



Neural correlates of the impact of prior outcomes on subsequent monetary decision-making in frequent poker players



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ABSTRACT

Individuals have a tendency to be more risky in their choices after having experienced a monetary loss, than after a reward. Here, we examined whether prior outcomes influence differently the patterns of neural activity of individuals who are used to taking monetary risk, namely poker players. High-frequency poker players and non-gamblers were scanned while performing a controlled task that allowed measuring the effect of prior outcomes on subsequent decisions. Both non-gamblers and poker players took more risks after losing a gamble than after winning one. Neuroimaging data revealed that non-gamblers exhibited higher brain activation than poker players when pondering a decision after losing, as compared to after winning. The opposite was found in poker players. This differential pattern of activation was observed in brain regions involved in high-order motor processes (the dorsal premotor cortex). These results suggest that gambling habits introduce significant changes in action preparation during decision-making following wins and losses.

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1. Introduction

Evoking memories of past actions is a key process in human's ability to adapt to their environment. It usually involves the integration of cognitive (e.g., the maintenance and updating of relevant information) and affective/emotional processes, and it results in the ability to optimally anticipate the potential outcomes (e.g., gains versus losses) of a given decision (Bechara, 2005; Brevers, Bechara, Cleeremans, & Noël, 2013; Brevers & Noël, 2013; Damasio, 1996; Noël, Brevers, & Bechara, 2013a, Noël, Brevers, & Bechara, 2013b; Zelazo & Müller, 2002).

Some situations, however, require the individual to take some distance from memories of previous choice outcomes, and to focus exclusively on the current costs and benefits associated with available alternatives. Nevertheless, it has been repeatedly shown that individuals are more likely to persist in their choices when time and effort have been invested on it (i.e., the “escalation of commitment” or the “sunk-cost” effect; Thaler, 1980). For instance, at a supermarket, one is often more likely to keep waiting in the line

he/she just chose for paying despite the others line moving faster. This type of decision bias also impacts monetary decision-making where choice outcomes are independent from each other, such as during gambling. Indeed, a systematic observation in gambling is that individuals are more prone to take risky choices following a loss, as compared to following a win (Ayton & Fischer 2004; Barkan & Busemeyer, 2003; Campbell-Meiklejohn, Woolrich, Passingham, & Rogers, 2008; Clark, Lawrence, Astley-Jones, & Gray, 2009; Croson & Sundali 2005; Gilovich, Vallone, & Tversky, 1985; Hytönen et al., 2014; Laplace, 1951; Paulus, Rogalsky, Simmons, Feinstein, & Stein, 2003; Rabin, 2002; Tversky & Kahneman, 1992; Xue, Lu, Levin, & Bechara, 2011). This behavioral pattern is commonly referred to as “loss-chasing” (Dickerson, 1984; Kahneman & Tversky, 2000; Tversky & Kahneman, 1981).

Recent functional magnetic resonance imaging (fMRI) shed some lights on potential cognitive and affective processes involved in the effect of prior outcomes on subsequent monetary decision-making. Specifically, it has been highlighted that decision-making after losing a gamble is associated with increased activation in a frontoparietal neural network, which includes the supramarginal gyrus, the superior, middle and inferior frontal gyri, the orbitofrontal and ventromedial prefrontal cortex (Dong, Zhang, Xu, Lin, & Du, 2015; Losecaat Vermeer, Boksem, & Sanfey, 2014; Xue et al., 2011; Zeng, Zhang, Chen, Yu, & Gong, 2013). Thus, it

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appears that one's attempt to recover from prior losses involves the engagement of a brain network important for value encoding, the regulation of affect, and the guidance of subsequent choice behavior (Barber & Carter 2005; Bunge, Hazeltine, Scanlon, Rosen, & Gabrieli, 2002; Derrfuss, Brass, Neumann, & von Cramon, 2005; Derrfuss, Brass, & Yves von Cramon, 2004; Hare, Camerer, & Rangel, 2009; Rosenbloom, Schmahmann, & Price, 2012; Xue, Ghahremani, & Poldrack, 2008). By contrast, resisting "loss chasing" has been reported to be associated with increased activation within the anterior cingulate cortex, the insular cortex and the amygdala (Campbell-Meiklejohn et al., 2008; Xue et al., 2011), that is, brain regions involved in conflict monitoring and risk aversion (De Martino, Camerer, & Adolphs, 2010; Paulus et al., 2003; Rushworth, Walton, Kennerley, & Bannerman, 2004; Sokol-Hessner, Camerer, & Phelps, 2013; Samanez-Larkin, Hollon, Carstensen, & Knutson, 2008). With regard to risk-taking following a gain, it has been shown that the neural activity in the caudate and ventral striatum is higher when compared to decision-making after loss (Xue et al., 2011). Hence, deciding after winning activates reward and reinforcement learning processes (Daw, O'Doherty, Dayan, Seymour, & Dolan, 2006; Haruno & Kawato 2006; O'Doherty et al., 2004; Schultz, 2002; Tricomi, Delgado, & Fiez, 2004; Xue et al., 2008)). One possible explanation for this finding is that experiencing a win might decrease one's subsequent temptation to gamble, by "locking-in" the gain that he/she just obtained.

One gap of knowledge from prior brain-imaging studies is that the neural correlates of risk-taking following wins and losses have not been examined in individuals who are highly exposed to monetary risk-taking, such as poker players. Specifically, during poker playing, the individual could always learn from their opponents' strategy (e.g., in order to infer some betting patterns), but it is also critical for them to compute the risk of their decision based on the cards at hands, and also to disengage from recently experienced outcomes. In other words, poker players are often required to keep playing (or leave the game) based solely on the odds associated with their forthcoming choices. Hence, the ability to proficiently regulate one's emotions while playing—such as being able to cope with frustration that might be induced by previous losses—is an important part of success in poker (Browne, 1989; Laakasuo, Palomäki, & Salmela, 2014; Laakasuo, Palomäki, & Salmela, 2015; Palomäki, Laakasuo, & Salmela, 2013; Palomäki, Laakasuo, & Salmela, 2014). It follows that experienced poker players might be able to "let go" of unfavorable outcomes from previous actions, and consequently they might be better skilled at regulating themselves when facing monetary risky decisions (Laakasuo et al., 2014; Palomäki et al., 2013, 2014). Besides, previous neuroimaging studies on decision-making in gamblers have been undertaken with individuals suffering from gambling disorders and recruited from addiction treatment centers (Choi et al., 2012; van Holst, Veltman, Büchel, van den Brink, & Goudriaan, 2012) or did not control for gamblers' preferred type of gambling (e.g., poker vs. slot-machine; Balodis et al., 2012; Brevers et al., 2015a; Chase & Clark, 2010; Miedl, Fehr, Meyer, & Herrmann, 2010; Peters, Miedl, & Büchel, 2013; Power, Goodyear, & Crockford, 2012; van Holst, Chase, & Clark, 2014). This could have biased gambler participants' approach towards monetary risk-taking (Lorains et al., 2014; Turner, 2014). Hence, fundamental research is currently needed in order to get better grasp of the impact of frequent gambling on specific processes involved in decision-making.

In the present study, we aimed to examine how prior choice outcomes may influence the behavioral and neural activity of poker players' subsequent gambling choice, relative to non-gambler individuals. Since in a previous study we collected data from a sample of non-gamblers (Xue, Lu, Levin, & Bechara, 2010, [Xue et al., 2011]2011), the current study involved the collection a matching dataset from a sample of high-frequent poker players, and then

comparing the two datasets. In the experimental task of the previous study (the Modified Cups Task; Weller, Levin, Shiv, & Bechara, 2007; Xue et al., 2010, 2011), participants were asked to decide whether or not to take a risky-choice based on the probability of winning, and also on the available win/loss ratio. This is consistent with the pattern of probabilistic monetary decision-making that characterizes poker playing. We hypothesized that frequent poker players would be better at disengaging themselves from their previous choice outcome, as compared to non-gambler controls. More specifically, on a behavioral level, we hypothesized that loss-chasing (i.e., higher proportion of risky choices after losing than after winning a gamble) would be lower in poker players than in controls. On a neural level, we hypothesized that controls would exhibit higher brain activations than poker gamblers while deciding to take a risk or not after having experienced a loss.

2. Materials and methods

2.1. Participants

Fifteen regular poker players (gender: 6 males, 9 females; age: mean = 24.67, median = 24, 25th = 20, 75th = 26; education level: mean = 15.31, median = 15, 25th = 12, 75th = 18) and 14 non-gambler controls participated in this study (gender: 7 females, 7 males; age: mean = 23.80, median = 23.5, 25th = 22, 75th = 25, education level: mean = 16.12, median = 17, 25th = 15, 75th = 18). The two-groups did not differ in age (Mann-Whitney U statistic = 101.50, $Z = -0.15$, $p = 0.88$), gender ($\chi^2 = 0.59$, $p = 0.72$) and level of education (Mann-Whitney U statistic = 87.00, $Z = -0.84$, $p = 0.45$). All participants gave informed consent to the experimental procedure, which was approved by the University of Southern California Institutional Review Board. One gambler participant was excluded from the analyses due to technical failure with the MRI-compatible button press box. Hence, our final sample consisted of fourteen frequent gamblers and fourteen controls.

Poker gamblers were recruited on the Internet through advertisement displayed on online forums for poker players based in Los Angeles. The ads asked for participants who "played poker frequently" to participate in a one-day study to explore factors associated with decision-making in poker gambling. An email-screening interview was conducted in order to examine gambling frequency, problem gambling severity, history of therapeutic intervention focused on gambling behavior, medical history (as assessed with an MRI screening form; see also Brevers, Noël, He, Melrose, & Bechara, 2015b), substance abuse (items taken from the Addiction Severity Index Short Form), episodes of major depression or other psychiatric disorders (see also Brevers et al., 2015b). Only high-frequency poker players were recruited in our study. Specifically, only individuals who reported playing poker at least than twice a week (over the last 18 months) were included in this study. None of the poker player participants reported a history of therapeutic treatment focused on gambling behavior or having suffered of any major psychiatric disorders.

Control participants were recruited by word of mouth from the community (see also Xue et al., 2011). They were free of neurological or psychiatric history, and gave informed consent to the experimental procedure. Medical history was taken via completion of an MRI screening form. All subjects were right handed and had normal or corrected-to-normal vision. Problem gambling severity was assessed the day of study with the South Oaks Gambling Screen (SOGS; Lesieur & Blume, 1987). All controls scored zero on the SOGS. Poker players' SOGS scores and information on their frequency of poker playing (per week) and minimum amount of money spent on poker (per week) is depicted in Table 1.

Table 1
SOGS score, poker playing frequency, weekly poker budget in the poker player group ($n = 15$).

SOGS score (average)	$M = 3.60, SD = 3.48$
Non-problem gambling (SOGS score ranging from 0 to 1)	$n = 4$
Low problem gambling (SOGS score ranging from 2 to 4)	$n = 6$
High problem gambling (SOGS score >5)	$n = 5$
Poker playing frequency (day per week)	$M = 3.53, SD = 1.34$
Minimum amount of money spent on poker (in dollars per week)	$M = 128.67, SD = 46.73$

SOGS, South Oaks Gambling Screen; M , mean; SD , Standard Deviation; n , number of subject.

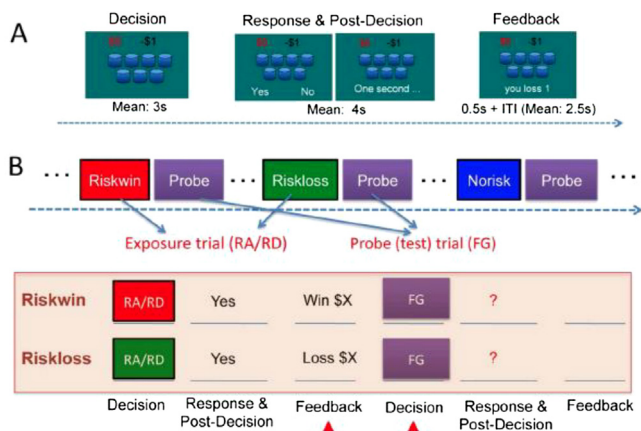


Fig. 1. The (A) structure of the Modified Cup Task and (B) the experimental design. In each gamble, a number of cups were presented with the first one containing a large gain and all the others containing a small loss. At the Decision stage, participants were shown the gamble and were asked to contemplate the gamble and make a decision of whether or not to take the gamble, without indicating any button response. After a varied period of delay, the response cue (“Yes” and “No” on each side) was shown on the screen and participants were asked to indicate a button press. After the response, a 0.5 s feedback was presented after some delay to inform participants of the outcome. The next trial would begin after a jittered delay. Depending on the combination of the reward amplitude and probability (determined by the number of cups), the gamble could be a fair gamble (FG), risk advantageous (RA) or risk disadvantageous (RD) (See Methods). The RA and RD trials were used as the exposure trials, each followed by a FG trial serving as the probe trial to examine the effect of prior outcome on subsequent decisions. The present study thus focused on the Riskwin and Riskloss trials and the probe trials that followed them.

2.2. The modified cups task

Fig. 1A depicts the Modified Cups Task and the experimental design (Weller et al., 2007; Xue et al., 2010, 2011). In each gamble, a number of cups (ranging from 3 to 11) were presented on the computer screen, with the first cup containing a large gain (ranging from \$3 to \$8) and all the rest containing a small loss (−\$1). The probability (as determined by the number of cups) and magnitude of the gain were independently manipulated such that some combinations create fair gambles (FG; number of cups ranging from 4 to 9, gain ranging from \$3 to \$8), that is, the expected value (EV) of the gamble equals zero (e.g., \$5 gain in one cup and \$1 loss in the other five cups). Some combinations are slightly risk advantageous (RA; number of cups ranging from 3 to 6, gain ranging from \$3 to \$8), meaning that the EV is larger than zero (e.g., \$5 gain in one cup and \$1 loss in the other three cups). Some combinations are slightly risk-disadvantageous (RD; number of cups ranging from 8 to 11, gain ranging from \$4 to \$8), meaning that the EV is smaller than zero (e.g., \$5 gain in one cup and \$1 loss in the other six cups). Participants were simply asked to play a series of gambles. For each gamble, they could choose to gamble or not to gamble. If they took a gamble, the computer would randomly choose one cup and deter-

mine whether they won or lost (see an exception below, which was unknown to the subjects). If they chose to pass on a gamble, they would win or lose nothing.

2.3. The experimental conditions and design

The present study used an approach that enables better control of prior outcomes, and it minimizes the requirement for post hoc matching. More specifically, we included two types of trials in this experiment: exposure trials and probe trials (Fig. 1B). The exposure trials included one of three possibilities: risk and win (Riskwin), risk and lose (Riskloss), or no risk (Norisk), depending on participants' choices and outcomes. Immediately following each exposure trial, a probe trial was presented. Our previous study showed that participants (irrespective of their risk preference) would make a risky choice on most of the RA trials and seldom take a risk on the RD trials, whereas the risk rate on the FG trials varied significantly across participants (Xue et al., 2009, 2010, 2011). Accordingly, the FG trials were used as probe trials to provide a sensitive measure of the prior outcome effect. RA and RD trials were used as exposure trials. For the purpose of the present study, half of the RA trials (where participants were most likely to gamble) were predetermined as win trials and the other half as loss trials, if participants chose to gamble. For all other trials, the computer would randomly choose one cup and determine whether they won or lost. It should be noted that, past studies from our team, highlighted that, although this manipulation slightly increased the probability of win for the RA trials, this did not significantly change the overall probability of a win; Xue et al., 2010, 2011). Moreover, post-experiment debriefing undertaken in these past studies indicated that participants did not notice this manipulation, nor did they change their gambling strategies accordingly (Xue et al., 2010, 2011). In total, each run included 72 trials: 36 exposure trials (24 RA, 12 RD) and 36 probe trials (FG). Within each block, a probe trial (FG) always followed an exposure trial (RA or RD; see also Table S1 in Supplementary materials for an example of trial succession within a single run of 72 trials). Because all probe trials were FG trials, they were thus matched in several decision parameters, including expected value, risk (defined as reward variance), reward probability and reward amplitude. Therefore, any behavioral and neural differences observed in these trials could only be attributed to the prior outcome manipulation. Since the structure of the exposure trials and the probe trials was identical and participants were simply told to decide whether or not to take each gamble, participants were not aware of the differences between the two types of trials, nor were they aware of the purpose of the study. Participants were told in advance that their final payoff would be randomly chosen (by flipping a coin) from one of the two fMRI runs, which was to avoid the wealth effect, i.e., participants' decisions are affected by how much they have earned through the course of the experiment.

2.4. MRI procedure

Participants layed supine on the scanner bed, and viewed visual stimuli back-projected onto a screen through a mirror attached onto the head coil. Foam pads were used to minimize head motion. Stimulus presentation and timing of all stimuli and response events were achieved using Matlab 7.14 (Mathworks) and Psychtoolbox 3.0 (www.psychtoolbox.org) on an IBM compatible PC. Participants' responses were collected online using an MRI-compatible button press box. An event-related design was used in this fMRI study. To separate the neural responses associated with the decision from those associated with feedback processing, each trial was divided into three stages: Decision, Response and post-decision, and Feedback (Fig. 1A). Random jitters were added between each stage and the sequence was optimized for design efficiency (Dale, 1999) using

an in-house program. At the Decision stage, a gamble was presented on the screen and participants were asked to contemplate the gamble without committing to any button response. After a varied period of delay (jittered, mean = 3s, ranging from 1.5 to 5s), the response cue (“Yes” and “No” on each side) was shown on the screen and participants were to indicate their choice by pressing a button within 3 s, otherwise they would lose \$1. The spatial position of the response cue (i.e., to accept or reject a gamble) varied from trial to trial so that participants were not able to predict its position and plan any motor response at the decision stage. After the response and some delay (jittered, mean = 4s, ranging from 2.5 to 6s), a 0.5 s feedback was presented to inform participants of the outcome. The next trial would begin after a jittered delay (mean = 2.5s, ranging from 1 to 4s). The jittering of ISI among three stages were optimized using a in-house script to minimize the correlation between time series of different stages. In total, each run lasted 12 min. Participants finished two runs of the gambling game.

2.5. MRI data acquisition

fMRI imaging was conducted in a 3T Siemens MAGNETOM Tim/Trio scanner in the Dana and David Dornsife Cognitive Neuroscience Imaging Center at the University of Southern

California. Functional scanning used a z-shim gradient echo EPI sequence with PACE (prospective acquisition correction). This specific sequence is dedicated to reduce signal loss in the prefrontal and orbitofrontal areas. The PACE option can help reduce the impact of head motion during data acquisition. The parameters are: TR = 2000 ms; TE = 25 ms; flip angle = 90°; 64 × 64 matrix size with resolution 3 × 3 mm². Thirty-one 3.5 mm axial slices were used to cover the whole cerebral cortex and most of the cerebellum with no gap. The slices were tilted about 30° clockwise along the AC-PC plane to obtain better signals in the orbitofrontal cortex. The anatomical T1-weighted structural scan was done using an

MPRAGE sequence (TI = 800 ms; TR = 2530 ms; TE = 3.1 ms; flip angle 10; 208 sagittal slices; 256 × 256 matrix size with spatial resolution as 1 × 1 × 1 mm³).

2.6. Image preprocessing and statistical analysis

Image preprocessing and statistical analysis were carried out using FEAT (FMRI Expert Analysis Tool) version 5.98, part of the FSL package (FMRIB software library, version 4.1, www.fmrib.ox.ac.uk/fsl). The first four volumes before the task were automatically discarded by the scanner to allow for T1 equilibrium. The remaining images were then realigned to compensate for small residual head movements that were not captured by the PACE sequence (Jenkinson & Smith, 2001). Translational movement parameters never exceeded 1 voxel in any direction for any subject or session. Data were spatially smoothed using a 5-mm full-width-half-maximum (FWHM) Gaussian kernel. The data were filtered in the temporal domain using a non-linear high pass filter with a 100-s cut-off. A three-step registration procedure was used whereby EPI images were first registered to the matched-bandwidth high-resolution scan, then to the MPRAGE structural image, and finally into standard (MNI) space, using affine transformations (Jenkinson & Smith, 2001). Registration from MPRAGE structural image to standard space was further refined using FNIRT nonlinear registration (Andersson, Jenkinson, & Smith, 2007a; Andersson, Jenkinson, & Smith, 2007b). Statistical analyses were performed in the native image space, with the statistical maps normalized to the standard space prior to higher-level analysis.

The data were modeled at the first level using a general linear model within FSL's FILM module. The following six trial types were modeled: three contextual trial types (Riskwin, Riskloss and Norisk) and their respective follow-up probe trials. Each trial was modeled

as three distinct events, corresponding to the different stages of the trial: Decision, Response/post-decision, and Feedback. Hence, there were [3 (risk win trial, risk loss trial, no risk trial) + 3 (probe after risk win, probe after risk loss, probe after no risk)] * 3 (decision, post decision, feedback) task based regressors. The event onsets were convolved with canonical hemodynamic response function (HRF, double-gamma) to generate the regressors used in the GLM. Temporal derivatives were included as covariates of no interest to improve statistical sensitivity. Null events were not explicitly modeled, and therefore constituted an implicit baseline. In this paper, we were particularly interested in BOLD responses associated with (i) the feedback stage for exposure trials (RD and RA) on which participants decided to take the gamble (Riskwin and Riskloss); and (ii) the decision stage on probe trials following Riskwin and Riskloss on exposure trials (see also Fig. S1 and Table S2 for detailed information in the absolute number of Riskwin and Riskloss trials experienced by each participants during the experiment).

A higher-level analysis created cross-run contrasts for each subject for a set of contrast images using a fixed effect model. Specifically, the following contrast images were computed for each subject: decision after win minus decision after loss, decision after loss minus decision after loss, feedback risk loss minus feedback risk win, feedback risk win minus feedback risk loss. These were then input into a random-effect model for group analysis using ordinary least squares (OLS) simple mixed effect with automatic outlier detection (Woolrich, 2008). Group images were thresholded using cluster detection statistics, with a height threshold of $z > 2.3$ and a cluster probability of $p < 0.05$, corrected for whole-brain multiple comparisons using Gaussian Random Field Theory (GRFT).

Due to the small sample size and non-normal distributions, non-parametric tests were used to examine behavioral performance. First, Wilcoxon Signed Ranks Tests were performed on the whole sample of participants (N = 28) in order to compare the proportion of risky choice on probe trials after a win and after a loss. Mann-Whitney *U* tests were then performed to examine between-groups differences. The risk rate for trials following a Norisk trial was not considered. In addition, to quantify the “loss-chasing” bias for each participant, the risk rate after Riskwin from was subtracted from the risk rate after Riskloss. Spearman rho (adjusted for multiple comparisons using Bonferroni-Holms corrections) was used to examine the association between indices of “loss-chasing” and the imaging data (extraction of parameter estimates). These analyses were carried out using SPSS software (SPSS, Inc., Chicago, Illinois) and SigmaXL for Mac OS X.

3. Results

3.1. In scanner behavior

By comparing the proportion of risky choices for the probe trials after Riskwin and after Riskloss, Wilcoxon Signed Ranks Tests revealed that participants (N = 28) made significantly less risky choices after winning the prior gamble (mean = 0.26, median = 0.27, 25th = 0.01, 75th = 0.40) than after losing it (mean = 0.36, median = 0.35, 25th = 0.09, 75th = 0.54, $Z = -2.74$, $p = 0.006$; see also Fig. 2 for spread in the poker player and the control group). Mann-Whitney *U* tests were then performed to examine between-groups differences on the proportion of risky choices for the probe trials after Riskwin and after Riskloss. These analyses revealed no between-groups difference for risky choices for the probe trials after Riskwin (poker players: mean = 0.20, median = 0.21, 25th = 0.00, 75th = 0.39; controls: mean = 0.29, median = 0.30, 25th = 0.03, 75th = 0.46; Mann-Whitney *U* statistic = 81.00, $Z = -0.79$, $p = 0.43$) and after Riskloss (poker players: mean = 0.35, median = 0.34, 25th = 0.08,

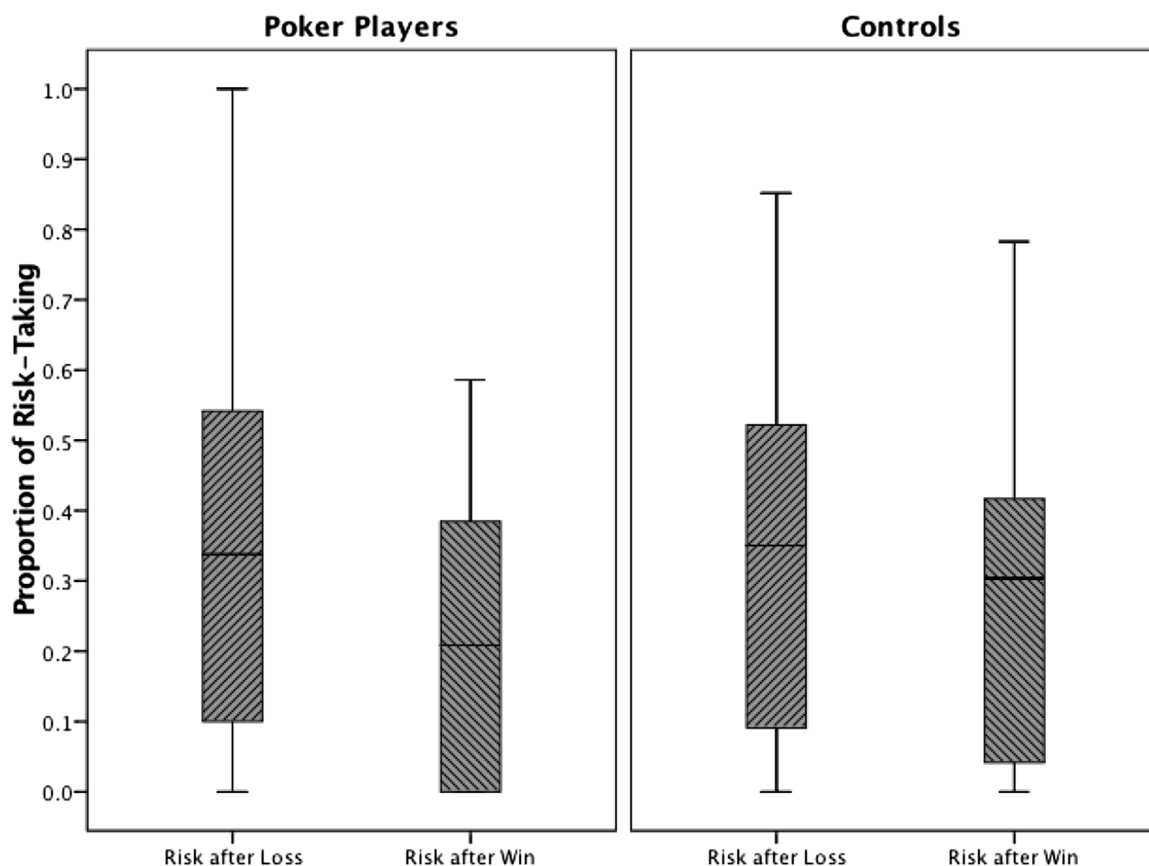


Fig. 2. Median, interquartile ranges and range on the proportion of risky choices for the probe trials after Riskwin and after Riskloss in the poker player and the control groups.

75th=0.55; controls: mean=0.36, median=0.35, 25th=0.07, 75th=0.58; Mann–Whitney U statistic=97.00, $Z=-0.98$, $p=0.96$). There was also no significant between-groups difference on the “loss-chasing” indices (poker players: mean=0.21, median=0.15, 25th=0.03, 75th=0.35; controls: mean=0.11, median=0.11, 25th=0.00, 75th=0.20; Mann–Whitney U statistic=85.00, $Z=-0.81$, $p=0.42$).

3.2. Imaging results

3.2.1. Controls minus poker players

See Fig. 3 and Table 2. The contrast “Decision after win minus decision after loss”, and “feedback risk loss minus feedback risk win” did not reach any significant activation.

3.2.1.1. Decision after loss minus decision after win. When comparing the brain responses associated with decisions after losing the previous gamble (i.e., Riskloss) to decisions after winning it (i.e., Riskwin), controls demonstrated increased activation in cingulate and paracingulate gyrus and left middle frontal gyrus. The activation peak in the left middle frontal gyrus was located in the dorsal premotor cortex (Brodmann Area 6). No significant correlation (within either the whole sample or the control group) was found between these activations (extraction of parameter estimates), and the behavioral indices of loss-chasing (all $p > 0.05$, corrected).

3.2.1.2. Feedback risk win minus feedback risk loss. When comparing the brain responses at the feedback stage during Riskwin minus Riskloss, controls demonstrated increased activations in right middle frontal and superior frontal gyrus; left superior parietal lobule; right cerebellum; right inferior frontal gyrus extending to frontal

orbital cortex; left middle frontal gyrus; left lateral occipital cortex; right accumbens extending to putamen and caudates; right superior temporal gyrus and middle temporal gyrus.

3.2.2. Poker players minus controls

See Fig. 4 and Table 3. The contrast “Decision after loss minus decision after win”, and all contrasts attached to the feedback stage did not reach any significant activation.

3.2.2.1. Decision after win minus decision after loss. When comparing the brain responses associated with decisions after winning the previous gamble (i.e., Riskwin) to decisions after losing it (i.e., Riskloss), poker players demonstrated increased activation in bilateral middle frontal gyrus and right superior frontal gyrus. The activation peaks in the middle frontal gyrus and the right superior frontal gyrus were located in the dorsal premotor cortex (Brodmann Area 6). No significant correlation (within either the whole sample or the poker player group) was found between these activations (extraction of parameter estimates), and the behavioral indices of loss-chasing, and also with the scores on the SOGS (within the poker player group only; all $p > 0.05$, corrected).

4. Discussion

The present study aimed to better specify the brain mechanisms that are engaged when frequent poker players elaborate on their forthcoming gambling choice. These neuroimaging findings were obtained through the use of the Modified Cups task (Weller et al., 2007; Xue et al., 2010, 2011), which mimic the pattern of probabilistic monetary decision-making involved in poker playing.

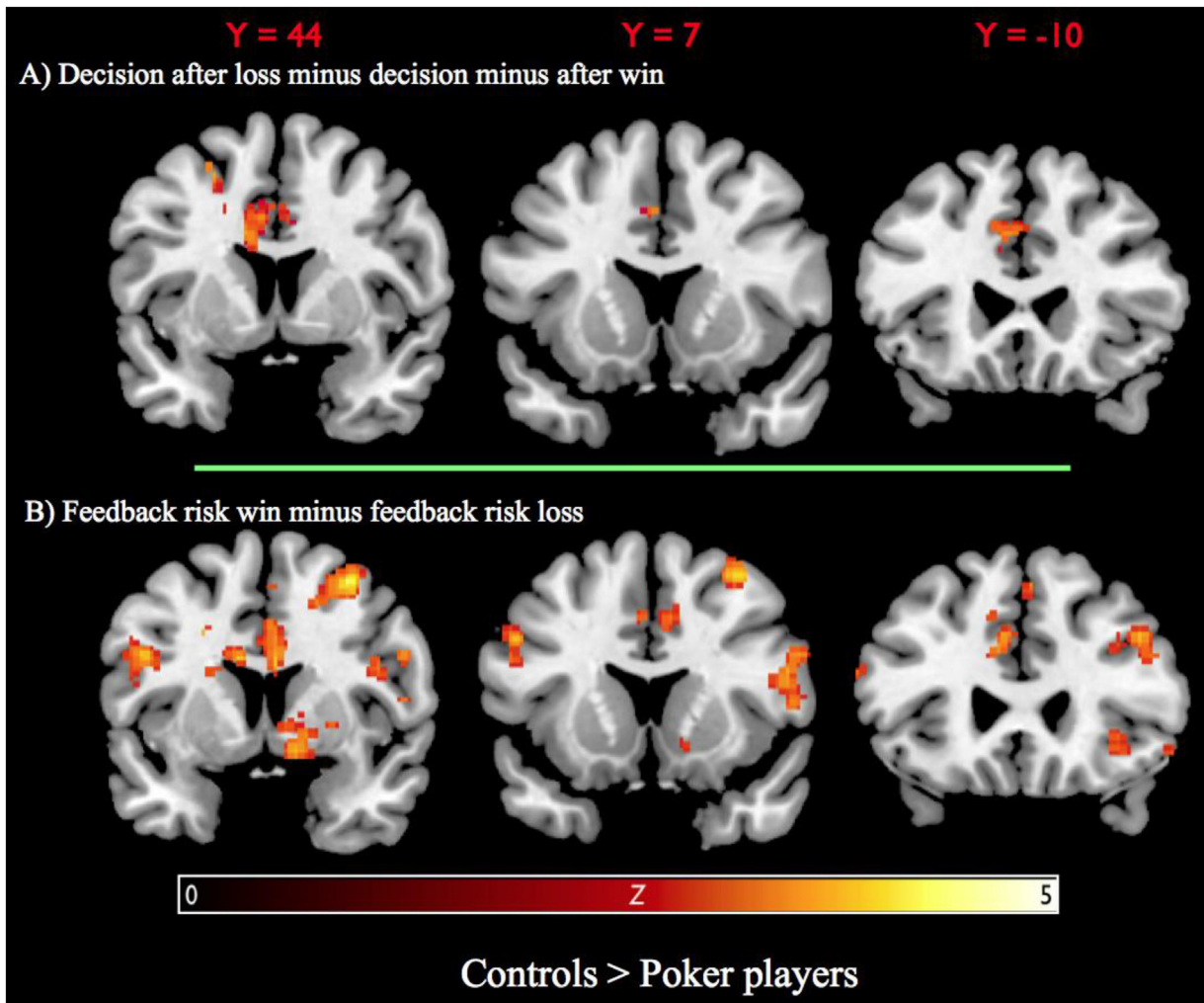


Fig. 3. Control minus poker player group differences on the Cups task. Brain activation maps demonstrate differences in the “decision after loss minus decision after win” and the “feedback risk win minus feedback risk loss” contrasts. All contrast maps are thresholded at an height threshold of $z > 2.3$ and a cluster probability of $p < 0.05$, corrected for whole-brain multiple comparisons. The right side of the brain is on the right.

Table 2

Peak cluster activation for the controls minus poker players contrasts.

MSST Contrast	Structure	Left/right	BA	MNI Coordinates				Z value
				k	x	y	z	
Controls > poker players								
Decision_after win > decision_after loss	–	–	–	–	–	–	–	–
Decision_after loss > decision_after win	Cingulate Gyrus	L/R	–	182	2	0	38	3.53
	Paracingulate Gyrus	L/R	32	66	–4	26	34	3.28
	Superior Frontal Gyrus/Middle Frontal Gyrus	L	6	30	–24	6	52	3.29
Feedback_risk win > feedback_risk loss	Middle Frontal Gyrus/Superior Frontal Gyrus	R	6	2471	32	6	56	4.59
	Superior Parietal Lobule	L	–	776	–28	–50	38	4.10
	Cerebellum	R	–	482	6	–74	–28	3.71
	Inferior Frontal Gyrus/Frontal Orbital Cortex	R	47	475	52	42	–2	3.58
	Middle Frontal Gyrus	L	9	472	–52	20	30	4.21
	Lateral Occipital Cortex	L	–	434	–42	–66	–4	3.99
	Accumbens/Putamen/Caudates	R	–	351	16	8	–4	4.09
	Superior Temporal Gyrus/Middle Temporal Gyrus	R	22	313	70	–22	–8	4.48
Feedback_risk loss > feedback_risk win	–	–	–	–	–	–	–	–

BA, Brodmann Area; k, voxel cluster size (each voxel = 8 mm³); L, left; R, right; MNI, Montreal Neurological Institute.

At a behavioral level, we observed that, in both poker player and control groups, that there was a significant difference in the proportion of risky-choices made after winning, as compared to the proportion of risky-choices made after losing the prior gamble. This result is in line with previous studies (De Martino et al., 2010; Kahneman & Tversky, 1979; Losecaat Vermeer et al., 2014; Losecaat

Vermeer & Sanfey, 2015; Tversky & Kahneman, 1981, 1992; Tom, Fox, Trepel, & Poldrack, 2007; Xue et al., 2011) and confirms that when an individual has just experienced a loss, he/she is more prone to take a risky gamble, as compared to when gains preceded the choice.

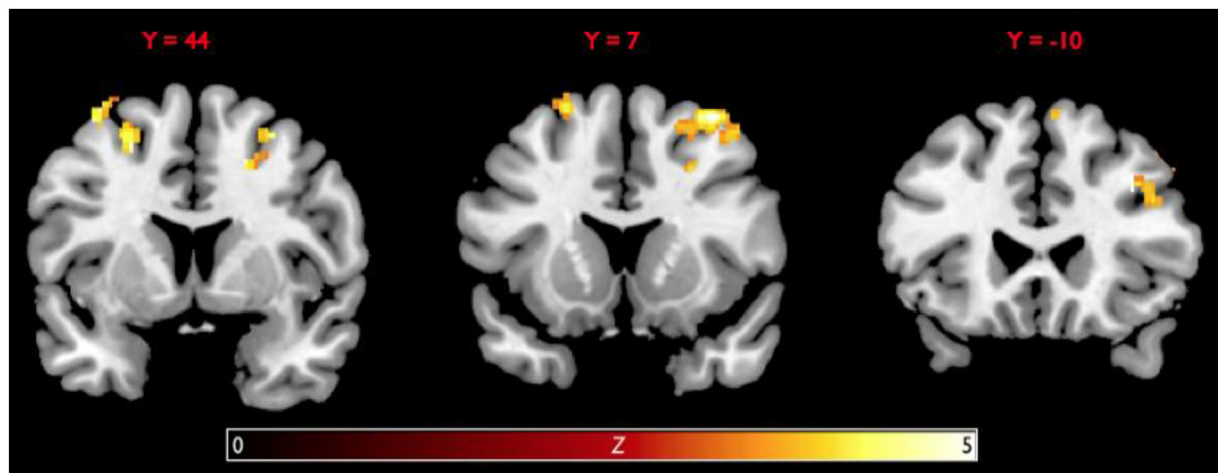


Fig. 4. Poker player minus control group differences on the Cups task. Brain activation maps demonstrate differences in the “decision after win minus decision after loss” contrast. Activations maps are thresholded at an height threshold of $z > 2.3$ and a cluster probability of $p < 0.05$, corrected for whole-brain multiple comparisons.

Table 3
Peak cluster activation for the poker players minus controls contrasts.

MSST Contrast	Structure	Left/right	BA	MNI Coordinates				Z value
				k	x	y	z	
Poker players > controls								
Decision.after win > decision.after loss	Middle Frontal Gyrus	R	9	317	32	4	56	3.67
	Middle Frontal Gyrus	L	6	224	-32	0	70	3.95
	Superior Frontal Gyrus	R	6	32	12	34	60	3.45
Decision.after loss > decision.after win	-	-	-	-	-	-	-	-
Feedback.risk win > feedback.risk loss	-	-	-	-	-	-	-	-
Feedback.risk loss > feedback.risk win	-	-	-	-	-	-	-	-

At a neural level, we observed that controls exhibited higher brain activations than poker players when elaborating on a decision after losing, as compared to after winning. The opposite was found in poker players, who exhibited higher brain activation than controls when elaborating on a decision after winning the previous gamble. These patterns of activations were observed in the posterior areas of the superior frontal gyrus (specifically the dorsal area of the premotor cortex, Brodmann Area 6), and in the dorsal anterior cingulate cortex. These are brain regions thought to be involved in the mental representation (e.g., [Cisek & Kalaska, 2005](#); [Pilgramm et al., 2010](#)), the planning (e.g., [Delnooz, Helmich, Medendorp, Van de Warrenburg, & Toni, 2013](#); [Hartwigsen & Siebner, 2015](#)), and the execution (e.g., [Nakayama, Yamagata, Tanji, & Hoshi, 2008](#); [Rizzolatti, Fadiga, Gallese, & Fogassi, 1996](#)) of high-order motor actions (e.g., conditional visuo-motor associations, response selection, or motor imagery; [Picard & Strick, 2001](#); [Cisek & Kalaska, 2004](#); [Tanaka, Honda, & Sadato, 2005](#)).

One possible explanation for these neural findings is that, in controls, deciding after a loss might have induced higher action preparation for the upcoming decision, potentially coding for participants' high anticipation to recover from their previous loss. With regard to poker players, greater activation in the dorsal premotor cortex might indicate higher motor preparation after winning than after losing a gamble. Importantly, brain-imaging analyses on feedback reactivity highlighted higher brain activations in controls when receiving a monetary gain, as compared to poker players. This is in line with previous studies showing that frequent and problem gamblers exhibit lowered brain reactivity to monetary feedback ([de Ruiter et al., 2009](#); [Lole, Gonsalvez, & Barry, 2015](#); [Reuter et al., 2005](#); [Tanabe et al., 2007](#); but see [Hewig et al., 2010](#); [Oberg, Christie, & Tata, 2011](#)). This finding also suggests functional distinction between early (i.e., feedback reactivity on exposure trials) and latter stages (i.e., the elaboration of the next gambling decision during

probe trials) of outcome processing in poker players. More specifically, poker players might be less reactive to a monetary gain while receiving it, but seem to integrate this information while anticipating the execution of their forthcoming choice. In other words, in poker players, prior win outcomes might be especially relevant while pondering the next gambling strategy.

There are several limitations in this study that should be considered. First, due to the small sample size, non-significant result must be interpreted with caution. Second, because no significant correlation was observed between behavioral and neuroimaging findings, current interpretations remain tentative and of an exploratory nature. One explanation for this lack of association is that neuroimaging findings were obtained during the pondering of the choice, that is, a phase of decision-making that does not involve any overt motor action (e.g., pressing the response key). Hence, while this design allowed the neural acquisition of decision processes that are closest to prior win/loss outcomes, neural findings only covered one portion of the processes involved in the enactment of a gambling-related decision (e.g., the planning but not the execution of the decision). Moreover, the current design did not distinguish the response phase (i.e., to press “Yes” or “No”) from the post-decision phase (i.e., the participant made his/her choice and wait for the outcome). Hence, the experimental procedure should be refined in order to get more insight on specific processes that modulate risk-taking following wins and losses (for an alternative design procedure, see [Losecaat Vermeer et al., 2014](#)). Another point is that, because we obtained higher proportion of gambles after a loss than after to a win, fMRI signal observed during the “decision stage” could also be driven by the decision the participant is about to make (i.e., accepting or rejecting a gamble during the “response stage”). Further studies are needed to specifically examine this issue. Finally, because we used the same (small) sample of control participants in two other studies ([Xue et al., 2010](#),

2011), present results should be read as complementary to those previously published findings.

In sum, we observed that high-frequent poker players and non-gambler controls exhibit differential patterns of brain activation when pondering a risky decision after having experienced either a win or a loss. These activations have been shown to principally engage the dorsal premotor cortex. This confirms that brain regions involved in high-order motor control are central for the planning of a subsequent monetary decision. Altogether, the present findings add to the existing neuroimaging literature on gambling, as they provide a useful theoretical and methodological framework that could be used to model the impact of gambling habits on monetary risk-taking.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.biopsycho.2017.01.009>.

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