-makers can make advantageous long-term choices. Conversely, patients with VMPFC lesions perform poorly (Bechara et al., 1997; Bechara et al., 1998; Bechara et al., 1999). Related neuropsychological studies have identified some brain regions, particularly those related to SM operations (i.e., the VMPFC, amygdala, insula (IN), somatosensory cortex (S1), and some brain stem nuclei), that are essential to decision-making with help from the SM (Bechara et al., 1999; Bechara, 2001; Bechara et al., 2001).

Notably, extensive neurological evidence obtained by the Iowa group clearly demonstrates that the VMPFC, and not the dorsolateral prefrontal cortex (DLPFC), is critical to regulating emotions and decision-making under uncertainty (Bechara et al., 1998). A critical IGT-related neurological study of the function of the VMPFC and DLPFC showed that the primary function of the VMPFC is to make snap emotionally loaded decisions under uncertainty, whereas the DLPFC is not used for making emotionally loaded decisions. In addition, previous investigations of the DLPFC have found that the DLPFC may be crucial in "cool" executive functions (such as working memory and time-free, logic-loaded decision-making behavior) in situations of certainty, that is, situations with clear information and without time constraints (Bechara et al., 1998; Farah, 2006; Krain et al., 2006).

According to Damasio (Greenfield, 2001), in a "logic-launched" and "informative" situation of risk, the brain circuitry should differ from the original brain loops that are referred to by the SMH, or the activation of SM loops should decline (Bechara, 2001). In the risk-IGT, the gain-loss value, probability associated with each deck, and information about the expected value of each deck were disclosed to the subjects; thus, the neuronal substrates for working memory and logic-loaded decisions should have been activated (Roger et al., 1999; Huettel et al., 2005; Huettel et al., 2006), and the brain activation of SMH loops should have decreased from uncertainty to risk. Based on the findings of Bechara et al. (1998), the DLPFC is associated with working memory, logic-loaded information processing, and non-emotion-loaded decision-making. Hence, when subjects are under relative certainty in informative environments, they are forced to use logical reasoning, and the DLPFC should be activated (Bechara et al., 1998). If the SMH holds, then DLPFC activation increases and that of the VMPFC decreases during the risk-IGT. First, this investigation classifies brain maps that are associated with the IGT under risk, which are helpful in identifying the neuronal correlates that drive decisions and evaluating outcomes under uncertainty and risk (Fukui et al., 2005; Krain et al., 2006; Northoff et al., 2006; Tanabe et al., 2007; Lin et al., 2008a; Lawrence et al., 2009; Li et al., 2010). Second, in this study, we compare IGT-fMRI results under uncertainty from our previous study (Lin et al., 2008a) with brain imaging results to show the various stages associated with conditions of gain-loss, decks, and values during the anticipatory and response phases of the IGT under risk. Third, we examine the roles of the VMPFC and DLPFC under risk during the IGT. Regarding behavior, we previously proposed that normal subjects performed better under risk than under uncertainty (Lin et al., 2008a). The subjects' selection patterns can be the index that marks the difference in brain-loops

between uncertainty and risk. The various brain-loops of the uncertainty-IGT and risk-IGT require verification.

## METHODS

Our previous study involved 24 volunteers, 16 men and 8 women (mean age = 21.0; SD = 3.1), (Lin et al., 2008a) who, in the first session, performed the IGT first without being given any information about probability or value (the results are published in BMC Neuroscience) (Lin et al., 2008a). In the second session (risk period, in this study mainly), gain-loss probability and value information concerning each deck were disclosed to the subjects. Each subject gave informed consent before playing the game and undergoing fMRI scanning. The investigation was approved by the Institutional Ethics Committee of Taipei Veterans General Hospital. It was conducted according to the Declaration of Helsinki.

### Paradigms

The IGT, a computerized version of a four-card game, was explained to each subject. Subjects were told to earn as much money or lose as little money as possible. Each subject was informed that each card is either red or black and that the color is unrelated to gain or loss. As in the original IGT, subjects did not know when the game would end. The subjects had to work out the rules of the game by trial (Bechara et al., 1994; Bechara et al., 1997; Bechara et al., 1999; Bechara et al., 2000). Additionally, the probability and value information of each deck in this study was presented on a gray square on each deck (Figure 1).

To prevent the confounding effect of card order and visual field, each subject was presented cards in various positions (e.g., ABCD, BCDA). To increase their motivation, subjects were told that they were playing for real money (New Taiwan Dollars), and that they could keep the money they earned. For example, a subject with a balance of NT$300,000 at the end of the game was rewarded NT$300 (approximately US$10). Subjects were informed of the exchange rate (N/1000) before the start of the game. In each trial during a scan, subjects used an MR-compatible joystick to select cards and were free to choose from decks at their own speed. Following each choice, the computer presented the results on the screen for approximately 10s and locked an interval for signal modeling in event-related fMRI. (See Figure 1 and the legend for details). All of the subjects recruited for this study are the same as those who participated in our previous research, and they completed the first session of the original IGT without being given any information while under fMRI scanning, as in our previous study.

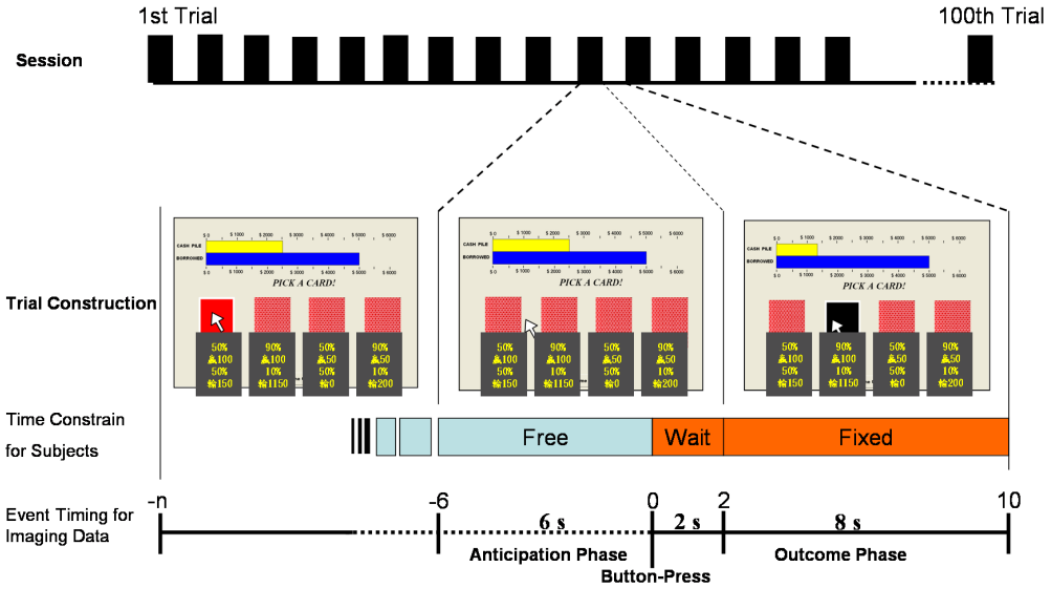


Figure 1. Computer version of the IGT and event-related fMRI under risk. In the IGT-risk, subjects were given probability and value information concerning each deck. This deck information was taken from the IGT table (ten-trial in first circle) of Bechara et al. (1994). Gambling information was displayed on a computer screen using the net gain-loss value in each trial and probability on an average of 10 trials. The gain-loss information of each deck was presented to subjects throughout the game. Subjects were allowed to choose a card in each trial. However, when a decision was made (i.e., the button was pressed) and the outcome was revealed (after a 2-s interval), the computer screen remained fixed for approximately 8 s to calculate the fMRI signal.

Then, they completed the second session after being given information on probability and value for each deck while under the second fMRI scanning. After a 15-min rest period outside the scanner, structural and anatomical images were obtained.

## fMRI Data Acquisition

The fMRI studies were performed using a quadrature head coil on a 3.0 T MedSpec S300 MRI scanner (Bruker, Kalsrube, Germany). During MRI scanning, a vacuum-beam pad was used to fix the heads of the subjects to minimize voluntary head movement. A gradient-echo Echo-Planar-Image (EPI) pulse sequence was adopted to capture functional images. The image parameters with whole-brain coverage were: image matrix = 64 × 64; field of view (FOV) = 230 × 230 $mm^2$; slice number = 20; slice thickness + gap = 5 + 1 mm, and, TR (repetition time)/TE (echo time) /θ (flip angle) = 2000 ms/50 ms/90°. In each fMRI session, the first 5 images, dummy scans, were discarded to obtain a series of functional images under a steady state. To localize functional information, a high-resolution T1-weighted image was acquired as an anatomical image with a 3D gradient-echo pulse sequence and Modified Driven Equilibrium Fourier Transform (MDEFT). Its image parameters were image matrix = 256 × 256; FOV = 230 × 230 $mm^2$; slice number = 128; slice thickness = 1.5 mm; and, TR/TE/TI (inversion time) = 88.1 ms/4.12 ms/650 ms.

## Data Processing and Analysis

Matlab 6.5 and 7.0 were used to record choice patterns and reaction times in the IGT, as well as to co-register fMRI signals. Statistical testing and data analysis were conducted using Statistical Parametric Mapping (SPM2, SPM8, SPM12b) (Welcome Department of Cognitive Neurology, London, UK), and data were presented using xjView 8.0 (Human Neuroimaging Lab, Baylor College of Medicine, Houston, TX, USA). The fMRI images were realigned, coregistered, normalized, time-corrected, and spatially smoothed using a 4 mm full-width-at-half-maximum (FWHM) Gaussian kernel, using standard SPM2 methods. Subjects were free to make decisions in each trial, but not during a fixed period of approximately 10 s after a card had been turned over. Each subject made 100 choices, and the range of numbers of scans (images) that were taken from the 24 subjects was 526–602 (with a mean of 573). First level analysis: The General Linear Model (GLM) in SPM2 was launched first to model the event-time course for each subject. The first level of statistical analysis for each subject was launched to look for the specific voxel in response to specific events (e.g., largest loss (-$1150)). After all the results (maps) for each subject (total 24 subjects) were completed, the second level of statistical analysis (random effect model) was conducted across subjects in each condition. Second level analysis: The random-effect model was applied to exclude individual artifacts and present the averaged brain response in each condition. The second-level (group) analysis of most conditions was based on the consistent criteria (P *uncorrected* = 0.0001, K = 30 in most cases; for criteria, see figure legends). Talairach and Tournoux's 3-D brain stereotaxic system (Talairach and Tournoux, 1988) with a Montreal Neurological Institute (MNI) template (305 T1) in SPM2 and xjView 8 was used to determine the coordinates of the local T-maxima.

The conventional neurological perspective was adopted to present imaging data (the left image of the brain was of a subject's left-brain). To model brain responses during the period of anticipation, the event was defined as 6 s (three scans) forward shifting of the time-point of the button press. To model brain response during the period of experience, the event was defined as the time at which the button was pressed. The modified hemodynamic response function (hrf with time derivative) in SPM2 was used to model the rapid response as shown by the blood-oxygen-level-dependent (BOLD) signal. The experimental designs adopted 4 comparisons: 1) total events—anticipation- and experience-related brain activation across all subjects; 2) gain-loss status—gain-, draw- (revealed in deck C only), and loss-related brain activation across all subjects; 3) deck category—A-, B-, C-, and D-related brain activation across all subjects; 4) largest loss (-$1150) of deck B—the "big shock" is important for identifying the inhibitory function of the MPFC during both periods (anticipation and experience periods) under risk. Brain activation and deactivation according to monetary value in NT$ (US$)—5000(100), 2500(50), 1250(25), 0, -1250(-25), -2500(-50), -5000(-100), -7500(-150), -10000(-200), -12500(-250), and -57500(-1150) were also analyzed. Marsbar 0.43 was applied to analyze the ROIs for the MPFC and DLPFC during the anticipation and experience periods under both uncertainty and risk. This part of the analysis utilized the AAL database to define the sub-regions (ROIs) of MPFC and DLPFC. The estimated brain areas were revealed with the uncorrected p-value (0.05) to largely specify the sampled brain regions.

# RESULTS

## Behavior Data and Learning Curve

Behavioral data demonstrate that most subjects were affected by the experience and information about probability and value during the risk-IGT (mean number of cards selected: A (16.71), B (19.00), C (43.79), and D (20.50)) (Figure 2).

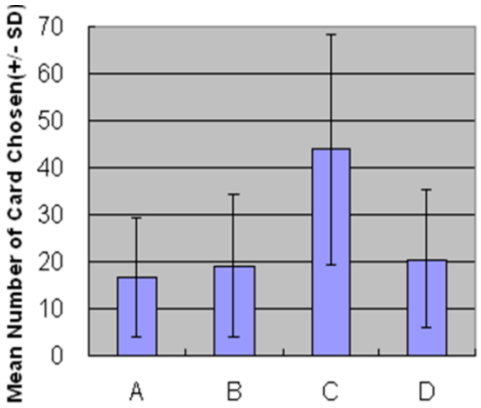


Figure 2. Mean Number of Card Selection under Risk. The choice pattern across 24 subjects shows that the experience and provided information influenced most subjects. Good decks were chosen more often than bad decks. Most subjects preferred good-deck C to the other three decks.

Repeated measurement ANOVA for the decks shows that most decision-makers preferred good deck C to the other three decks (Greenhouse-Geisser correction: $F(1.98) = 9.58$, $P < 0.01$, $Eta^2 = .29$). The learning curves (blocks 1–5) associated with all decks (A, B, C, and D) demonstrate that decision-makers chose good deck C to the other three decks at the beginning of the game (Figure 3); however, the main effect of the block (Greenhouse-Geisser correction: $F(1)= 1$, $P = .33$, $Eta^2 = .04$) and the interaction between factors (deck × block) were insignificant (Greenhouse-Geisser correction: $F(4.81) = 1.30$, $P = .27$, $Eta^2 = .05$). Furthermore, according to the one-way ANOVA statistical testing of the choice pattern, the mean number of cards chosen differed significantly with respect to uncertainty (Lin et al., 2008a) and risk situations in most decks (deck $A_{U-R}$: $F(1, 46) = 6.93$, $P < .05$; deck $B_{U-R}$: $F(1, 46) = 6.18$, $P < .05$; deck $C_{U-R}$: $F(1, 46) = 15.08$, $P < .01$; deck $D_{U-R}$: $F(1, 46) = 1.43$, $P = .24$).

## Brain Activation during Anticipation and Experience

By simply using map overlaps, brain loops under risk (using logical or informative reasoning) did not differ entirely from brain loops under uncertainty in the IGT, particularly during the phase of anticipation (Lin et al., 2008a) (Figure 4, left). Furthermore, the paired t-test between conditions of uncertainty and risk demonstrates that a few differences existed in the basal forebrain and the midline of the brain during the phase of anticipation (Figure 4, upper-right panel); however, during the experience phase, brain activity in response to uncertainty was higher than that in response to risk (Figure 4, lower-right panel). Activation

of the midline basal-forebrain, frontal-parietal loops under uncertainty (Lin et al., 2008a), was higher than that under risk.

Conversely, activation of the IN, the supplementary motor area (SMA), precentral gyrus (M1), medial temporal gyrus (MTG), anterior cingulate cortex (ACC), posterior cingulate cortex (PCC), and visual cortex (VC) under risk was relatively higher than that under uncertainty (Lin et al., 2008a) (Figure 4, lower-right panel).

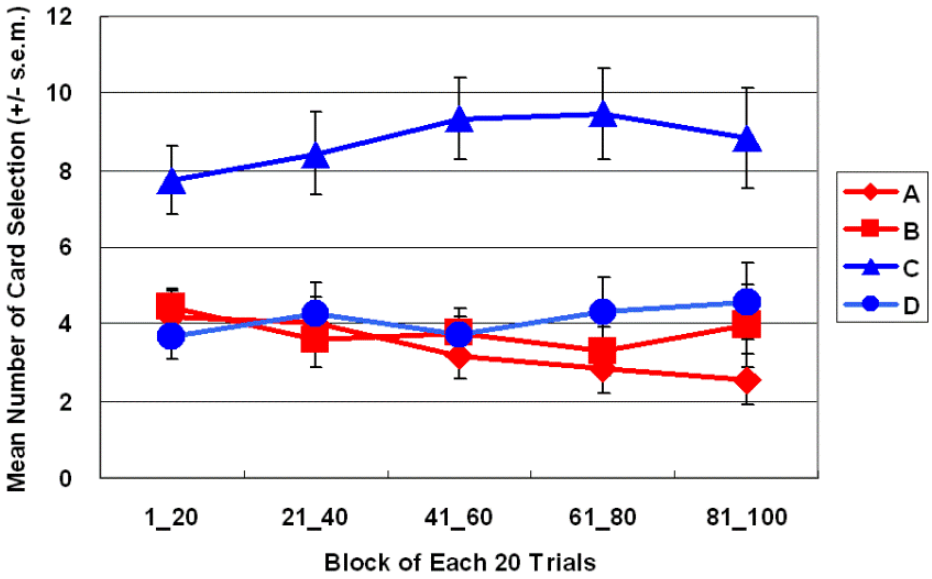


Figure 3. Mean Number of Card Selection in Each Block of 20 Trials under Risk. The learning curve indicates that most subjects preferred good-deck C at the beginning of the game. As determined through comparison with data from our previous investigation (Lin et al., 2008a), the behavioral result in this study demonstrates that previous experience and changing the information about probability and value provided to normal decision-makers dramatically altered their choice patterns.

Following the procedure in our earlier investigation (Lin et al., 2008a), the bilateral IN, lentiform nucleus (LN), inferior parietal lobule (IPL), superior temporal gyrus (STG), and ACC were observed during the period of anticipation of decision making (Figure 4, upper-left panel; Figure 5; see Table 1 for details of brain regions), and the IPL was activated during the experience phase (Figure 4, lower-left panel; Figure 5) (Table 2). Notably, during the anticipatory period in a risk situation, the SMA, paracentral lobule (PaL), superior frontal gyrus (SFG), precentral gyrus (motor cortex, M1), and postcentral gyrus (somatosensory cortex, S1) were also observed. These newly revealed brain areas under risk may be in response to motor planning in goal-directed decisions (Li et al., 2010). Conversely, the bilateral visual cortex (VC) was also activated during the experience phase. (The left side of Figure 4 shows a detailed comparison of the brain maps obtained in this and in our previous study (Lin et al., 2008a)).

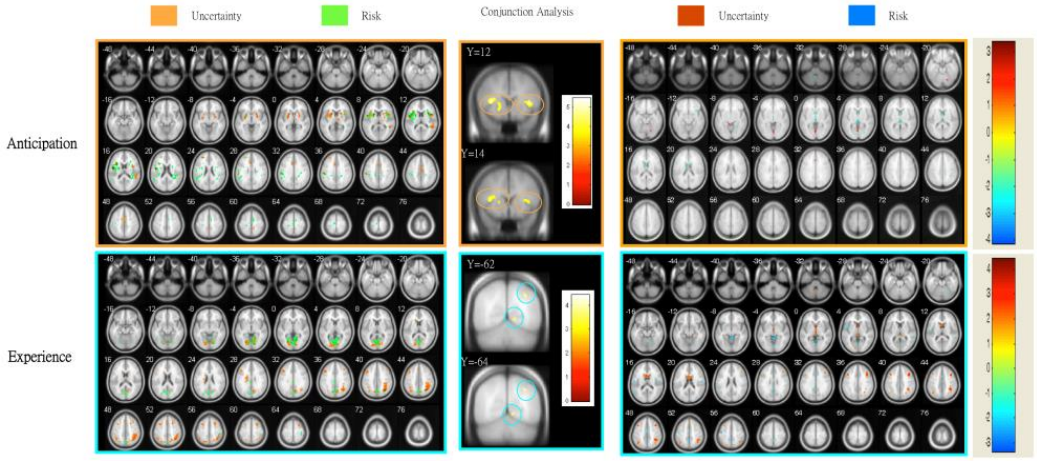


Figure 4. Comparison of Brain Activation during the Anticipatory and Experience Periods under Uncertainty and Risk. Descriptive Results: In the upper-left panel of Figure 4, the orange mark indicates brain responses during the anticipatory period under uncertainty (Lin et al., 2008a) and the green mark indicates brain responses during the anticipatory period under risk (the present study). The bilateral IN, LN, and STG were stably observed in both studies (Random Effect: $P_{uncorrected}$ = 0.001, K = 50). However, the activation of the ACC and precuneus were observed mostly under uncertainty; the SMA and some motor-related regions were revealed under risk. In the lower-left panel of Figure 4, the orange mark indicates brain responses during the period of experience under uncertainty (Lin et al., 2008a), and the green mark indicates brain responses during the period of experience under risk in this study. The bilateral VC, IPL, and cuneus were stably observed in both studies (Random Effect: $P_{uncorrected}$ = 0.001, K = 50). However, the IPL(R), bilateral SFG, MFG, and MPFC exhibited more robust activation under uncertainty than under risk. Conversely, the VC exhibited relatively strong activation under risk than under uncertainty. Statistical Results: The conjunction analysis demonstrated that the two conditions (uncertainty and risk) were associated with the activation of some brain regions in common (P= 0.001, K = 0)—IN and LN—during anticipation (Figure 4, upper-middle panel), and the IPL and VC during experience (Figure 4, lower-middle panel). In the statistical contrast maps (paired sample T-test and two-sample t-test), red marks the activation of the brain, which under uncertainty is greater than that under risk; blue marks the activation of the brain, which is greater under risk than under uncertainty. During the anticipatory period (Figure 4, upper-right panel), red marks the activation of the MPFC (BA 10), ACC (BA 32), MCC, VC, and vermis (AAL 4, 5) under uncertainty; blue marks activation of the MFG(R), IFG(L), caudate, septum, thalamus, IPL(R), insula(R), S1, vermis (AAL 9), and brainstem under risk. During the period of experience (Figure 4, lower-right panel), red spots show that the activation of the MFG, IFG, LN, septum, thalamus, IPL, superior parietal lobe, brainstem, and vermis (AAL 9) under uncertainty was significantly higher than that under risk; blue spots show that activation of the ACC, MCC, SMA, M1 (L), superior temporal gyrus (BA 43), precuneus, PCC, MT, VC, vermis (AAL 3, 4, 5), and cerebellum (AAL 6) under risk was significantly higher than that under uncertainty.

IN and LN were significantly involved in driving decisions (before card-turning), according to a conjunction analysis under the two conditions (uncertainty vs. risk) (Figure 4, middle). The conjunction effect showed that the IPL and VC may have been involved in value representation under not only uncertainty but also risk (Figure 4, middle). Under risk, the brain was activated less than under uncertainty (Lin et al., 2008a), even after controlling for most within-subject variables. The DLPFC (Brodmann Areas 46 and 9) was not clearly active during the periods of anticipation and experience under risk.

**Table 1. Brain Activation during Anticipation Period**

| Brain Region (Hemisphere) | MNI coordinate For the voxel with local maxima | | | Cluster Size (Voxel) | T | $P_{FWE\text{-}Corr}$ |
|---|---|---|---|---|---|---|
| | X | Y | Z | | | |
| Insula (L)<br>Lentiform Nucleus (L)<br>Rolandic Operculum (L) | −32 | 8 | 12 | 1170 | 7.34 | 0.010 |
| Inferior Parietal Lobule (L) | −56 | −44 | 36 | 795 | 5.88 | 0.191 |
| Superior Temporal Gyrus (R) | 32 | −48 | 16 | 385 | 5.38 | 0.423 |
| Supplementary Motor Area (R) | 10 | −10 | 60 | 172 | 5.32 | 0.459 |
| Insula (R) | 26 | 26 | 12 | 507 | 5.19 | 0.548 |
| Middle Cingulate Cortex (L) | −10 | −36 | 40 | 67 | 5.00 | 0.677 |
| Paracentral Lobule (L) | −12 | −20 | 60 | 101 | 4.79 | 0.814 |
| Middle Cingulate Cortex (R) | 34 | −22 | 34 | 178 | 4.77 | 0.829 |
| Superior Frontal Gyrus (L) | −20 | 44 | 22 | 72 | 4.39 | 0.972 |
| Precentral & Postcentral Gyrus (L) | −30 | −30 | 72 | 76 | 4.30 | 0.985 |

Note: (Random Effect: $P_{uncorrected} = 0.001$, K = 50).

**Table 2. Brain Activation during Experience Period**

| Brain Region (Hemisphere) | MNI coordinate For the voxel with local maxima | | | Cluster Size (Voxel) | T | $P_{FWE\text{-}Corr}$ |
|---|---|---|---|---|---|---|
| | X | Y | Z | | | |
| Lingual Gyrus (R) | 4 | −68 | 4 | 2451 | 5.75 | 0.225 |
| Postcentral Gyrus (R) | 46 | −34 | 56 | 121 | 4.45 | 0.948 |
| Middle Cingulate Cortex (L, R) | 0 | −30 | 34 | 127 | 4.33 | 0.977 |
| Inferior Parietal Lobule (R) | 32 | −64 | 44 | 89 | 4.31 | 0.978 |
| Middle Occipital Lobe (L) | −24 | −80 | 24 | 65 | 4.21 | 0.990 |

Note: (Random Effect: $P_{uncorrected} = 0.001$, K = 50).

## Brain Activation Associated with Gain, Loss, and Draw

The brain-loops for gain, draw, and loss were similar to those under uncertainty in the IGT in our previous investigation (Lin et al., 2008a). The IN, LN, and MTG were generally active for gain, loss, and draw during the anticipatory phase (Figure 6, upper panel).

However, the intensity of activation of these brain regions was generally lower than the one in our earlier study with uncertainty (Lin et al., 2008a). Conversely, the SMA, left-side M1 and S1 were active during action planning under all conditions (gain, loss, and draw) under risk. During the experience phase, the bilateral VC, precuneus, and right-side parietal lobe were active for gain, loss, and draw (Figure 6, lower panel). Notably, the activation of the middle frontal gyrus (MFG), SFG and the hippocampus were higher with gain than with loss or draw. The activation of these brain regions may involve estimating gains and encoding or retrieving game-related information. Supplementary Figure 2(a)-(c) and 3 (a)-(c) exhibit a detailed brain-image (uncertainty vs. risk) under conditions of gain, loss, and draw during the periods of anticipation and experience.

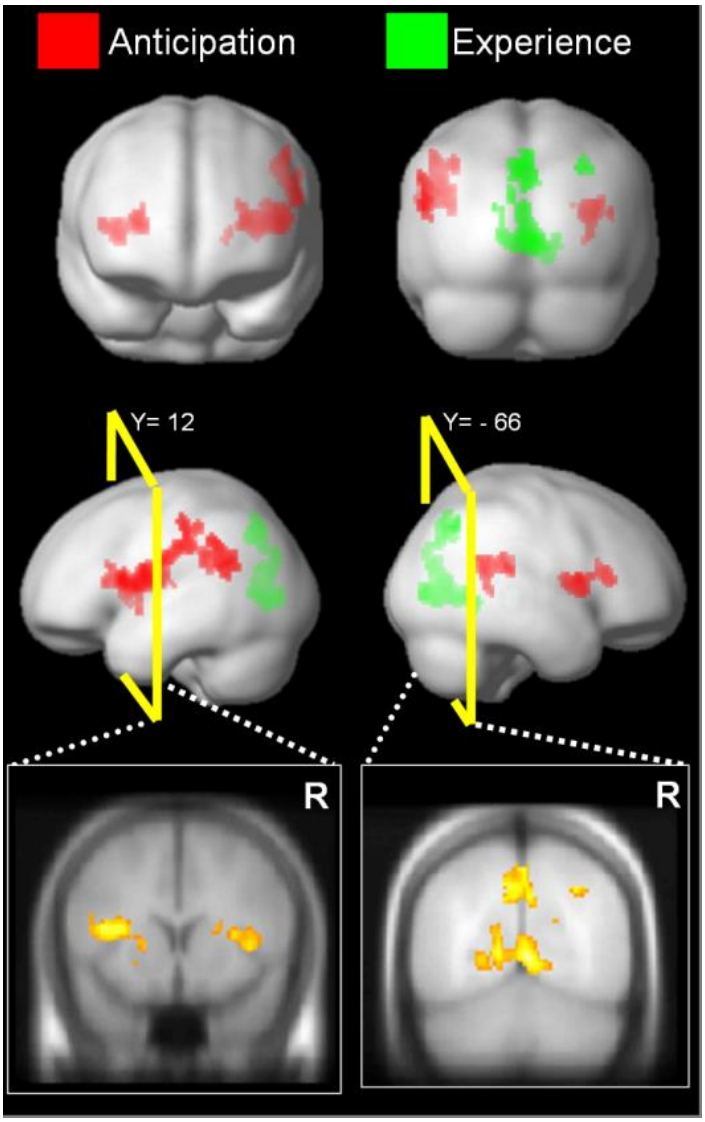


Figure 5. Brain Activation during the Phases of Anticipation and Experience under Risk. The red marks in the upper and middle panels indicate brain responses during the anticipation period. The bilateral IN and LN were activated under risk (random effect: $P_{uncorrected}$ = 0.001, K = 50). The bilateral lingual gyrus, precuneus, right superior and inferior parietal lobules were activated during the period of experience (random effect: $P_{uncorrected}$ = 0.005, K = 50). Notably, the brain regions activated during anticipation were deactivated during the experience phase (please see Figure 5).

## Brain Activation Associated with Decks (A, B, C, and D)

During the anticipatory period, the IN, LN, thalamus, left-side M1-S1, SMA, and MTG were activated, and the brain maps mostly overlaid among the conditions of decks A, B, C, and D. Additionally, only deck B induced ACC and MPFC activation, and deck C induced ACC and PCC activation during this period of anticipation (Figure 7, upper panel).

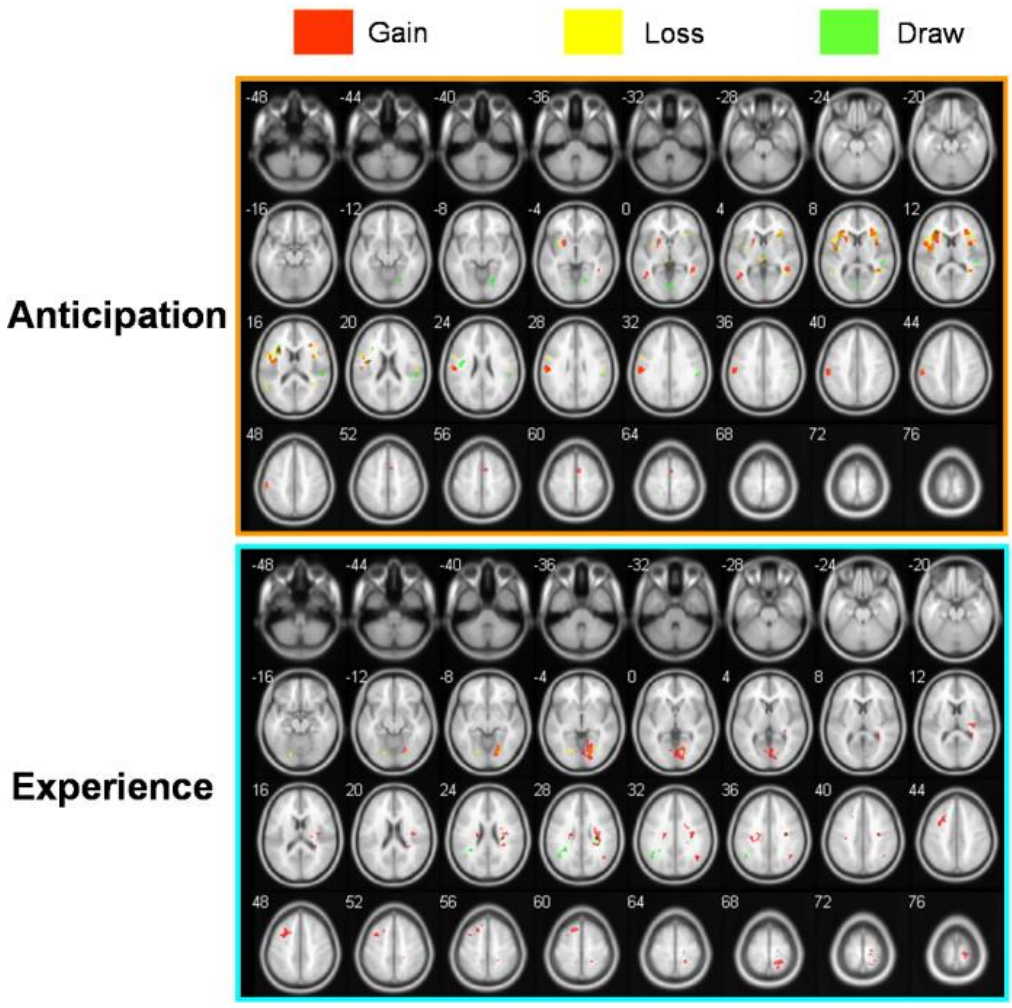


Figure 6. Brain Activation under Gain, Loss, and Draw Conditions during the Phases of Anticipation and Experience. Red clusters mark brain activation upon gain, yellow clusters mark brain activation upon loss, and green clusters mark brain activation upon draws (random effect: $P_{uncorrected} = 0.001$, K = 80). Before a card was turned over, the three clusters overlaid the IN, LN, and MTG, indicating that the cognitive states of expectation of reward and fear of punishment before a card was turned over under uncertainty (Lin et al., 2008a) were similar to those under risk. The gain condition induced relatively large and widespread brain activation during the phases of both anticipation and experience. The VC, IPL, and MFG were activated during the experience phase. (random effect: $P_{uncorrected} = 0.001$, K = 80).

During the experience phase, the bilateral VC, right-side parietal lobe, and the MFG were active under conditions A, B, C, and D. Notably, the MFG was strongly activated after deck A was chosen; deck A is associated with a relatively high frequency of loss and negative EV. The outcome associated with deck C activated the most brain circuitry, including some white matter regions. The activation of the hippocampus after the selection of deck C shows that the brain is sensitive to rewards that can be predicted by selecting certain stimuli (deck C) (Figure 7, lower panel). Supplementary Figures 2 (d)-(g) and 3 (d)-(g) show a detailed brain image (uncertainty vs. risk) under each deck condition during the periods of anticipation and experience.

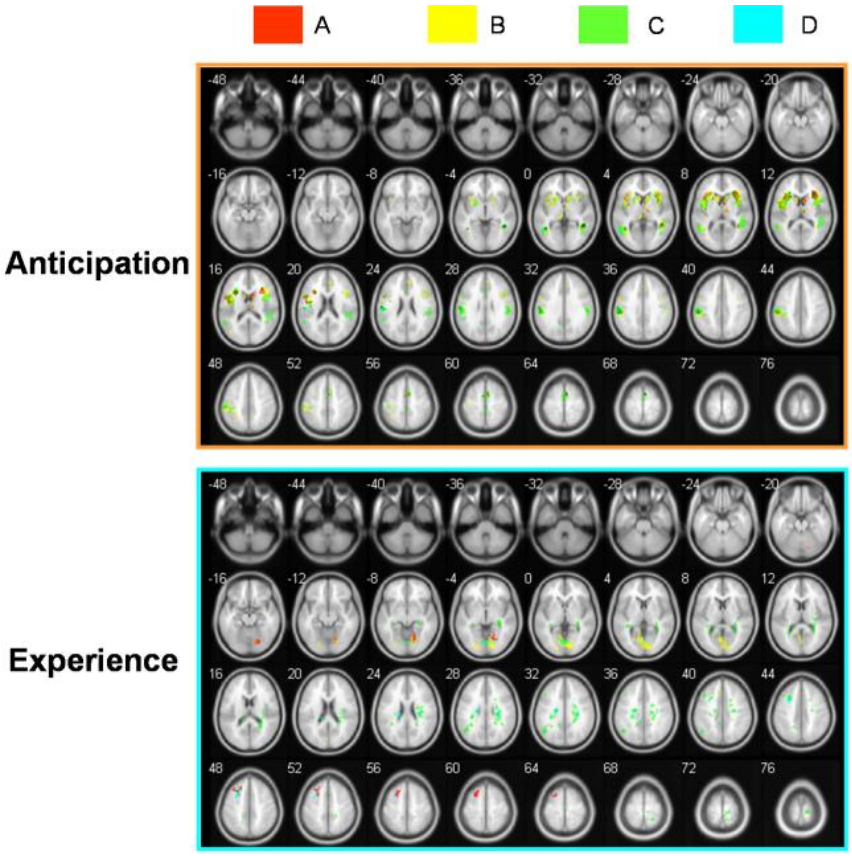


Figure 7. Brain Activation associated with Each Deck during Anticipation and Experience Phases. Red, yellow, green, and blue clusters indicate decks A, B, C, and D, respectively (random effect: $P_{uncorrected}$ = 0.005, K = 50). During the anticipatory phase, the brain maps associated with the four decks overlaid mostly the IN, LN, and MTG. Furthermore, the LN, ACC, M1-S1, and SMA were clearly activated in response to decks C and B in the expectation phase. This finding implies that subjects were relatively confident when choosing certain cards. For the experience phase, large areas of the VC, MFG, and SFG were activated (random effect: $P_{uncorrected}$ = 0.005, K = 100). Notably, decks C and B activated the VC more than did the other two decks. Additionally, only deck C strongly activated the hippocampus, parietal lobe, and some white-matter regions.

## Brain Activation Associated with Value Conditions and Experiences of the Subjects Involving the Largest Loss (-$1150) of Deck B

Supplementary Figure 4 and 5 display a detailed brain image (activation vs. deactivation) under each value condition during the periods of anticipation and experience. The brain map for each value (from $100 to -$1150) show that the IN, LN, and thalamus were activated under most value conditions before the card was turned over. Notably, however, the critical brain region of the rewarding system, the LN and the MPFC, did not respond only to positive-value conditions (such as $50), but also to negative-value conditions (such as -$100) during the period of experience.

Brain activation associated with deck B, in which a subject experiences the largest possible loss (-$1150), was mostly consistent with the findings in our previous study (Lin et

al., 2008a). The IN, LN, and MTG were active during the anticipatory period, and the IPL, VC, precuneus, PCC, and MPFC were active during the experience phase. Nevertheless, under risk, the MPFC was active not only following the largest loss (-$1150) but also before the event was revealed. Furthermore, the VC was involved in processing information during the experience phase (Figure 8). Supplementary Figure 6 shows statistical test results using the paired sample T-test (these results were also checked with the two-sample t-test) for the largest loss (-$1150) under uncertainty and risk during the periods of anticipation and experience.

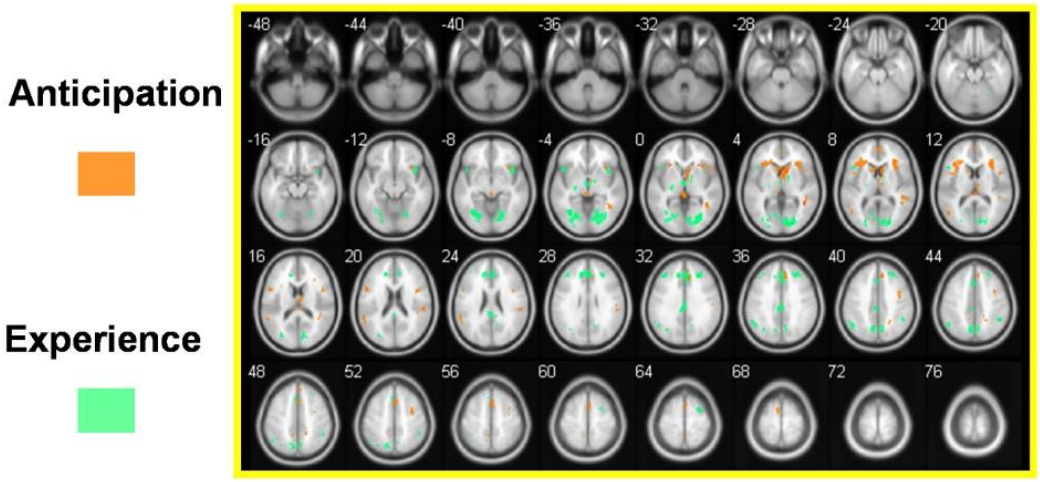


Figure 8. Brain Activation by Largest Loss in Deck B during Anticipation and Experience Phases. The orange clusters mark the brain response in anticipation before the largest loss (-$1150) and the green spots mark the brain response when the largest loss was shown to subjects. Under risk, due to the extremely few trials associated with the largest loss (-$1150), the P-value was decreased for presentation purposes (random effect: $P_{uncorrected} = 0.05$, K = 50). Before the card with the largest loss was turned over, the LN, IN, MTG, thalamus, brainstem nuclei, SMA and MPFC were activated. After the card was turned over, the largest loss activated the VC, PCC, ACC, MPFC, IPL, precuneus, MFG, thalamus, IN, and LN.

## Brain Activation during Anticipation and Experience Phase Associated with MPFC and DLPFC

The results in this study do not support the extended version SMH—that DLPFC is activated increasingly and MPFC is activated decreasingly with time-unlimited and information- and logic-loaded conditions. The region-of-interest (ROI) analysis for the MPFC and DLPFC indicates that the right MPFC was very active during the anticipatory period under risk (Table 3). Moreover, the detailed ROI analysis was used to assess MPFC and DLPFC activation under the uncertainty-IGT (Lin et al., 2008a). According to analytical results of Lin et al. (2008a) study, the bilateral DLPFC was activated only during the period of experience (Supplementary Table 2).

Nevertheless, the results of this study do not correspond completely with those of Krain et al. (2006), whose meta-analysis showed that the DLPFC is activated decreasingly from uncertainty to risk and the VMPFC activated increasingly from uncertainty to risk. Analysis

results of brain activation during anticipation and experience in 100 trials (Figure 5) indicate that the MPFC and DLPFC were not clearly observed in the risk-IGT (Supplementary Figure 7, Table 3). Only some activation of the right MPFC was observed under a specific condition (-$1150) during the periods of anticipation and experience (Figure 8).

**Table 3. ROI analysis for the MPFC and DLPFC during the anticipation and experience phases under risk**

| Phase | Target Region (Hemisphere) | ROI name (MNI: AAL) | Contrast value | T | $P_{Uncorr}$ |
|---|---|---|---|---|---|
| Anticipation | MPFC (L) | Frontal_Sup_Medial_L | 0.060 | 0.270 | 0.395 |
| | MPFC (R) | Frontal_Sup_Medial_R | 0.500 | 2.330 | ***0.012*** |
| | DLPFC (L) | Frontal_Mid_L | 0.110 | 0.730 | 0.233 |
| | DLPFC (R) | Frontal_Mid_R | 0.000 | -0.010 | 0.506 |
| Experience | MPFC (L) | Frontal_Sup_Medial_L | -0.340 | -1.340 | 0.907 |
| | MPFC (R) | Frontal_Sup_Medial_R | -0.640 | -2.140 | 0.981 |
| | DLPFC (L) | Frontal_Mid_L | -0.300 | -1.640 | 0.946 |
| | DLPFC (R) | Frontal_Mid_R | -0.100 | -0.530 | 0.701 |

# DISCUSSION

## Behavior Data and Learning Curve

Choice patterns under risk differ from those under uncertainty (Lin et al., 2008a). Under risk, subjects exhibited a significantly lower preference for bad decks A and B and a higher preference for good deck C but not good deck D than under uncertainty (Lin et al., 2008a). After the practical experience of the first session (Lin et al., 2008a) and the gain-loss information thus provided, the choice patterns of the subjects may indicate that subjects rapidly entered the conceptual state and had a hunch regarding the long-term outcome at the very beginning of the IGT (Figure 3). However, this rapid entrance into the conceptual state may have been caused by the provision of gambling information under risk. Subjects were provided with information about probability and value, and most subjects learned to choose good deck C over the other three decks. This phenomenon shows that the gain-loss information of each deck can assist subjects in using logical inference to obtain a good outcome. However, subjects markedly preferred good deck C to good deck D. Even though decks C and D had the same positive EV, subjects preferred only deck C. We posit that the information about deck C (50% win $50; 50% draw) influenced the subjects' preferences. The SMH cannot explain this finding consistently. In this net-value version of the IGT, deck C was associated with very few trials involving losses (Chiu and Lin, 2007). This fact may explain the subjects' preferences for deck C. Obviously, subjects preferred an absence of immediate loss and a positive long-term outcome. This farsighted behavior under risk can be explained by two factors—inference of EV or preference for infrequent losses (Crone et al., 2005; Fernie, 2007; Fum et al., 2008). Consequently, under risk with logical reasoning, the large loss associated with deck D prevented subjects from choosing deck D, even though deck D has a positive EV. The avoidance of good deck D is inconsistent with the original IGT

finding (Bechara et al., 1994; Bechara et al., 1997; Bechara et al., 1999; Bechara et al., 2000; Bechara and Damasio, 2005). This analytical result suggests that even under risk, EV may not be the main factor in guiding normal subjects (Lichtenstein et al., 1969). Instead, gain-loss frequency or value-magnitude may have a greater influence over subjects (Wilder et al., 1998; Fernie and Tunney, 2006; Lin et al., 2007b; Chiu et al., 2008; Lin et al., 2009). Using a modified IGT known as the Soochow Gambling Task, Chiu et al. (2008) confirmed that decision-making was generally dominated by gain-loss frequency under uncertainty. However, under risk, some subjects gradually shifted their preferences to good EV decks after the probability and value information of each deck were revealed to them (Chiu et al., 2006; Lin et al., 2008b). The series of information-providing studies by the Soochow group demonstrated that both the experience gained by practice and the gamble-information revealed to decision makers might be effective in influencing normal decision makers (Chiu et al., 2006; Lin et al., 2008b; Yen, 2013). It is worth noting, however, that the information (probability and value) provided might be confounded with the practice effect (Lin et al. 2008a) in the present study. The main effects and interaction between these two factors may require further verification in the near future.

Over the past two decades, an increasing number of theoretical (Rolls, 1999; Panksepp, 2003; Dunn et al., 2006; Rolls, 2007; Marr, 2010) and empirical studies (North and O'Carroll, 2001; Tomb et al., 2002; O'Carroll and Papps, 2003; Heims et al., 2004; Maia and McClelland, 2004; Leland and Grafman, 2005; Chiu and Lin, 2007; Fernie, 2007; Lin et al., 2007b; Fum et al., 2008; Lin et al., 2008a; Lin et al., 2008b) have yielded evidence against the SMH. Various IGT-related investigations have identified the prominent deck B phenomenon (PDB) in the IGT (Wilder et al., 1998; Toplak et al., 2005; Fernie, 2007; Lin et al., 2007a; Lin et al., 2007b; Fum et al., 2008; Horstmann et al., 2012; Upton et al., 2012; Lin, Song, Chen, Lee and Chiu, 2013; Steingroever et al., 2013). Under the PDB, normal decision-makers prefer disadvantageous deck B with almost the same frequency as they prefer advantageous decks C and D in the IGT; that is, normal subjects do not perform as well as Bechara et al. (1994) suggested. Notably, the performance of a normal control was the baseline for comparing the myopic decisions of those with VMPFC lesions and those with neurological or psychiatric diseases (Bechara, 2007). If the validity of the IGT, the key tool that supports the SMH, has a serious flaw, then the predictive power of the SMH is also seriously affected (Lin et al., 2013). In this study, most of the subjects preferred good deck C, which indicates that the PDB did not exist under risk. Because deck C has few small-magnitude losses, the preference for good deck C may have been caused by EV or gain-loss frequency (Chiu and Lin, 2007).

## Brain Activation during Anticipation and Experience

Brain maps under uncertainty differ from those under risk (Hsu et al., 2005; Huettel et al., 2005; Brand et al., 2006; Huettel et al., 2006; Tobler et al., 2007; Bach et al., 2009). Activity in some brain areas (the IN, LN, and STG) demonstrate that incentive was decreased from uncertainty to risk, whereas activity in some brain areas (IPL, SMA, and M1 and S1) increased from uncertainty to risk (Hartstra et al., 2010) (Figure 4). These findings imply that subjects have a stronger "gut feeling" under uncertainty than under risk (Schultz, 2010). Under uncertainty, subjects may apply an immediate snap strategy to cope with an

unpredictable environment. Conversely, in a state of logical reasoning, the driving force of decisions gradually shifted to a goal orientation, and the relationship between target and affect was gradually strengthened (McClure et al., 2004).

Most IGT brain-imaging investigations over the past decade have used the popular contrast, i.e., the subtraction of good (C, D) decks from bad (A, B) ones, and the only modeling involving the signal change of the time-points after button press. Some investigations (e.g., Knutson et al., 2001) have distinguished between processing before and after a decision. In this study, the brain maps obtained in the phase analyses before and after cards were turned over facilitated the obtainment of brain maps during the phases of anticipation and experience. In the risk-IGT, observations during the anticipatory phase demonstrate that decision-making was driven by the IN, LN, IPL, and STG. This finding is consistent with observations made in our previous uncertainty-IGT study (Lin et al., 2008a). The conjunction analysis in the two studies show that the IN and LN were activated before card-turning under both uncertainty and risk. Alternatively, the IPL and VC participated in value representation under not only uncertainty but also risk (Figure 4, middle). Notably, this finding showed that even under different conditions (uncertainty vs. risk), decision-making processing shared some common brain mechanisms before and after a choice was made. Conjunction analysis results may help to identify the general circuitry for decision making, which has also been suggested by some IGT-related studies (e.g., Krain et al., 2006).

However, some observations in this study differ from those in Lin et al. (2008a). In the anticipatory phase, several brain regions (the IN, LN, and STG) were overlaid in the two studies, and the magnitude of activation in the risk-IGT (Figure 5, Supplementary Figure 1, and Table 1) was generally less than the one in the uncertain-IGT (Lin et al., 2008a). This implies that incentive under risk (Bach et al., 2009; Stern et al., 2010; Yaxley et al., 2011) was not as strong as that under uncertainty. Additionally, some brain regions that were involved in motor planning (Campos et al., 2005) (M1 and S1, SMA, and PaL) were activated in the risk-IGT (Hartstra et al., 2010), but less so in the uncertainty-IGT (Lin et al., 2008a). This finding may confirm that subjects were relatively certain about the gain-loss structure and long-term outcome of each deck and that they were entering a conceptual state (Bechara et al. 1997; Maia & McClelland 2004; Lawrence et al., 2009). These findings echo the result of some previous risk-related studies (Huettel et al., 2005; Huettel et al., 2006), indicating that reduced uncertainty is associated with a weaker activation of some affective brain regions such as the IN, LN, and STG in the incentive state. The finding for anticipation in the risk-IGT is consistent with those of numerous brain-imaging studies on appetitive and avoidance systems (Roger et al., 1999; Knutson et al., 2001; Schienle et al., 2002; Hsu et al., 2005; Kuhnen and Knutson, 2005; Haruno and Kawato, 2006; Basar et al., 2010; Hartstra et al., 2010).

Conversely, during the phase of experience, the activation of the IPL in the risk-IGT was lower than in the uncertainty-IGT (Figure 4). However, the precuneus and occipital lobe were considerably activated when the outcome appeared. The neuronal correlates during the experience phase in the risk-IGT differed from those in the uncertainty-IGT (Lin et al., 2008a). However, the IPL was clearly observable under conditions of risk and uncertainty. The difference between the activation patterns under risk and uncertainty during the period of experience show that the incentive state (e.g., IPL) decreased from uncertainty (target unclear) to risk (target clear) (Bach et al., 2009; Stern et al., 2010; Yaxley et al., 2011) and awareness increased (VC) from uncertainty to risk (Tong, 2003; Whatham et al., 2003;

Amting et al., 2010; Monti et al., 2013). Nonetheless, in this study, DLPFC activation was not observed during the phase of anticipation or experience in the risk-IGT. Activated regions relatively close to the DLPFC were the Rolandic operculum and the SFG (Figure 4). This result differs substantially from those in previous brain-imaging studies of decision behavior under risk (Roger et al., 1999; Knutson et al., 2001; Schienle et al., 2002; Hsu et al., 2005; Kuhnen and Knutson, 2005; Haruno and Kawato, 2006; Hartstra et al., 2010). Accordingly, the function of the DLPFC in the IGT remains controversial.

Moreover, Lawrence et al. (2009), using the IGT combined fMRI to identify the role of the prefrontal cortex, found that both the DLPFC and VMPFC were involved in decision processing during the IGT (Lawrence et al., 2009). This observation is also inconsistent with the previous interpretation of the Iowa group for DLPFC function with neurological evidence (Bechara et al., 1998). Li et al. (2010) (the extended Iowa group) used event-related fMRI combined with the IGT performance of normal subjects to redemonstrate the function of the SM loop.

They used a block-design fMRI paradigm (which is different from the original IGT event-related paradigm) and specific regressors in a GLM and identified the original brain circuitry associated with the SMH (e.g., the VMPFC and IN); however, some new brain regions (e.g., the posterior cingulate cortex (PCC), ventral striatum, SMA, and ACC) were revealed. Notably, the role of the DLPFC was also identified in the IGT-fMRI study by Li et al. (2010).

The studies of Lawrence et al. (2009) and Li et al. (2010) partially support the findings of Fellows and Farah (2005), but not the neurological evidence obtained by Bechara et al. (1998). Over the past few years, the brain loops of the SMH have been modified many times by the Iowa group, but the corresponding neuronal correlates observed during performance of the IGT have not been matched in a stable manner (Figure 4). Having said that, a summary of the modified brain loops of the SMH and the present research might reveal that the IN, LN, CC and MPFC are the most relevant and critical brain regions when performing the IGT.

## Brain Activation Associated with Gain, Loss, and Draw

Brain activation under the conditions of gain, loss, and draw in the risk-IGT was generally similar to that in the uncertainty-IGT (Lin et al., 2008a). Expectation of risk induced IN, LN, and MTG activation before a card was turned over (Figure 6, upper panel). However, the SMA and left-side M1 were more strongly activated in gain trials than in loss and draw trials. This finding differs from the brain maps associated with the uncertainty-IGT, implying that relatively certain and predictive choices, particularly those involving reward, are associated with the motor-planning system (Campos et al., 2005).

In the experience phase, brain activation associated with gain was greater than the one associated with loss or draw. Activation of the parietal lobe, MFG, and SFG in this study is similar to the one in the brain map in the uncertainty-IGT (Lin et al., 2008a). This observation may indicate that a common mechanism exists for utility representation and risk evaluation during the experience period under both uncertainty and risk. Furthermore, the occipital lobe was strongly activated during the period of experience, a finding that differs slightly from the brain map of the uncertainty-IGT. These two conditions may differ in the various degrees of attention and awareness (Tong, 2003; Whatham et al., 2003; Amting et al., 2010; Monti et al.,

2013). The processing of gain, loss, and draw that is gradually associated with targets (decks) under risk, but not under uncertainty. Moreover, the hippocampus was also activated in the experience phase, particularly under the condition of gain. Activation of the VC and hippocampus in the risk-IGT may underlie the encoding process for certain choices, indicating that some brain mechanisms are observable only in the risk-IGT.

## Brain Activation Associated with Decks (A, B, C, and D)

In the expectation phase, the IN, LN, thalamus, left M1-S1, SMA, and MTG were active when the subject was turning decks A, B, C, and D (Figure 7, upper panel). This finding is similar to those obtained in earlier investigations under uncertainty in most cases. The mental state—the anticipation and fear of harm prior to decision-making—may be similar under uncertainty and risk, even though gambling information was given to subjects in the risk-IGT. However, decks C and B induced a stronger activation of the ACC, PCC, and MPFC than the other two decks did. Deck B was chosen more often than decks A, C, and D in some IGT studies (Crone et al., 2004; Rodriguez-Sanchez et al., 2005; Toplak et al., 2005; Fernie and Tunney, 2006; Fernie, 2007; Fum et al., 2008) and in the uncertainty-IGT (Lin et al., 2008a). Wilder et al. (1998) were the first to state that a frequency effect may cause normal decision-makers to prefer a frequent-gain deck with a poor EV in the IGT. In fact, deck B had a higher reward frequency and larger reward magnitude than decks A, C, and D, even though it was the bad deck in the original IGT (Bechara et al., 1994; Bechara et al., 1997; Bechara and Damasio, 2005). Accordingly, significant activation in the SMA and the PaL associated with deck B may be caused by the fact that the subjects performed the uncertainty-IGT task first and therefore maintained conclusions about it (Lin et al., 2008a). Additionally, deck C was most preferred under risk; thus, the marked activation of the SMA, PaL, and cingulate cortex may represent planning and the act of looking forward to a predicted outcome.

In the experience phase (Figure 7, lower panel), most activation patterns associated with the decks resembled those in the uncertainty-IGT (Lin et al., 2008a). Decks C and B had the greatest activation volume in the VC. Particularly, deck C activated the VC, parietal lobe, MFG, hippocampus, and some white-matter areas. This observation demonstrates that these regions may participate in the outcome-representation process associated with certain choices. Furthermore, the hippocampus was activated after deck C was selected under risk; therefore, the hippocampus may be involved in the encoding-retrieval process when deck C is chosen.

## Brain Activation Associated with Value Conditions and Experiences of the Subjects Involving the Largest Loss (-$1150) of Deck B

When the subject anticipates the largest loss from deck B, the brain maps of the anticipatory phase (Figure 8) are similar to those in most anticipation trials, and they show activation mostly of the anterior part of the brain (Figure 5 and 6); the brain maps of the experience phase (Figure 8) are similar to those in most outcome trials and show activation mostly of the posterior part of brain (Figure 5 and 6); the subject's behavior after experiencing the large-loss trial (-$1150) with bad deck B is an important index for demonstrating the inhibitive function of the MPFC, as suggested by the SMH and some

theories about the frontal function (Stuss and Knight, 2002; Farah, 2006; Takano et al., 2010). The empirical results of the large-loss trial (-$1150) with bad deck B differ from those in our previous study. The MPFC was activated during the experience phase in the uncertainty-IGT, but not during the anticipatory phase. However, in the relatively certain IGT, the MPFC was active after the largest loss and before a card was turned over (Figure 8), suggesting that the MPFC has an error-detection function when an outcome becomes evident (Lin et al., 2008a). Furthermore, under risk (in a target-lacking circumstance), the MPFC was also involved in monitoring forthcoming results before a decision in a goal-directed situation.

## Brain Activation during Anticipation and Experience Phase Associated with VMPFC and DLPFC

In this study, the VMPFC and DLPFC were not observed clearly during the periods of anticipation and experience (Supplementary Figure 7). The response of the VMPFC to the largest loss (-$1150) resulting from deck B in the risk situation was observed (Figure 8). These findings are partially supported by Krain et al. (2006), wherein the VMPFC (OFC) was activated in a risk situation, and the DLPFC was activated in a situation of uncertainty. However, this finding does not support the extended SMH, in which the VMPFC was involved in the "hot" executive function and the DLPFC in the "cool" executive function (Stocco et al., 2009; Singh 2012; 2013). A comparison of uncertainty-IGT and risk-IGT demonstrate that although the choice patterns differed significantly in these two conditions, the activation patterns of the VMPFC and DLPFC did not differ noticeably. One explanation may be based on the findings that 1) the conditions of uncertainty-IGT and risk-IGT did not reveal the differences between the "hot" and "cool" executive functions adequately. Both the uncertainty-IGT and risk-IGT can enroll the "hot" executive function, as evidenced by the activation of the affective regions—the IN and LN—during the anticipatory period and IPL during the experiential period. The two conditions (uncertainty vs. risk) may vary only in degree. 2) The categorization of "hot" and "cool" executive functions with the activation patterns of the VMPFC and DLPFC may be unrelated to the real processing of brain functions. Recent brain imaging techniques related to the connectome and functional connectivity (Sporns, 2011) may prove helpful for understanding the functions of the VMPFC and DLPFC and their interaction with the basal forebrain under dynamic decision-making.

On the other hand, some investigations have directly monitored the involvement of somatic signals in assessing the performance of normal subjects or impaired patients in the IGT. Nevertheless, most investigations have found that modulating somatic signals does not affect IGT performance (North and O'Carroll, 2001; O'Carroll and Papps, 2003; Heims et al., 2004), which suggests that the IGT may not directly reflect the relationship between choice behavior and somatic signals (Tomb et al., 2002; Maia and McClelland, 2004; Rolls, 2007). However, the Iowa group provided another interpretation concerning the SM system (Bechara, 2001, Bechara and Damasio 2005).

Remarkably, Rolls argued that very few scientific studies have reported that lesions in somatic brain regions (such as the S1) result in deficits in real-life decision-making or in IGT performance (Rolls, 1999; Heims et al., 2004; Rolls, 2007). Furthermore, Dunn et al. (2006) conducted a global review of the IGT and SMH and found that numerous neurological, psychiatric, and brain-imaging studies have shown evidence for somatic brain-loops to be

inconsistent (Ernst et al., 2002; Adinoff et al., 2003; Bolla et al., 2003; Ernst et al., 2003; Tucker et al., 2004; Bolla et al., 2005; Fukui et al., 2005; Northoff et al., 2006; Tanabe et al., 2007; Li et al. 2010). This investigation found that the left side PaL (close to the Secondary Somatosensory Cortex, S2), S1, and M1 were activated before a card was turned over under risk (Figure 6). Echoing these arguments, M1, S1, or S2 may be activated to process signals in a goal-oriented situation, but not in an uncertainty situation. This finding may prove helpful in refining the two brain-loops of the SMH (Damasio, 1994; Bechara, 2001, 2004). These studies of SM neuronal circuits in the peripheral and central nervous systems focus mainly on observing signal changes under uncertainty. In this investigation, a controlled experiment under risk was conducted to clarify the alternative perspective of the SMH. These findings may be useful not only in rectifying the neuronal loops of the SMH, but also in depicting the brain loops of dynamic decisions associated with uncertainty vs. risk (Suchy, 2011). Briefly, the choice behavior in a dynamic situation (including uncertainty and risk situations), may be mostly driven by the relatively old brain regions (IN, LN) and vice versa. Under the risk-IGT, the brain activation pattern was similar to that under uncertainty; however, some brain maps and activation patterns under risk and under uncertainty differed. The IN, LN, IPL, and STG were involved in processing anticipation and drove decision-making in situations of both uncertainty and risk (Lin et al., 2008a). Some brain regions (e.g., SMA, PaL, M1 and S1) were probably involved in motor planning; this finding may be consistent with behavioral data, indicating that subjects may have known which deck to select. Moreover, during the period of experience, the relatively large region of the VC was activated upon the revelation of the outcome, which is different from the observation in our previous study (Lin et al., 2008a). This result may imply that awareness was increased to lock a certain choice that is associated with the good consequence, and the function of value association (the activation of IPL decreased) was gradually unnecessary in an informative (risk) situation. Under risk, the key structures of the SMH and MPFC were activated during the periods of experience and anticipation. Unlike in our previous study (Lin et al., 2008a), the MPFC in this study was responsible not only for error-detection in a low-ambiguity situation (when information was revealed or after a card was turned over), but also for forward-prediction in a high-ambiguity situation (in which information was not revealed or before a card was turned over).

## CONCLUSION

To summarize, in this research, we observed that the patterns of choice behavior were not entirely different in situations of uncertainty as compared to situations involving risk. However, the dynamic brain loops associated with decision-making under uncertainty and risk may share some common neural mechanisms (e.g., IN, LN). During a dynamic decision-making task, the basal forebrain might play an important role in making predictions (but not in forming reward value representations) in most uncertain and risk situations. This observation may be helpful to validate the key function of the basal forebrain during decision-making (Knutson et al., 2001; Schultz 2010). In addition, the roles of the VMPFC and DLPFC under both types of conditions should be reevaluated in a comparatively simple context. Furthermore, the decisions made in situations of uncertainty and in risk situations are

mostly framed by the immediate heuristics (Kahneman and Tversky 1979; Chiu et al., 2011; Lin et al., 2011; Kahneman 2003), which are driven by the relatively ancient brain regions (e.g., IN, LN). Notably, the so-called dual code processing (or hot-cool model) may not clearly correspond to uncertainty and risk situations separately (Fox and Poldrack, 2009, see also Figure 4). Based on the observations of the present research, the hot-cool function probably activates in response to the subcortical-cortical brain regions during the anticipation and experience periods of decision making.

## AUTHORS' CONTRIBUTIONS

CH and YC contributed to the conceptual innovation, literature review, data interpretation, and drafting of the preliminary manuscript. Both CH and CM acquired all data, and CM was responsible for MRI scanning and data reconstruction. CH analyzed behavioral and image data and wrote the manuscript. TC provided important discussions related to the default-mode brain, working memory, and explicit processing by the DLPFC. JC arranged all imaging experiments and finalized the fMRI data interpretations and the manuscript with CH. All authors have consented to the submission and publication of this manuscript.

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