The Neural, Cognitive and Behavioural Mechanisms of EGM Play

Ruobing Shao

Department of Psychiatry

St. Anne's College

University of Oxford

Thesis submitted for Degree of Doctor of Philosophy

2012

Approx 48,000 words

Dedication

For my Mum.

Declaration

The work presented in this thesis was conducted by the author. No part of this thesis has been submitted for another degree at this or any other university.

The neural, cognitive and behavioural mechanisms of EGM play

Ruobing Shao, St. Anne's College, University of Oxford

Thesis submitted for the degree of D.phil

Michaelmas term, 2012

Abstract

BACKGROUND: Electronic Gaming Machine (EGM) play may be particularly addictive. However, we know little about the relationships between near-misses, illusions of control, impulsivity and people's attitudes and behaviours towards the game, as well as changes in neural systems as people acquire more experience with EGM play. METHODS: Experiment 1 used the indirect Functional Magnetic Resonance Image (fMRI) technique to examine the neural signals of dopaminergic reinforcement circuitries evoked by playing a simple slot-machine among practiced participants who had previous game experience and unpracticed participants who had no such experience. Experiment 2 examined the influence of impulsivity and illusions of control on Blood Oxygen Level Dependent (BOLD) signals elicited by slot-machine outcomes. Experiment 3-5 investigated the effect of near-miss frequency on people's valuations of slot-machine games, indicated mainly by purchasing of optional plays, when co-occurring with different frequencies of wins. We also tested how the interactive influence of near-miss and winning frequencies on game valuations was associated with gambling-related cognitive biases. Experiment 3-5 also tested a novel card-guessing game designed to provide valid behavioural measure of illusions of control. RESULTS: Prior slot-machine experience was associated with shift of dopaminergic signals in the ventral striatum from the rewarding outcomes to the reel-spins. Impulsivity enhanced dopaminergic responses to wins but suppressed signals to near-misses. Illusions of control potentiated neural signals to near-misses in the practiced participants. Winning slot-machine outcomes exerted principle influence on game valuations, whereas the effect of near-misses was weak. However, some evidence indicated that the influence of near-miss frequency on game valuations depended on the frequency of wins. Individuals holding more positive gambling expectancies showed buying behaviours that were under less positive interactive influence of winning and near-miss frequencies. Our card-guessing game was successful in eliciting behavioural patterns indicative of illusions of control. CONCLUSIONS: A dopaminergic neural mechanism is implicated in the acquisition of slot-machine experience. Near-misses may not simply act as 'mini-wins'. The effect of near-misses on game valuation is subtle and may depend on the frequency of co-occurring wins.

ACKNOWLEDGEMENTS

My research was generously funded by a Clarendon scholarship awarded by the University of Oxford and BBSRC funding awarded to Prof. Robert Rogers.

Throughout the course of my D.phil I received invaluable support from a number of colleagues and staffs. First, I would like to thank all the staffs in FMRIB and OCMR who kindly helped me with the collection and analysis of image data, including, but not limited to, Mr. Steve Knight who operated the scan for me and taught me a lot of knowledge about data collection, Dr. Clare Mackay and Prof. Steve Smith who helped me with fMRI analysis problems, and Dr. Duncan Mortimer and Mr. Dave Flitney who offered good computer support. I would also want to give special thanks to Dr. Tim Behrens, who has helped much with the analysis of image data and Matlab scripting. I also want to thank Miss Chloe Connolly for helping me a lot with the collection and analysis of image data.

Second, I would like to thank all my current and previous colleagues in the lab. I thank Mrs. Judi Wakeley for her enthusiastic help with task programming, participant screening and testing, and problem solving. I also thank Dr. Joanne Lloyd and Dr. Rebecca Chandler for their kind helps with answering my data analysis questions, and Dr. Kate Saunders for her medical help. I thank Mr. Judah Weathers for his personal support and friendship, and Mr. Matthew Lim, Miss Sarah Yip, Mr. Patrick Worhunsky, Dr. Corin Bourne, Dr. Charidimos Tzagarakis for their company, friendship, comfort and support. I would also like to thank all my colleagues who helped me with task programming and piloting. Perhaps even more importantly, I would like to thank all my colleagues for their sincere care, help and support during the time following my car accident. I would not have recovered so quickly and well without you. I owe a big favour to all of you.

On a more personal note, I would like to thank Miss Amy Bilderbeck who has always been both a supportive colleague of mine and a best friend. She operated the scan for me during many weekends and out-of-office hours, without which I could not have collected so much data so quickly. Besides all the academic and professional support and advice, she provided great company and comfort and helped me massively during my recovery from the accident. I also thank Dr. Anca Popescu, who was really supportive, helpful and offered me a lot of advice in life.

Finally, I would like to thank my supervisor, Prof. Robert Rogers, who has helped me and taught me very much throughout my D.phil. In particular, I thank Prof. Rogers for allowing me the freedom to explore and expand my own research and work in my own rhythm, for his unforgettable help and support following my accident, and for his trust in my skills and potentials to carry out independent research and to be a good scientist. I also like to thank my college tutor, Kate Watkins, for her care and support on my personal and academic life. I also must give special thanks to all the staffs of St. Anne's College of which I have been a member for more than 7 years, including, but not limited to, Dr. Anne Mullen, Miss Christine Foard and the college principle Mr. Tim Gardam for their invaluable help and support following my accident on accommodating my parents, providing financial allowance and taking care of my health. Many, many thanks to all of you.

TABLE OF CONTENTS

CHAPTER I

A GENERAL INTRODUCTION

Overview……..17

Part 1 – Pathological gambling: Etiology theories

***Overview*……20**

***The 'near-miss' effect in gambling*.....21**

***Illusions of control in gambling*.....27**

***Impulsivity and problem gambling*……30**

Part 2 – The brain reinforcement systems and EGM play

***Overview*……33**

***The midbrain dopamine system*……..35**

***The ventral striatum/nucleus accumbens*……37**

***The dorsal (dorsomedial) striatum (caudate nucleus)*……...40**

***The amygdala*……41**

***The anterior cingulate cortex (ACC)*……..43**

***The insular cortex*…….....45**

***The dopaminergic processing of near-miss outcomes*……46**

***The dopaminergic pathways and pathological gambling*……48**

***The dopaminergic basis of impulsivity*……50**

An overview of experiments in this thesis……53

Chapter II

Experiment 1: Neural response to slot-machine play: the influences of prior game experience

Introduction……56

Methods……60

Subjects……61

Psychometric assessments……61

Design……62

Computer-simulated slot-machine game……64

Procedure……67

Functional image acquisition……68

Pre-processing……69

Data analysis……69

Model……70

Timeseries analysis……71

Matching analysis for participants……72

Behavioural and BOLD data analysis……72

Results

Participant characteristics……73

The reaction times (RT) of slot-machine play……73

An overview of analysis on neural signals……73

The omnibus multi-factorial ANOVA on BOLD responses……78

Testing the effects of infrequency: wins vs. near-misses……81

Testing anatomical specificity: BOLD signals in posterior areas……82

Testing BOLD signals evoked by the control game……85

Outcome value analysis……87

Discussion……87

Chapter III

Experiment 2: Neural response to slot-machine play: the influences of impulsivity and illusions of control

Introduction……..93

Methods

Subjects……98

Psychometric assessments……..98

GBQ……99

Design, game structure and procedure……101

Image acquisition and data analysis……..101

Model……..101

Timeseries analysis……101

Behavioural and neural signal analysis……102

Results

Participant characteristics……103

The reaction times (RT) of slot-machine play.....103

Impulsivity influences BOLD signals to wins and near-misses……103

Illusions of control, practice and near-misses……..109

Discussion……110

Impulsivity influences BOLD signals to game outcomes……...111

Illusions of control potentiate near-miss signals after practice……115

Experiment 3-5: The effects of winning and near-miss frequencies and their interaction on people's valuations of slot-machine games

Chapter IV

Experiment3

Introduction……119

***The near-miss effect on gambling*……119**

***Near-misses act as 'mini-wins'*……120**

***Near-misses induce negative affect and frustration*……122**

***Near-misses potentiate illusions of control*……122**

***Testing the illusions of control effect on gambling behaviour*……124**

Methods

***Subjects*……128**

***Psychometric assessments*……129**

CHQ……130

GRCS……130

***Design*……133**

***Computer-simulated slot-machine game*…… 133**

***Computer-simulated card-guessing game*…… 136**

***Procedure*……139**

***Statistical analyses*……140**

Slot-machine data analyses.....140

Card-game data analyses……141

Results

Psychometrics……142

Slot-machine buying behaviour

ANOVA……143

Multiple linear regression analyses……144

Card-game betting behaviour

ANOVA……146

Regression analyses……147

Discussion

An overview of results.....148

Near-misses interact with wins to influence game valuations……149

The interactive influence of near-miss and winning frequencies was associated with predictive control……152

Participants' betting behaviours in the card-guessing game……154

A summary of results and an outline of Experiment 4……156

Chapter V

Experiment4

Introduction……158

Methods

Subjects……161

***Psychometric assessments*……..…..162**

***Design*……..…164**

***Computer-simulated slot-machine game*……165**

***Computer-simulated card game*……..167**

***Procedure*……168**

***Statistical analyses*……168**

***Slot-machine data analyses*……168**

***Card-game data analyses*……169**

Results

***Slot-machine analyses*……170**

***Frequent gamblers*.....171**

***Infrequent gamblers*……172**

***ANOVA analyses on enjoyment ratings*……174**

***ANOVA analyses on luckiness ratings*……...177**

***Linear regression analyses on buying behaviour*……177**

Card-game betting behaviour

***ANOVA*……..180**

***Regression analyses*……182**

Discussion

***An overview of results*……..184**

***Slot-machine outcomes influence game valuations*……..185**

***Slot-machine outcomes influence ratings of enjoyment*……..188**

***The interactive influence of winning and near-miss frequencies and cognitive bias*……..189**

***Participants' betting behaviours in the card-guessing game*……..190**

***A summary of results and directions for Experiment 5*……191**

Chapter VI

Experiment5

Introduction……..193

Methods

***Subjects*……..196**

***Psychometric assessments*……...197**

***Design*……..198**

***Computer-simulated slot-machine game*……199**

***Computer-simulated card-guessing game*……202**

***Procedure*……202**

***Statistical analyses*……..202**

***Slot-machine data analyses*……..203**

***Card-game data analyses*……..204**

Results

***Psychometrics*……..204**

Slot-machine analyses

***ANOVA analyses on buying behaviours*.....205**

***ANOVA analyses on win-chance ratings*.....207**

***ANOVA analyses on enjoyment ratings*……208**

***ANOVA analyses on luckiness ratings*……...209**

***Linear regression analyses on buying behaviour*……209**

Card-game betting behaviour

ANOVA……..211

Regression analyses……212

Discussion

Overview……..213

Slot-machine outcomes influence game valuations……214

Slot-machine outcomes influence win-chance ratings……217

The interactive influence of winning and near-miss frequencies and gambling expectancy……218

Participants' betting behaviours and illusions of control……...219

A summary of major results……220

Chapter VII

A general discussion of the thesis

Overview……..222

Experiment 1: the effects of prior game experience on neural signals during slot-machine play

Outline of experiment and results……223

Further implications of results……225

Experiment 2: Impulsivity and illusions of control modulate neural responses to slot-machine outcomes

Outline of experiment……226

Impulsivity modulates BOLD signals to wins and near-misses……227

Illusions of control modulate near-miss signals after practice.....230

Limitations of Experiment 1 and 2……231

Experiment 3-5: The influence of winning and near-miss frequencies on

people's slot-machine game valuations

***Outline of experiment*……233**

***The influence of slot-machine outcomes on game valuations*……235**

***Implications of the findings*……236**

***The interactive influence of winning and near-miss frequencies on game valuation and gambling expectancy*……240**

***Illusions of control and the card-guessing game*……242**

Limitations of Experiment 3-5……243

Conclusion and final remarks……245

References……246

ABBREVIATIONS

Abbreviation	Meaning
ACC	Anterior Cingulate Cortex
ANOVA	One-Way Analyses of Variance
BET	Brain Extraction tool
BIS	Barratt Impulsiveness Scale
BOLD	Blood Oxygen Level Dependent
CBT	Cognitive Behavioural Therapy
D2/D3	Dopamine receptor subtypes
DA	Dopamine
DLPFC	Dorsolateral Prefrontal Cortex
dmPFC	Dorsomedial Prefrontal Cortex
DSM	Diagnostic and Statistical Manual of Mental Disorders
EGM	Electronic Gaming Machine
EIS/I7	Eysenck's Impulsiveness Scale
EPI	Echo-Planar Image
EV	Event-Related Variables
fMRI	Functional Magnetic Resonance Image
GBQ	Gamblers' Beliefs Questionnaire
GBQ-IoC	The illusion of control subscale of the Gamblers' Beliefs Questionnaire
GLM	General Linear Model
GRCS	Gambling Related Cognitions Scale
HI/LI	High Impulsive/Low Impulsive
HRF	Hemodynamic Response Function
LDW	Losses Disguised as Wins
MCFLIRT	Motion Correction Using FMRIB's Linear Image Registration Tool
NAcc	Nucleus Accumbens
NART	National Adult Reading Test
OFC	Orbitofrontal Cortex
PD	Parkinson's Disease
PE	Prediction Error
PET	Positron Emission Tomography
PG	Pathological Gambling

ROI	Regions of Interest
RT	Reaction time
RTP	Return to Player
SCID-I	Structured Clinical Interview for DSM-IV Axis-I Disorders
SE	Standard Error (of the mean)
SN	Substantia Nigra
SOGS	South Oaks Gambling Screen
T1	Spin-Lattice Relaxation Time
T2	Spin-Spin Relaxation time
TD	Temporal Difference
TE	Echo Time
TR	Repetition Time
VMPFC	Ventromedial Prefrontal Cortex
VR	Variable Ratio
VS	Ventral Striatum
VTA	Ventral Tegmental Areas

Chapter I—A General Introduction

Overview

Opportunities to gamble have increased substantially over the last 20 to 30 years (Orford, 2010), with the most recent estimates of gambling participation indicating that, excluding the national lottery, 73% of the UK adult population gambled within the last year (Wardle et al., 2011). The increased opportunities to gamble highlight the need for research to study the psychological, emotional and neural substrates of gambling problems, and to understand the best ways to identify and treat those who are the most vulnerable.

Pathological gambling (PG) is often considered as an urge to gamble despite harmful negative consequences or a desire to stop. It is currently categorized as an impulse control disorder in DSM-IV (APA, 1994); however, the disorder will be realigned as a behavioural addiction in DSM-V (Holden, 2010). Diagnostic criteria for PG include those such as preoccupation of gambling, tolerance, withdrawal, chasing, lying, loss of control, illegal acts and risked significant relationship (APA, 1994). The estimated prevalence for problem gambling in the UK is 0.9% for adults aged 16 or over, slightly higher than both in 2007 and 1999 (Wardle et al., 2011). This prevalence rate is similar to rates observed in other European countries, but lower than countries such as the USA, Australia and South Africa (Loba et al., 2001; Potenza et al., 2001). On the other hand, gambling problems is increasingly viewed as existing along a continuum

(MacKillop et al., 2006). In the UK, the prevalence of low-risk gambling is estimated to be 5.5% and moderate-risk gambling is 1.8% (Wardle et al., 2011).

In this thesis, I will be discussing experiments investigating the cognitive, behavioural and neural mechanisms of Electronic Gaming Machine (EGM) play. EGMs such as slot-machines and video poker represent one of the most popular forms of gambling activity and constitute one of the most profitable revenue streams for commercial gambling outlets (Eadington, 2007; Turner and Horbay, 2004). As such, they are often considered as the most aggressively promoted gambling activity (Australian Productivity Commission, 1999; Norwegian Gambling Authority, 2006; Williams and Wood, 2004) with increasing accessibility over the recent years in both European and Australian regions (Cho´liz, 2009; Thomas et al., 2009).

Notwithstanding their commercial values, gambling on EGMs such as slot-machines has been characterised as one of the most addictive forms of gambling (e.g. Dickerson, 2004) with several possible reasons in relate to the games' structural characteristics, such as rapid event frequency, short time between stake and payout, reinforcing sounds and colours and the heightened risk for overspendings (Dowling et al., 2005). Increased availability of EGMs has been linked to the increase in gambling problems in the Australasian context (Australia PC, 2009). There is also clinical evidence that the majority of patients who seek treatment for pathological gambling problems engage in EGM play (Jackson et al., 2000), and some provisional evidence that pathological

gambling may appear more rapidly in EGMs than in any other types of gambling (Breen and Zimmerman, 2005).

The heightened risks associated with EGMs for problem gambling have aroused wide government and public concern and regulatory efforts to control EGM availability and features (e.g. Griffiths, 2008a). Measures that have been proposed include the featuring of mandatory breaks in continuous EGM games (Griffiths, 2008a), 'pop-up' message windows advising the players how long they have been playing (Monaghan, 2008), and the removal of note acceptors from the machines (Hansen and Rossow, 2010). It is also being recognized that more specific structural characteristics of EGMs (e.g. slot-machines), such as the delivery of 'near-miss' outcomes, may encourage gambling (e.g. Kassinove and Schare, 2001; Griffiths, 1993a), and regulatory measures have been introduced to set restrictions on the frequency of near-miss outcomes delivered by EGMs (Harrigan, 2007, 2009). However, to date there is still a lack of empirical evidence about EGM gambling, including detailed investigations on the relationship between the game's structural characteristics (Parke and Griffiths, 2006) and players' attitudes and behaviours towards the game, as well as the changes in neural systems as people acquire more experience with EGM play. Epidemiological investigations on whether EGM players are at higher risks of developing gambling problems are complicated by the wider range of gambling activities observed in problematic individuals (Dowling et al., 2005), though there is some suggestion that EGMs may be particularly problematic in recent prevalence data (La Plante et al., 2011). Thus, my thesis consists of 5

empirical studies, by carrying out which we aim to supplement the existing literature on the above questions.

Part 1—Pathological gambling: etiology theories

Overview

The identification of the aetiological processes that might lead to gambling problems has been the focus of much research (Milosevic and Ledgerwood, 2010). According to Blaszczynski (2000)'s influential model, there are three subtypes of gamblers: the gamblers who are not pathologically disturbed; the gamblers who are emotionally vulnerable; and the gamblers who are biologically impulsive. The undisturbed gamblers may become trapped into gambling through processes such as classical/operant conditioning and cognitive biases (Skinner, 1953). The emotionally disturbed group use gambling as a way of escaping from negative emotions such as depression or anxiety. Finally, the impulsive group is vulnerable to develop gambling problems because high impulsivity is represented by a greater propensity to seek out rewards, unable to delay gratification and diminished response to punishment. Blaszczynski's model subsequently received support from other researchers (e.g. Milosevix and Ledgerwood, 2010).

In particular, cognitive perspectives on gambling emphasizes that mistaken beliefs and biased thinking play a significant role in sustaining gambling behaviour and, in some vulnerable individuals, facilitate gambling problems (Toneatto et al., 1997). One prominent set of bias include illusions of control in which gamblers believe that they are able to influence the outcomes of chance events (Ladouceur et al., 1988). Illusions of control can involve active beliefs that particular actions change the outcomes of gambling, or passive beliefs in luck as a personal attribute that can also influence the results of gamble (Langer, 1975; Wohl and Enzle, 2003). Illusions of control are significantly enhanced in individuals who gamble regularly and among those with clinically significant gambling problems (Joukhador et al., 2003).

The ‘near-miss’ effect in gambling

A near-miss is a special kind of failure to reach a goal, one that comes close to being successful (Reid, 1986). It has been well recognized that the occurrence of near-miss outcomes during gambling can facilitate and motivate persistent play (Kassinove and Schare, 2001; Cote et al., 2003). This has stimulated research on the structural characteristics of Electronic Gambling Machines (EGMs) such as slot machines and suggestions that virtual slot-machine games are programmed to produce disproportionately high frequencies of near-miss outcomes in order to encourage people to play (Harrigan, 2007; Harrigan, 2009).

In 1967, Strickland and Grote manipulated whether the winning signs of a slot-like game came first or last in the reel-stopping sequence and found that players who experienced more-frequent occurrence of near-miss outcomes were more likely to continue playing. A later study by Kassinove and Schare (2001) found that participants who previously played a slot-machine game containing 30% near-miss outcomes showed the greatest persistence at play in the extinction phase when no winning or near-miss outcomes occurred, compared to those who played games with 15% or 45% near-miss outcomes. Thus, an inverse-U shaped relationship was observed between the frequency of near-miss outcomes and persistence. Similarly, Cote et al. (2003) asked participants to play one of two three-reel slot-machine games, neither of which had any winning outcomes. However, one game contained 25% near-miss outcomes and the other contained none. It was found that players in the near-miss condition played one-third more games than those in the other condition. Moreover, MacLin et al. (2007) found that participants who preferred playing slot-machine with 45% near-miss outcomes over the machine delivering 15% near-miss outcomes showed greater persistence in play during the extinction phase containing no winning outcomes. Finally, consistent with the findings of Kassinove and Schare (2001), a recent study showed that participants preferred to play slot-machine game with 30% near-miss outcomes compared to 0% or 15% near-misses, but disliked the game delivering 45% near-miss outcomes (Kurucz and Kormendi, 2011).

The above findings collectively suggest that near-miss outcomes, at least when delivered at particular frequencies, encourage persistent gambling behaviours.

However, these studies also have limitations. First, most of the above studies employed slot-machine games with generous return-to-player, calculated as the total amount won divided by the total amount cost to play. The RTP of the game was 100% in Cote et al. (2003), 200% in MacLin et al. (2007) and >100% in Kurucz and Kormendi (2011). These RTPs, while possible to occur in commercial gambling settings during a particular episode of play, mean that the above findings may not generalize to slot-machines with more stringent RTPs. Second, 3 of the 4 studies described above used participants' persistence in the extinction phase when no winning outcomes occur as the only index of the effect of near-miss outcomes in potentiating gambling. The advantage of this is that the researcher can get a 'pure' measure of the near-miss effect that is not confounded by the rate of winning during play. However, one might argue that players' persistence measured in the extinction phase is not representative of their persistence during normal play which involves delivery of winning outcomes. Third, none of the above studies investigated whether the effect of near-miss outcomes interacts with the reinforcement environment i.e. the frequency of winning outcomes. It is possible, even likely, that the value of near-misses depends upon the co-occurrence of winning outcomes, and that the near-miss outcomes might have different effects on gambling when a large number of winning outcomes were also delivered, compared to when no winning outcomes occurred. The latter experiments of my thesis address these possibilities directly.

Different theories have been proposed to explain the near-miss effect. According to one theory, the occurrence of a near-miss may be taken as a

positive predictive signal, confirming the player's strategy and raising hopes for future success (Reid, 1986). This theory is related to the cognitive bias of illusions of control (Langer, 1975), such that players may erroneously consider chance situations in gambling as skill-based, and perceive near-miss outcomes as signalling improvement in skills or strategies (e.g. Griffiths, 1994). Although some argue that illusions of control play a lesser role in games such as slot-machines which are not traditionally considered as skill-based (O'Connor and Dickerson, 2003), others suggest that regular slot-machine players tend to consider the game as skill-oriented (e.g. Griffiths, 1994; Dickerson, 1993). Thus, this theory of the near-miss effect proposes that near-miss outcomes encourage further play through acting as instrumental conditioned reinforcers, leading the player to believe future wins are imminent (Reid, 1986). One recent study showed that people who hold a strong skill-oriented view about gambling report greater subjective desire to play following near-miss slot-machine outcomes, supporting the idea that near-miss outcomes foster illusions of control (Billieux et al., 2011).

Alternatively, near-miss outcomes produce frustration and cognitive regret, and taking the opportunity to play again may be one way of eliminating regret (Loftus and Loftus, 1983). Evidence consistent with this proposal was found by Clark et al. (2009), who observed on a slot-machine-like game that the near-miss outcomes were generally experienced by the players as aversive, but simultaneously increased ratings of "continue to play". In addition, near-miss outcomes were rated more unpleasant and motivating if they occurred on plays over which the players had more personal control. It's possible that when

players assumed self-responsibility for the almost-winning outcomes, they experienced greater levels of cognitive regret, thus perceiving the near-miss outcomes as both more unpleasant and more motivating. One limitation of Clark et al. (2009) is that their game does not take money away from participants upon losing outcomes, which is rarely the case in real-life gambling scenarios.

Near-miss outcomes may also act at a lower cognitive and/or physiological level by producing some of the excitement of a win (Griffiths, 1991). More behaviourally, near-miss outcomes may have the same kind of conditioning effect on behaviour as a success, either through stimulus generalization, whereby stimuli that share commonalities in appearance are processed similarly (Pearce, 1987), or through secondary conditioning whereby near-miss outcomes become conditioned first to actual winning outcomes and then to gambling behaviours (Reid, 1986). For example, one study on recreational gamblers found that all participants rated near-miss outcomes as closer to wins than loss outcomes (Dixon and Schreiber, 2004). Similar results were found by Dixon et al. (2009), who further showed that the association between winning and near-miss outcomes could be altered by verbal association training. However, it might be argued that participants' ratings of the similarity of winning and near-miss outcomes presented as static graph images do not equate with their processing of these types of outcomes during game play.

It should be noted that the above theories of the near-miss effect may not be mutually exclusive. Near-miss outcomes may exert influences on gambling

behaviours in more than one ways. For example, it is perfectly possible that near-miss outcomes are positively reinforcing after being conditioned to winning outcomes through Pavlovian processes, *as well as* acting as positive instrumental-conditioned reinforcers that signal imminent success (e.g. the illusions of control theory).

Dixon et al. (2010) also studied a particular kind of loss on multi-line slot-machines, namely “loss disguised as wins” (LDW), which happens when the player gains some money from winning on one or several lines but loses money overall due to losses that occurred on other lines. LDWs can be considered as one type of near-miss, since it represents a situation in which the player is closer to his goal of winning money overall than if he did not win on any line. Examination of players’ physiological responses revealed that while heart rate deceleration was greater after winning outcomes compared to both LDWs and other losing outcomes, their skin conductance levels were higher for both wins and LDWs compared to other losses. Similarly, Clark et al. (2011) studied participants’ physiological measures during slot-machine play and found that their electrodermal activities were higher for both winning and near-miss outcomes compared to other losing outcomes when participants had control over selecting the winning symbol. These findings collectively suggest that near-miss outcomes produce some of the physiological responses associated with winning outcomes. However, the meanings of these physiological responses in relation to broader cognitions or behaviours during gambling are unclear.

Finally, although it was suggested that near-miss outcomes encourage gambling, one experiment showed that it is the ‘almost-losing’, instead of ‘almost-winning’, that brings the feeling of luckiness to people and motivate further play (Wohl and Enzle, 2003). On a wheel-of-fortune game, participants in the near-big-loss condition, who almost went bankrupted, perceived themselves as personally luckier and placed larger bets on a subsequent roulette game than participants in the near-big-win condition who almost won a big prize. However, these findings need replication as several subsequent studies failed to obtain the same results (e.g. Daugherty and MacLin, 2007).

Illusions of control in gambling

Illusions of control are defined as “an expectancy of a personal success probability inappropriately higher than the objective probability would warrant” (Langer, 1975). Factors which may lead to greater illusions of control include personal choice, stimulus or response familiarity, passive or active involvement and competition (Langer, 1975; Ladouceur and Sevigny, 2005). Langer and Roth (1975) also showed a primary effect on people’s perceived illusions of control, such that players who received more winning outcomes at early stages of the game rated themselves as more skilled and predicted more future wins than those who received more wins towards the end of the game.

Subsequent research confirmed the presence of illusions of control in a wide variety of gambling activities. For example, Strickland et al. (1966) showed that

on a dice-tossing game, people bet less money and were less confident if the dice was thrown by someone else (rather than by themselves), although the chances of success were the same. Another study reported that crap players would throw the dice softly for low numbers and hard for high numbers (Henslin, 1967). In addition, Oldman (1974) reported that roulette players see the games as skilful and offer explanations for losses, and Gilovich and Douglas (1986) described cognitive processes in sports betting whereby losses are attributed to random events while wins are attributed to skills. Similarly, Gaboury and Ladouceur (1988) found that people attribute success to personal factors such as skills and losses to external factors such as back luck. All these studies show that people tend to adopt skill-oriented view about gambling and interpret past gambling outcomes in ways that are consistent with their own possession of good skills. On the other hand, it is also possible that some gambling activities such as sports-betting involve elements of real control, which need to be distinguished from the non-existent illusory controls.

Recently, Martinez et al. (2011) manipulated the levels of illusions of control by providing participants with different amounts of information about the other players' performance. On a French roulette game, participants who were notified about the amount won by the previous player were more risk-taking and reported greater illusions of control. Illusions of control also mediated the effect of notification on players' later risk-taking behaviours.

Based on the extensive evidence supporting the presence of illusions of control in gambling, Blaszczynski (2000) proposed that cognitive schemes such as illusions of control constitute one common factor in the development of problem gambling. More recently, Parke et al. (2007) suggested that gamblers may cope with stress and losses by adopting an overoptimistic view which overestimates self-control.

Furthermore, a number of studies have found that people with more serious gambling problems tend to show greater illusions of control than those with fewer problems. In an earlier study, Griffiths (1990) found that adolescent gambling addicts tend to think people with more play skills would be able to stay on the fruit machine for longer with less money. A subsequent study found that, although they did not differ on the amount of time they managed to stay on the slot machine, regular gamblers tended to consider the slot game as more skill-oriented and themselves as possessing more skills than irregular gamblers did (Griffiths, 1994). Similarly, dependent gamblers believe that gambling involves more skills and attribute wins to their own abilities (Carol and Huxley, 1994). They also overestimate winnings on familiar machines.

There is also clinical evidence that high levels of illusions of control are frequently associated with gambling problems (Myrseth et al., 2010). Among a participant sample mainly comprised of problem gamblers, active illusory control was the most frequently reported cognitive distortion (Toneatto et al., 1997). A skill orientation was also more frequently adopted by those with a lifetime

history of problem gambling. Similarly, Strickland et al. (2006) found that frequent gamblers made more statements suggesting illusions of control than infrequent gamblers, who tended to consider luck and chance as more important than skills. Collectively, the above findings suggest that cognitive illusions of control play an important role in the development and maintenance of problem gambling behaviours.

Impulsivity and problem gambling

In a multi-pathway model of pathological gambling proposed by Blaszczynski (2000), there exists one group of gamblers who are biological impulsive, who are also the most likely to have a wider range of behavioural problems. These gamblers manifest a marked propensity to seek out rewards, are unable to delay gratification, and show a diminished response to punishments. Similarly, Steel and Blaszczynski (2002) proposed that the impulsivity-psychopathy construct mediates the effect of emotional and biological vulnerability on gambling.

Indeed, substantial evidence indicates that problem and pathological gamblers exhibit greater levels of impulsivity than non-gamblers. Impulsivity level as measured by the Eysenck's Impulsiveness Scale (EIS) (Eysenck et al., 1985) is one explanatory factor of pathological gambling, which predicted earlier age of commencing gambling behaviours, higher likelihood of divorce as a result of gambling, and higher likelihood to engage in gambling-related illegal activities

(Steel and Blaszczynski, 1996). Similarly, Moore and Ohtsuka (1997) and Clarke (2004) found that problem gambling was predicted by high impulsiveness measured by EIS. Moreover, pathologically gamblers who scored high on the EIS were more likely to drop out from treatment (Leblond et al., 2003), and impulsivity as measured by neuro-cognitive disinhibition tasks predicted relapse in pathological gamblers after treatment (Goudriaan et al., 2008).

Furthermore, Nower et al. (2004) found that young (17-21 years old) pathological gamblers differed from both non-gamblers and social gamblers on EIS scores. Testing a sample of university students, Clarke (2006) found that impulsivity measured by EIS had a full mediating effect on the prediction of gambling problems by depression. Finally, Ledgerwood et al. (2009) found greater non-planning and attention deficits, measured with the Barratt Impulsiveness Scale (BIS) (Barratt, 1985), among gamblers with or without comorbid substance-use disorders.

Thus, the findings strongly suggest that problem gamblers in general exhibit higher levels of self-reported impulsivity than non-gamblers, and the levels of impulsivity may be even higher for those with very severe gambling problems. However, at least one previous study failed to find the link between high impulsivity and pathological gambling (Allcock and Grace, 1988). Also, none of the above studies showed that impulsivity is a vulnerability factor for problem

gambling, as they were carried out among people with established gambling histories.

In one of the few studies aiming to establish a causal link between impulsivity and problem gambling, Vitaro et al. (1999) measured impulsivity in young adolescents (13-14 years old) and assessed their gambling problems later when they were 17 years old. Impulsivity was assessed in various ways including teacher rating, self report (Eysenck's Impulsiveness Scale), and objective measures (delay of gratification and card-playing task). It was found that high scores on the Eysenck's impulsiveness scale and worse performance on the card-play task predicted later onset of gambling problems. Thus, we have some evidence that high impulsivity predisposes later development of gambling problems at least among some individuals.

Although, as described above, there exists extensive literature on the association between high impulsivity and problem gambling, to my knowledge there has been no study looking at the interaction between impulsivity and the structural characteristics of EGMs such as near-miss outcomes. The investigation on the processing of near-miss outcomes among people with different levels of impulsivity might improve our understanding on both the mechanisms of the near-miss effect and why high-impulsive individuals are more vulnerable to become heavily involved in gambling.

Part 2—The brain reinforcement systems and EGM play

Overview

In part of this thesis, I'll be discussing experiments looking at the role of brain reinforcement circuitries in learning about EGMs such as slot-machine games, and the processing of the game's structural features such as near-miss outcomes, using functional magnetic resonance image (fMRI) techniques. The influence of impulsivity and illusions of control on the neural responses during game play was also examined. Extensive research indicates that the dopaminergic neural pathways are involved in signalling rewards, and the mediation of reinforcement, pleasure, and drive (Wise, 2002). Drugs of abuse are rewarding when directly injected into the nucleus accumbens, which is a key component of the mesolimbic dopamine pathway and receives direct inputs from the ventral tegmental area and other midbrain areas which contain dopamine nerve cell bodies (Hoebel et al., 1983; Carlezon et al., 1995). These findings lend further support to the idea that the dopaminergic pathways function to process and signal reinforcements, particularly the positive ones (Schultz et al., 2000). Other evidence suggests that activities within the dopaminergic circuitries code the reinforcement properties of external stimuli including those associated with gambling behaviours (Winstanley et al., 2011).

There are three inter-connected dopaminergic pathways that are involved in signalling, learning about and acting upon reinforcements (Alexander et al.,

1986; Ongur and Prize, 2000). The mesolimbic pathway delivers dopaminergic transmissions from the midbrain ventral tegmental areas (VTA) to the nucleus accumbens (NAcc), which is located in the ventral part of the striatum. NAcc has reciprocal connections with amygdala and hippocampus (Alexander et al., 1986). The mesocortical pathway transmits dopamine from the VTA to the frontal cortices, including the dorsolateral prefrontal cortex (DLPFC), the anterior cingulate cortex (ACC), the ventromedial prefrontal cortex (VMPFC) and the orbitofrontal cortex (OFC). These latter structures are also implicated in coding reward value (e.g. Glascher et al., 2009). The nigrostriatal pathway delivers dopaminergic transmission from the midbrain substantia nigra (SN) to more dorsal parts of the striatum such as the caudate nucleus and the putamen. The caudate nucleus was found to code reward-prediction errors in goal-directed behaviours (Haruno and Kawato, 2006), whereas the putamen was considered to mediate stimulus-response associations that form the basis for habit learning (Balleine et al., 2007).

In this part of the introduction, I'll start by discussing research on the functions of different parts of the dopamine (DA) system in reinforcement signalling, learning and actions, followed by evidence that near-miss outcomes of slot-machine games activate parts of the reinforcement pathways. I'll then talk about the association between abnormal functioning of the dopaminergic reinforcement systems and problem gambling, as well as evidence suggesting that impulsivity has a dopaminergic basis.

The midbrain dopamine system

According to Schultz (1997a), dopamine neurons in the VTA and substantia nigra of monkeys are phasically activated by the delivery of both primary and secondary rewards. However, aversive and neutral stimuli are generally ineffective at stimulating dopamine neurons. In addition, dopamine neurons respond only to unpredicted stimuli. In the case of fully predicted rewards, the neuronal response is transferred to the earliest reward-predicting stimuli. Moreover, once a reward is reliably predicted, dopamine neurons show depressed activities if the reward fails to occur (Hollerman and Schultz, 1998). Therefore, the midbrain dopaminergic responses constitute good 'teaching signals', or 'prediction-error' (PE) signals (O'Doherty et al., 2003), for its efferent targets such as the striatum, the amygdala and cortical areas, which may code more specific aspects of rewards.

The findings of the above electrophysiological studies have been confirmed by fMRI studies with humans. O'Doherty et al. (2006) employed a classical-conditioning task and found that the ventral striatum show activities related to the prediction error and subjective preference of the reward-predicting cue. Similar results were found in D'Ardenne et al. (2008). In another 2 fMRI studies using more complex slot-machine tasks, partially-predicted monetary rewards lead to increased Blood Oxygen Level Dependent (BOLD) signals in the midbrain compared to non-rewarding outcomes (Clark et al. 2009; Chase and Clark, 2010).

The level or extent of a reward is generally calculated as a product of its magnitude and probability of occurrence, which gives the reward value. It has been suggested that dopamine neurons encode prediction errors by representing at each moment in time the difference between the actual experienced reward value and the expected reward value before the current sensory input (Tobler et al., 2005). There is extensive evidence that midbrain dopamine neurons are sensitive to the magnitude, the probability (and uncertainty), and the value of predicted and actual rewards. In an electrophysiological study on monkeys, reward-conditioned stimuli elicit phasic dopamine neuronal activities, the magnitude of which is greater with higher probability of predicted rewards (Fiorillo et al., 2003). On the contrary, the delivery of rewards leads to greater dopamine neuronal activities following conditioned stimuli with lower-probability reward predictions (i.e. greater prediction errors). The coding of reward probability at the time of both the cue and the outcome by an area corresponding to the midbrain was also found by Dreher et al. (2006) using fMRI on humans. Moreover, midbrain activity was found to correlate linearly with both the magnitude and the value of expected reward (Knutson et al., 2005).

Finally, a small population of dopamine neurons may be activated by physically or motivationally salient or aversive stimuli (Schultz, 2010). Using cell-recording technique on monkeys, Bromberg-Martin et al. (2010) found a phasic DA signal at the start of a saccade task which was equally present for both rewarding and punishing trials and appeared to code motivational salience.

The ventral striatum/nucleus accumbens

The ventral striatum (VS), including both areas of nucleus accumbens (NAcc) and ventral putamen, is reciprocally connected with many brain regions such as the ventral tegmental areas (VTA), the amygdala, the hippocampus, the insular cortex, the dorsolateral prefrontal cortex, the anterior cingulate cortex and the orbitofrontal cortex (Alexander et al., 1986; Everitt et al., 1989; Lehericy et al., 2004). It is the 'limbic' part of the striatum and is extensively involved in processing and learning about rewards, and initiating actions to obtain rewards (Lehericy et al., 2004). The ventral striatum plays the role of the 'critic' in the critic-actor model of learning (Sutton and Barto, 1998), which signals the reward-prediction error (Montague et al., 2004; O'Doherty et al., 2004a). Similar to the midbrain dopamine neurons, the ventral striatum codes the value of rewards (Knutson et al., 2005) and reward prediction errors (D'Ardenne et al., 2008; O'Doherty et al., 2004a), and it's activity tends to transfer from the actual reward to the predictive cue after learning has taken place (O'Doherty et al., 2003; O'Doherty et al., 2004b; Seymour et al., 2004; Galvan et al., 2005). However, the dopaminergic neurons in the VS are also involved in coding subjective value of rewards (Kable and Glimcher, 2007), both linear and non-linear processing of probabilities (Tobler et al., 2008; Hsu et al., 2009), signalling punishments/reward omissions (Jensen et al., 2003; Seymour et al., 2004; Pagnoni et al., 2002), and signalling neutral stimuli that are physically salient (Zink et al., 2003).

Imaging studies on humans have obtained evidence suggesting that ventral striatum is involved in reward processing. In one such study, dopamine release was directly observed in the ventral striatum during video-game play using Positron Emission Tomography (PET) (Koepp et al., 1998). In another study using a random card-value guessing task, Delgado et al. (2000) observed ventral striatum activations that were more sustained for winning than for losing trials. Similarly, Elliott et al. (2000) showed ventral striatum activation which correlated positively with absolute reward levels, and Breiter et al. (2001) found higher ventral striatum activities associated with higher winning outcomes in a gambling task. Moreover, two imaging studies by Knutson et al. suggested that the NAcc is specifically activated by anticipation of rewards and is sensitive to reward magnitude (Knutson et al., 2001a), and that NAcc specifically encodes the magnitude and value of expected reward (Knutson et al., 2005). Furthermore, Schultz et al. (2008) pointed out that while some parts of the striatum encode the magnitude and probability of rewards in separation, a region in medial striatum appears to encode the value of rewards irrespective of the underlying combination of magnitude and probability.

There is also evidence suggesting that ventral striatum plays a role in forming behaviours guided by conditioned reinforcers (Fudge et al., 2002), which is partially mediated by its connections with the amygdala. Using drugs of abuse as the reward, Di Ciano and Everitt (2004) found that disruption of the integrity of the NAcc-amygdala system on both sides of the brain reduces cocaine-seeking behaviours of rats under a second-order reinforcement schedule.

Other evidence suggests that, similar to midbrain dopaminergic neurons, ventral striatum activities have been found to shift in time from the delivery of rewards to cues that predict rewards as learning takes place. Employing appetitive conditioning in humans, O'Doherty et al. (2003) examined the timecourse of neural activities in ventral putamen and found a transfer in peak of the hemodynamic response from the time of reward delivery to the time of the conditioned stimuli. Knutson et al. (2001b) found that the ventral striatum is specifically activated to the anticipation of reward during a delayed-incentive task, which involves the presentation of well-learned cues signalling potential monetary gain, loss or neutral outcomes. In addition, employing a cued delayed-response task, Galvan et al. (2005) found that as learning took place, there was an activity shift from the reward anticipatory phase to the earlier reward-predicting cue in the ventral striatum. This temporal shifting of reinforcement signals in the ventral striatum was also observed for negatively reinforcing stimuli following associative learning (Seymour et al. 2004).

Finally, some studies found ventral striatum activations that correlate with prediction errors for aversive stimuli, or omission of rewards (e.g. Jensen et al., 2003). For example, Seymour et al. (2004) found bilateral ventral putamen activities that correlate with prediction errors for pain stimuli during performance of a cued aversive learning task. In another study using an operant conditioning task, the NAcc showed activations to omission of predicted rewards (Pagnoni et al., 2002). Thus, ventral striatum activations had been observed in response to

both positive and negative stimuli (Jensen et al., 2007), which led those authors to conclude that this region encodes the incentive salience of stimuli rather than their absolute valence.

The dorsal (dorsomedial) striatum (caudate nucleus)

While the ventral striatum is implicated in both reward signalling and instrumental actions, the caudate nucleus may be primarily involved in reinforcement-directed action selection (Haruno and Kawato, 2006; Balleine et al., 2007). The caudate nucleus is part of the fronto-limbic-striatal network involving the globus pallidus, the substantia nigra and the subthalamic nucleus (Royce and Laine, 1984), which constitutes the motor system responsible for action selection and monitoring (Frank and O'Reilly, 2006).

In the critic-actor model of goal-directed behaviours (Montague et al., 2004), the role of "actor" may be performed by dorsal striatal areas, which utilize the prediction-error signals to learn stimulus-action associations so that actions associated with greater rewards are selected more often. One study carried out by O'Doherty et al. (2004a) found that caudate activity correlates with the prediction error signals in an instrumental task but not in a Pavlovian task, consistent with its role as the "actor".

Many other studies confirmed that the caudate is particularly involved in instrumental action selection and outcome monitoring. An early lesion study on

rats revealed that the dorsal striatum is needed for initiating reinforced approach responses to stimuli more often associated with rewards (Salinas and White, 1998). In addition, Ito et al. (2002) showed that the dorsal striatum is important for the initiation of cocaine-seeking behaviours under second-order reinforcement schedules. More recently, a study by Tricomi et al. (2004) on humans found that the caudate nucleus is selectively activated only when a perceived contingency exists between a self-initiated response and a reinforcing (positively or negatively) outcome. Finally, an fMRI study using a monetary cued card-guessing task on humans found that the caudate showed greater activations to the trial outcomes during early phases of the task, when the participant engaged in learning about the cues (Delgado et al., 2005). The outcome activation decreased for well-learned cues as learning progressed, suggesting an evolving adaptation of feedback expectancy as an action-outcome contingency became more predictable.

The amygdala

The amygdala is reciprocally connected with many areas implicated in reinforcement learning and execution of goal-directed actions, such as the ventral striatum (Russchen et al., 1985; Everitt et al., 1991), the caudate and putamen (Price et al., 2003), the anterior cingulate cortex (McCoy et al., 2003), the medial prefrontal cortex and the orbitofrontal cortex (Ongur and Price, 2000). It is also densely innervated by mesolimbic dopaminergic projections (Everitt et al., 1991).

Similar to the ventral striatum, there is evidence that once the associative learning has taken place, the amygdala tends to respond to the predictive stimulus rather than the reward itself (Knutson et al., 2001b; O'Doherty et al., 2002). In addition, the amygdala may be involved in both associative learning involving rewards, and the processing of aversive stimuli (Ambroggi et al., 2008). Early investigations by Spiegler and Mishkin (1981) found that amygdala lesions lead to impairments in forming short-term stimulus-reward associations, and Gaffan and Harrison (1987) suggested that the amygdala is necessary in maintaining the incentive values of secondary reinforcers. Later, Schultz (1997a) suggested that the amygdala may be involved in the detection of reward-predicting stimuli. However, the amygdala has also been shown to exhibit activations to aversive stimuli such as pain (Bornhovd et al., 2002). Moreover, one study by Yacubian et al. (2006) employing a monetary guessing task showed that the amygdala activity was related to the predicting and signalling of the value of monetary losses. Amygdala activity was also found to correlate with prediction errors for monetary loss while participants performed a probabilistically-cued instrumental task (Haruno and Kawato, 2006) and with negative expectancies of outcomes in a monetary incentive task (Breiter et al. 2001).

There is also extensive evidence that the amygdala is critically involved in instrumental learning and performance, particularly those guided by secondary reinforcers (Everitt et al., 1989). As such, this region may play an important role in sustaining reward-seeking behaviours triggered by conditioned stimuli. In rats, bilateral amygdala lesions completely abolished pre-established place

preference (Everitt et al., 1991), and lesions of the basolateral amygdala impaired the acquisition of drug-seeking behaviours under second-order reinforcement schedules (Di Ciano and Everitt, 2004; Everitt and Robbins, 2005). Di Ciano et al. (2003) also found that subjective report of craving following exposure to drug-paired stimuli was accompanied by basolateral amygdala activations, indicating that this region is important in mediating the effects of conditioned reinforcers to support instrumental behaviour. In a more recent imaging study, the prior probability that the current choice is correct, which informs about the expected reward value of the choice action, correlated with activity in amygdala (Hampton et al., 2006). Similarly, Hampton et al. (2007) suggested that signals related to behavioural choices in the orbitofrontal cortex and the anterior cingulate cortex rely directly on inputs from the amygdala, and that the primary function of the amygdala-ventromedial prefrontal cortex circuitries is to compute expected reward values which are then used to generate decisions about the available behavioural options.

The anterior cingulate cortex (ACC)

The anterior cingulate cortex (ACC) can be divided into a dorsal part, which projects to dorsolateral prefrontal cortex and motor systems and plays a ‘cognitive’ role, and a rostral-ventral part, which projects to OFC, striatum and brain stem and plays an ‘emotional’ role (Rogers et al., 2004). The human ACC sulcus has connections with both amygdala and striatum (Croxson et al., 2005), as well as with the anterior insular cortex (Paulus and Stein, 2006). Previous research has ascribed different functions to the ACC, including, but not limited

to, the computation of action-value relationships (Rushworth et al., 2007), the execution of reinforcement-guided actions (Balleine et al., 2007) and the processing of rewards (Knutson et al., 2005; Hsu et al., 2009).

Holroyd and Coles (2002) proposed that ACC uses the reward prediction error signals from the midbrain dopaminergic neurons to reinforce adaptive behaviours. Evidence consistent with this was reported by Rogers et al. (2004), who demonstrated, using a probabilistic decision-making task which required participants to choose between a fixed control gamble and an experimental gamble which varied in win probability, win size and loss size, that one region of the ACC was activated during the decision phase when large experimental-gamble win sizes were contrasted with small experimental-gambling win sizes. This signal was presumed to influence participants' task decisions. Also, ACC lesions were found to disrupt reward-guided action selection (Hadland et al., 2003). Furthermore, ACC lesions caused monkeys' difficulties in sustaining previous rewarded actions on a reverse learning task (Kennerley et al., 2006). These monkeys were also impaired at using information from previous outcome histories to guide their behaviours except that from the immediately previous trial.

There is also evidence that the ACC shows activities consistent with linear processing of reward probabilities (Hsu et al., 2009). ACC contains neurons which respond to the anticipation (Knutson et al., 2005) and delivery of reinforcement (Walton et al., 2004), and electrophysiological studies on

monkeys showed that both receipts and withholding of rewards can activate the ACC (Amiez et al., 2006). Finally, one study by Behrens et al. (2007) showed signals in part of the ACC which encode the volatility, or the stability of the stimulus-response-reward associations, of the environment, suggesting that the ACC is the region where higher-order processing of reward-related information is carried out.

The insular cortex

The insular cortex has reciprocal connections with both amygdala and NAcc (Reynolds and Zahm, 2005), as well as the ACC and orbitofrontal cortex (OFC) (Ongue and Price, 2000). This brain region is centrally placed to receive information about the reinforcement value of stimuli and integrate this information with the effects these stimuli may have on the body states of organisms (Craig, 2002; Paulus and Stein, 2006). The insular cortex is also important in linking emotions to cognitive processes. There is evidence that the insular cortex is activated by positive stimuli such as monetary gains (Izuma et al., 2008). Also, this brain region may play an important role in substance addiction (Wang et al., 1999).

There is extensive evidence that the insular cortex is responsive to rewarding stimuli. Anterior insular cortex was activated by the anticipation of obtaining rewards on a monetary delayed-incentive task (Bjork et al., 2008; Knutson et al., 2001a, 2005), and by both winning and near-miss slot-machine outcomes

compared to other losing outcomes (Clark et al., 2009). In addition, the insular cortex was activated by both high reward levels during winning streak and high penalty levels during losing streak on a two-card guessing game (Elliott et al., 2000), possibly because both these situations contain arousing or emotionally salient events. Furthermore, in one study employing a probabilistic reversal decision-making task, insular activity correlated with the prior probability that the current choice is incorrect, and increased when participants chose to switch to the other stimulus rather than to stay on the same stimulus, findings consistent with the function of this region in linking emotions with cognitions and motor actions (Hampton et al., 2006).

The insular cortex has also been implicated in substance addictions, including nicotine addiction (Naqvi et al., 2007), amphetamine seeking (Contreras et al., 2007), and the craving states triggered by cocaine-related stimuli (Wang et al., 1999). It was suggested that the role of the insular cortex in addiction may be to signal the interoceptive aspects of compulsive urges (Clark et al., 2009).

The dopaminergic processing of near-miss outcomes

Recently there has been evidence that near-miss and winning slot-machine outcomes activate overlapping dopaminergic reinforcement circuitries, which lends further support to the idea that near-miss outcomes act as ‘mini-wins’ or positive predictive stimuli for imminent success (Reid, 1986). In one study, Clark et al. (2009) found that both winning and near-miss outcomes of a slot-machine-

like game activated bilateral ventral striatum and right insular cortex in a sample of recreational gamblers. In a follow-up study, Chase and Clark (2010) revealed that among a group of regular gamblers, both winning and near-miss slot-machine outcomes caused right ventral striatum activations compared to other losses. In addition, participants' scores on the South Oaks Gambling Scale (SOGS) correlated with the near-miss minus loss activation in the midbrain, suggesting that those who perceived near-miss outcomes as more rewarding compared to other losses also reported more serious gambling problems. Moreover, studying pathological and non-pathological gamblers, Habib and Dixon (2010) found overlapping activations between winning and near-miss outcomes of a slot-machine game among the pathological gambler group in brain areas including the bilateral dorsal striatum, the left midbrain and the visual cortex compared to the non-pathological gambler group. Finally, a recent study showed that rats displayed more food-collecting responses to 'near-miss' events involving the illumination of 2 out of 3 lights compared to when only one light was 'on', which responses were further potentiated by a dopamine D2 agonist quinpirole, suggesting that near-miss outcomes are processed by the dopaminergic reinforcement circuitries (Winstanley et al., 2011).

Thus, it appears that certain parts of the dopaminergic reinforcement pathways are activated by both winning and near-miss gambling outcomes, notably the striatum, particularly among people with more severe gambling problems. However, evidence on the processing of near-miss outcomes by the dopaminergic circuitries among people with no or very little gambling experience is still relatively lacking.

The dopaminergic pathways and pathological gambling

Direct evidence on the link between dopamine activity and gambling problems is provided by the finding that pathological gambling developed in a minority of Parkinson's Disease (PD) patients receiving dopamine treatments (e.g. Dodd et al., 2005). For example, Geschwandtner et al. (2001) reported 2 patients who developed pathological gambling after engaging in self-medication with dopaminergic drugs. The pathological gambling symptoms reduced after decrease of dopamine therapy. Similarly, both Avanzi et al. (2004) and Bandini et al. (2007) described patients receiving dopaminergic therapy for Parkinson's disease who later became pathological gamblers. Again, their PG symptoms were alleviated following reduction of the therapy. Factors that influence the development of PG in PD patients receiving DA treatment include younger age at PG onset, higher novelty-seeking traits, and a personal or family history of alcohol use disorders (Voon et al., 2007). More recent research suggests that PD patients receiving DA treatment who developed compulsive behaviours such as pathological gambling showed faster learning rates in a probabilistic reinforcement task, which might be part of the basis for their PG symptoms (Voon et al., 2010).

There is also evidence that the levels of dopaminergic transmissions are different among pathological gamblers and controls. For example, Bergh et al. (1997) found decreased dopamine concentration but increased DA metabolites concentration in the cerebrospinal fluid of pathological gamblers compared to controls. The increased DA metabolites to DA ratio may suggest increased

release of dopamine in pathological gamblers. In another study, administration of d-amphetamine increased desire to gamble only in the problem gambler group, who also reported lower confidence to resist gambling after the drug (Zack and Poulos, 2004). Severity of problem gambling also correlated positively with drug-induced positive-affect and desire to gamble. A later study by the same researchers found that the dopamine D2 antagonist haloperidol increased subjective rewarding effect of gambling, post-game desire to gamble and improved reading speed of gambling words only in the gambler, but not control, group (Zack and Poulos, 2007). Thus, pharmacological challenges with DA agonist or antagonist appear to have different influences among problem gamblers and non-problem gamblers, implicating underlying differences in dopaminergic function.

If the dopaminergic system functions differently in problem gamblers and in controls, then brain areas receiving dense dopaminergic inputs may also show different levels of activities in gamblers and non-gamblers. Using a monetary card-guessing task, Reuter et al. (2005) found that pathological gamblers show less activation in the ventral striatum and in ventromedial and ventrolateral prefrontal areas to winning outcomes compared to controls, and that a negative linear correlation exists between severity of the gambling problems and activities in the ventral striatum and ventromedial prefrontal cortex. Reduced activation in the ventral striatal and ventral prefrontal areas may explain the impulsive choices exhibited by problem gamblers on risk decision-making tasks (Lawrence et al., 2009). Consistent findings were also reported by De Ruiter et al. (2009), who found that problem gamblers exhibit reduced activation of right

ventrolateral prefrontal cortex in response to both monetary gains and losses in a probabilistic reversal task. Moreover, Habib and Dixon (2010) found that during viewing and rating slot-machine outcomes, pathological gamblers show reduced left midbrain responses compared to controls. Also, among gamblers a range of areas including the right middle frontal gyrus and the ventral medial frontal gyrus show activities which correlate negatively with scores on the South Oaks Gambling Scale (SOGS).

Collectively, the above findings suggest that certain parts of the mesocortical and mesolimbic dopamine pathways, particularly the ventromedial and ventrolateral prefrontal areas, the striatum and the midbrain, are hypoactive in pathological gamblers, which may cause their deficits in decision-making in risky situations.

The dopaminergic basis of impulsivity

As discussed before, problem gamblers tend to make impulsive choices on decision-making tasks involving risk (Lawrence et al., 2009), which might be a consequence of their dysfunctional dopaminergic system (Reuter et al., 2005; Habib and Dixon, 2010). Impulsivity is a multidimensional construct involving risky behaviour and spur-of-the-moment, poorly judged decisions and actions (Besson et al., 2010). There is accumulating evidence that the levels of dopaminergic transmissions in the brain and the neural signals of dopaminergic

circuitries may be associated with the levels of impulsivity observed in animals and humans.

Cardinal et al. (2001) found that rats with lesions to the core of NAcc show a greater tendency of choosing smaller, immediate over larger, delayed rewards (i.e. greater temporal discounting). One other study found that rats show greater temporal discounting after amygdala lesions (Winstanley et al., 2004). Both the nucleus accumbens and the amygdala are parts of the mesolimbic dopamine pathway and these two areas are extensively inter-connected (Alexander et al., 1986). The projections from the amygdala to the ventral striatum may be important in mediating the effects of limbic processes on reinforcement –based behaviours (Everitt et al., 1989, 1991). The findings that damage to either the amygdala or NAcc leads to greater impulsivity in choice over reinforcements support the association between mesolimbic dopamine transmissions and impulsivity.

More recently, Dalley et al. (2007) measured the numbers of DA receptors in rats' brains and found that spontaneously high impulsive rats exhibit a decrease in the DA D2/D3 receptor availability in ventral striatum compared to low-impulsive rats. Moreover, the decreased DA receptor in VS is a predisposing neurobiological trait rather than effects due to later-life experiences. Another study by Besson et al. (2010) found that a D2 antagonist had different effects on the level of impulsivity in rats depending on which part of the ventral striatum it was infused to. Impulsivity increased after infusion to the NAcc shell but

decreased after infusion to the core, suggesting that different sub-regions of the nucleus accumbens play different roles in regulating impulsivity. Similar findings were also reported by Diergaarde et al. (2008), who observed increased and decreased electrically-evoked dopamine release in the NAcc shell and core respectively in high-impulsive compared to low-impulsive rats.

In humans, Bjork et al. (2008) found that on a monetary delayed-incentive task, participants' impulsivity scores correlate positively with their NAcc responses to small rewards. On the other hand, Riba et al. (2008) endorsed the view that people who have hypoactive reward systems, either as a predisposing trait or induced by pharmacological challenges, tend to make riskier and more impulsive choices. A more recent PET study suggested that high-impulsive individuals are characterised by diminished midbrain autoreceptor availability, leading to enhanced DA cell firing and potentiated DA release in the striatum following exposure to novel, salient or rewarding stimuli (Buckholtz et al., 2010). Participants' scores on the Barratt Impulsiveness Scale inversely correlated with the D2/D3 autoreceptor availability in the midbrain and positively correlated with d-amphetamine induced dopamine release in the striatum.

Collectively, the above research has provided considerable evidence that impulsivity has an underlying basis of the brain dopaminergic system. Studies using rats and behavioural measures of impulsivity tend to find that high impulsiveness is associated with altered dopaminergic activity within dissociable sub-regions of the striatum, whereas studies carried out on humans using

subjective measures of impulsivity tend to provide direct and indirect evidence that high impulsiveness is caused by over-active dopaminergic functions in striatal areas.

An overview of experiments in this thesis

My thesis is intending to address 3 key questions about EGM play. First, how do the dopaminergic reinforcement systems mediate learning about EGMs? In order to answer this question, we asked participants with limited gambling involvement to play a simple computer-simulated slot-machine game, and measured their neural responses during play using functional magnetic resonance image (fMRI) technique. We recruited people who reported no or limited participation in gambling because we wanted to study the neural mechanisms of slot-machine learning that was not confounded by pre-existing knowledge or experience with EGM play. Specifically, we randomly allocated participants to either an unpracticed group who played the slot-machine for the first time in the scanner, or a practiced group who played the game once before the scan in a separate session. Direct comparison of these 2 groups on neural responses during game play allowed us to test what signal changes in the dopaminergic reinforcement circuitries were implicated as people acquired more game experience.

Second, we wanted to study how personality traits and cognitive biases associated with gambling problems influence the neural processing of EGM outcomes. Previous research suggests that high impulsivity is associated with

heightened BOLD signals in the ventral striatum to monetary rewards (Bjork et al., 2008), and altered reward-anticipatory signals in ventral striatal areas (Hahn et al., 2009; Beck et al., 2009). However, to date no study has specifically investigated the association between impulsivity and dopaminergic signals to EGM play, in particular the neural processing of near-miss outcomes. Similarly, although there is extensive evidence suggesting the link between greater illusions of control and problem gambling (Myrseth et al., 2010), there is no evidence that people who endorse greater levels of illusions of control show different neural signals to EGM events compared to those with lower levels of such bias. Thus, we tried to fill the gap by testing the association between the levels of impulsivity and illusions of control in participants with limited gambling involvement, and their dopaminergic signals to winning and near-miss slot-machine outcomes.

Third, we were interested in testing how different outcomes of EGMs influence people's valuations of the games. Previous studies looked at the effect of near-miss outcomes on gambling behaviours. However, many of these studies assessed the near-miss effect by measuring players' persistence in gambling in extinction phases that deliver no wins (e.g. Kassinove and Schare, 2001; Cote et al., 2003), or simply asked people to choose between machines delivering different frequencies of near-misses (e.g. MacLin et al., 2007). Instead, we asked participants directly how much they valued the slot-machine game in terms of how much they would like to pay for purchasing extra plays. Importantly, we assessed participants' game valuations following each single episode, or round, of play, which delivered one of several combinations of

winning and near-miss frequencies. This design allowed us to test the effect of near-miss frequency on game valuations when co-occurring with different frequencies of wins.

Finally, my experiments also introduced a novel card-guessing game that was designed to provide valid and sensitive behavioural measures of illusions of control. We ensured that the game involves no element of real skill or control, and that the 2 game conditions differ very little except the level of perceived control that is allowed. We chose bet size as the behavioural measure which has been used previously as indicative of illusions of control (e.g. Langer, 1975; Martinez et al., 2011).

Collectively, findings of our experiments provide new information about the neural substrates of EGM learning and the association between impulsivity, illusions of control and gambling, the reward mechanisms that influence the valuation of EGMs, and how near-miss outcomes might reinforce gambling behaviour. As such, they help to generate new hypotheses about the neuropsychology and the cognitive-behavioural models of problem gambling.

Chapter II–Experiment 1

Neural response to slot-machine play: the influences of prior game experience

Introduction

Electronic gaming machines (EGMs) such as slot-machines and those involving poker, lotteries, roulette and other casino games represent one of the most popular forms of gambling activity and constitute one of the most profitable revenue streams for commercial gambling outlets (Turner and Horbay, 2004; Eadington, 2007). Income per unit can be considerable: for example, 23,000 slot-machines in the state of Ontario generated approximately $3,135,660,000 during 2004, amounting to over $130,000 per machine (Williams and Wood, 2004). As such, slot-machines and other EGMs are known to generate a very significant proportion of revenues within casinos (~80%) and other betting outlets (Ghezzi et al., 2000).

Notwithstanding their commercial value, EGMs may also represent a potentially compulsive form of gambling activity with heightened 'addictive potential' (Griffiths, 1995a; Petry, 2003). Increased availability of EGMs has been linked to the severity of gambling problems in the Australasian context (Australia PC, 2009) and has aroused significant public concern in other jurisdictions (Griffiths,

2008b). Tentative evidence suggests higher rates of gambling problems, alongside other psychiatric problems, amongst individuals who play slot-machines regularly (Griffiths, 1995a), as well as shorter intervals to the onset of problem gambling among individuals who choose slot-machines over other forms of gambling (Petry, 2003; Griffiths, 1991).

Still, we know little about the neural systems that underpin the attraction of EGMs. Specifically, there is a lack of knowledge on how prior play experiences with the game engage underlying neural processes associated with reinforcement learning to modulate the value of the game to players. Studying the nature of this engagement might help us understand the transition from exploratory to compulsive slot-machine plays often observed in clinics.

It is likely that the development of regular gambling on EGMs involves both classical Pavlovian and instrumental conditioning (Reid, 1986), while cognitive distortions and false beliefs about the probability of winning and the involvement of personal skills may also promote continued play, and possibly the development of gambling problems (Walker, 1992; Blaszczynski and Nower, 2002). Unsurprisingly, therefore, a number of studies suggest that activity within brain reinforcement circuitries involved in learning and coding the value of stimuli and actions, and their dopaminergic modulations (Pessiglione et al., 2006), are dysfunctional in pathological gamblers (Reuter et al., 2005; Potenza et al., 2003a, b; Zack and Poulos, 2004, 2007).

In my first experiment, we sought to investigate how prior play experience with a simple computer-simulated slot-machine game is expressed through changes in activity within reinforcement circuitries in participants recruited from a non-clinical, non-gambler population. Improved understanding of the effects of experience on the neural responses while playing a slot-machine game would help to answer the question that how problem gambling becomes established through previous gambling experience.

Contemporary models of reinforcement learning provide an appealing framework for investigating the impact of prior experience on EGMs (Schultz, 1997a, b; Hollerman and Schultz, 1998). According to these models, as learning proceeds, activity of dopamine neurons originating from the midbrain ventral tegmental areas (VTA) elicited by reward begins to diminish while activity invoked by cues that signal the future delivery of reward starts to increase (Hollerman and Schultz, 1998), possibly implementing a form of learning consistent with the temporal difference (TD) model (Schultz, 1997b; O'Doherty et al., 2003). Consistent with this, experiments using functional magnetic resonance imaging (fMRI) have shown that learning shifts reward-evoked activity within the striatum from the delivery of rewards (O'Doherty et al., 2003; Delgado et al., 2005) and from instrumental responses (Galvan et al., 2005) towards predictive stimuli that signal the future availability of rewards.

In addition, the ventral striatum receives important inputs from the basolateral nuclei of the amygdala (Fudge et al., 2002; Everitt et al., 1991) that may

function to establish the link between reward-related cues or stimuli and appropriate instrumental, goal-directed actions (Ambroggi et al., 2008; Di Ciano and Everitt, 2004). The dorsal part of the striatum, such as the caudate nucleus, may also play a particularly important role in the selection and monitoring of instrumental actions using reward prediction-error signals (Montague et al., 2004; Tricomi et al., 2004). However, to date the role of these reinforcement regions in the acquisition of slot-machine play has not been established.

Therefore, the main goal of Study 1 was to test the hypothesis that prior experience with a slot-machine game was associated with the shifting of reward-related activations away from the delivery of winning outcomes towards the anticipation phase of play (i.e. reel spin), reflecting the changing evaluation of anticipatory and consummatory aspects of the game. The data may inform us about the neural changes as people acquire more gambling experience and provide insights on neural mechanisms underlying progressive development of gambling problems.

Another goal of study 1 was to measure the neural responses within reinforcement circuitries to different types of slot-machine game outcomes, in particular the “near-misses”. Near-misses are defined as a special kind of failure that comes close to being successful (Reid, 1986), which have been found to stimulate persistent slot-machine play (Cote et al., 2003) especially when occurring at certain frequencies (Kassinove and Schare, 2001). Recently, Clark et al. (2009) reported that near-miss slot-machine outcomes, similar to wins,

activate bilateral ventral striatum and right anterior insula, suggesting that the experience of almost winning serves as “mini-wins” as expressed by the BOLD responses. Both wins and near-misses were also found to elicit right ventral striatum activations compared to other losses among a group of regular gamblers (Chase and Clark, 2010), and Habib and Dixon (2010) found overlapping brain activations between wins and near-miss outcomes of a slot-machine game among the problem-gambler group in areas including the bilateral dorsal striatum and the left midbrain compared to the non-problem gambler group. In Experiment 1 we sought to replicate the effects of near-misses on neural activities among non-gambler participants and further examined whether the near-miss activations, if any, were modulated by prior experience and learning

A formal experimental design to manipulate learning experience was required to assess the effects of prior practice with a slot-machine game on the neural signals involved when it was played again later. We accomplished this by comparing the BOLD amplitudes elicited by playing a simple single-pay line slot-machine in 2 groups of participants, one of which had played an extra practice session of the same game 1-3 days before the scan. The practice game, which lasted for twice as long as the game in the scanner, provided the participants with a prior learning experience that might alter the signalling of present or future rewards within dopaminergic reinforcement circuitries.

Methods

They study was approved by the National Health Service Oxfordshire Research Ethics Committee C. All participants provided fully-informed written consents.

Subjects Forty-four healthy, right-handed adults recruited from the University of Oxford and from the local community participated. One female was excluded due to noncompliance with task instructions and excessive movements inside the scanner, leaving 43 participants (21 females) in for data analyses. Participants' mean age was 24.42 ± 0.96 years (range: 18-44 years).

All participants were screened with a semi-structured SCID-I interview to ensure that none of the following exclusion criteria were met: i) major physical illnesses; ii) current or previous DSM-IV major mood or psychotic disorders; iii) current or previous DSM-IV substance abuse disorders. Participants were also assessed with the National Opinion Research centre DSM-IV Screen for Gambling Problems (NODS) (Gerstein et al., 1999) in order to establish that none of them had any history of DSM-IV pathological gambling. Participants from the practiced group were paid £35 and those from the unpracticed group were paid £30 for taking part, which amounts included base payments plus standard winnings from the slot machine game (see below).

Psychometric assessments Participants completed the Beck Depression Inventory (BDI-II) (Beck et al., 1996), Trait Positive Affect Negative Affect Schedule (PANAS) (Watson et al., 1988) and the South Oaks Gambling

Screening Questionnaire (SOGS) (Lesieur and Blume, 1987). Verbal IQ was assessed with the National Adult Reading Test (Nelson, 1982) (Table 1). Impulsivity was measured using the Eysenck Impulsiveness Scale (Eysenck and Eysenck, 1985), which had been shown to predict gambling problems (Steel and Blaszczynski, 1998). All participants included in the study scored <=6 on the BDI. As intended, this sample of participants reported no or very limited engagement in gambling activities, confined to sport-betting, horse-betting, poker, lottery and occasional visits to the casino. Participants' scores on SOGS were mostly 0 and 1, with 2 participants scoring 2 and another 2 participants scoring 3, indicating little evidence of pathological gambling.

Design This experiment used a between-group design. Twenty-one participants (ten females) were randomly allocated to the practiced group and to complete an extra practice session of the slot-machine game 1-3 days (mean = 2.10 ± 0.17 days; mode = 2 days) before the scan session. The other twenty-two participants (eleven females) were randomly allocated to the unpracticed group. The practiced group completed 120 practice plays of the slot-machine game during their first study visit before completing 60 plays of the same game inside the scanner as part of an fMRI protocol. The unpracticed group only performed 60 plays in the scanner.

	Age	Gender	BDI	PANAS-P	PANAS-N	I-7	SOGS	IQ (NARTS)
Practiced	24.57±1.31	10/11	2.05±0.47	34.00±1.26	13.38±0.74	7.10±0.88	0.52±0.21	117.10±1.02
Unpracticed	24.27±1.43	11/11	1.41±0.41	36.55±1.34	13.77±1.01	7.18±0.98	0.32±0.12	117.64±0.92
Total	24.42±0.96	21/22	1.72±0.31	35.30±0.93	13.58±0.63	7.14±0.65	0.42±0.12	117.37±0.68

Table 1. Demographic and psychometric details of 43 healthy adult participants who completed a simulated slot-machine game as part of a standard fMRI protocol. Twenty one participants had prior experience of the game before being scanned while 22 players had no prior experience. Verbal IQ (NART) = National Adult Reading Test (Nelson, 1982); Recent depressive symptoms (BDI) = Beck's Depression Inventory (Beck, 1996); Trait positive/negative affect (PANAS-P/PANAS-N) = Trait Positive Affect Negative Affect Scale (Watson et al. 1998); Impulsivity (I-7) = Eysenck Impulsiveness Scale (Eysenck and Eysenck, 1985); Gambling problems (SOGS) = South Oaks Gambling Screening Questionnaire (Lesieur and Blume, 1987).

Computer-simulated slot-machine game The slot-machine game was designed and implemented using Presentation v.11.3 software (Neurobehavioral Systems, San Pablo, USA) (Figure 1). As in conventional slot-machine games, the display consisted of three horizontal “reels” showing fruit symbols. Accumulated game credits were displayed on the top. Winning prizes associated with different combinations of symbols were shown below the credits (Figure 1).

On each play, participants waited for the presentation of a cue (“Click to play” positioned in the bottom centre of the display) before making a single-button response with the index finger of their right hand to initiate the spin. Immediately after, the fruit symbols in all three reels changed randomly with a frequency of 5Hz (each symbol held for 200 milliseconds during spin). Following a variable interval between 4 and 10 seconds with a mean of 7 seconds (Poisson distributed), all three reels stopped simultaneously to show the outcome. If the reels displayed three identical fruit symbols in a row, the player won a monetary reward (ranged between 50p to £3), which amount was determined by the particular symbol s that appeared. Viewing from left to right, if the first two reels showed the same symbol while the third reel showed a different symbol, the outcome was recorded as a “near-miss” (i.e. “AAB”). All other non-win outcomes were counted as losses. Other possible near-miss outcomes of the forms “ABA” or “ABB” never appeared in the game.

Play outcomes were displayed for a fixed interval of 4 seconds followed by a blank display which remained in place for variable delays of 3.5 to 9.5 seconds (mean=6.5 seconds, Poisson distributed). The game was constructed so that 1/6 of all plays ended with winning outcomes (a variable ratio, or VR, of 6) and 1/5 ended with near-miss outcomes (a VR of 5). All other plays ended with losing outcomes consisting of 3 different fruit symbols. Our slot-machine game implemented a return-to-player (RTP) of 80%, which is representative of at least some commercial EGMs widely available in the United Kingdom (http://www.gamblingcommission.gov.uk/shared_content_areas/gaming_machines_technical_stan.aspx). This reinforcement schedule was designed to mimic the typical experience that players might recognise from their own play in a pub or bar, in which game credits are steadily eroded during a slot-machine episode despite occasional winning prizes.

The slot-machine game also included separate “control” plays, which controlled for the gross visual and motor features of the game by involving similar visual displays and identical motor commands, except that all the fruit and credit symbols were replaced by similarly-coloured hashes (“#”). The event structure and the delays between events were the same in the control plays.

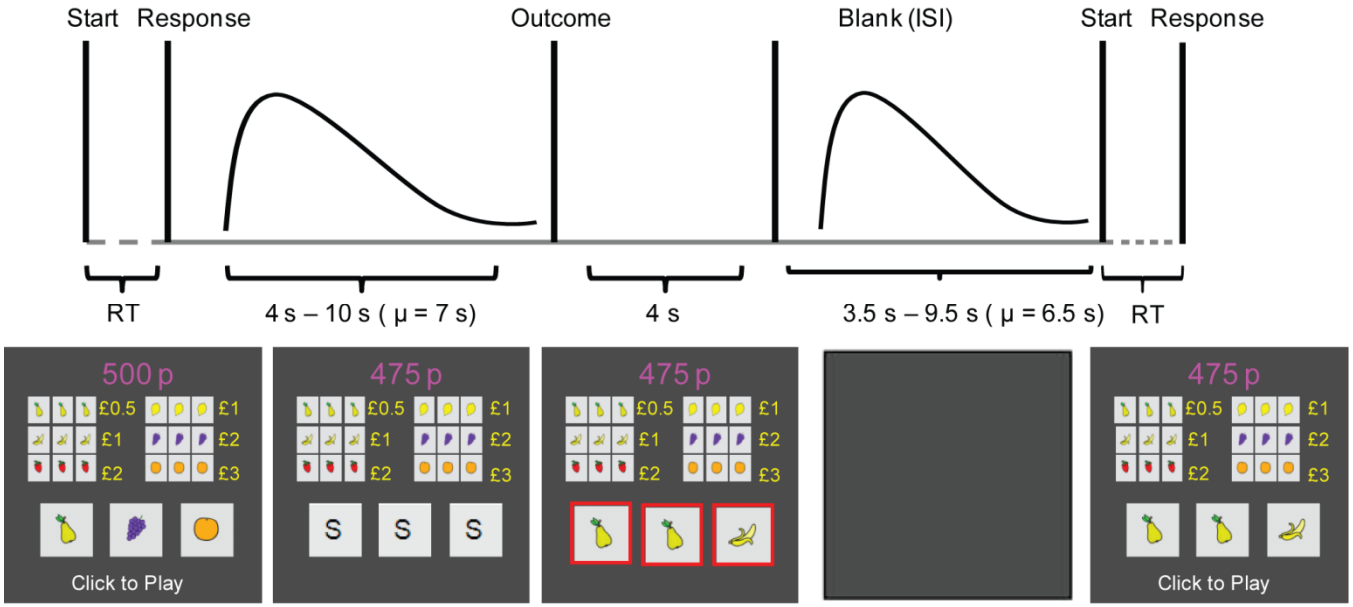


Figure 1. Structure of the simulated slot-machine game. On being shown the cue 'Click to play', participants made a single button press to start the slot machine. Immediately after, all 3 reels displayed a random sequence of 6 different fruits with a frequency of 5Hz. All 3 reels stopped simultaneously following a Poisson-distributed latency of 4-10s and showed the game outcome for a fixed 4s. The game reels were bordered in green to indicate winning outcomes, and in red to indicate near-miss and losing outcomes. The fMRI model included 3 1s regressor for reel spins following winning, near-miss and losing outcomes, 1 extended regressor for the jittered duration of the reel spins, 3 1s impulse regressor for winning, near-miss and losing outcomes, and 2 1s impulse regressor for the value of winning and near-miss outcomes. The display was blanked before the next play started, with a Poisson-distributed inter-trial interval (ITI) of 3.5-9.5s. When this game was played outside the scanner, this latter ITI was shortened to an average of 2.5s. See text for more details.

Procedure On study visit 1, participants arrived at the University Department of Psychiatry and completed the screening procedures as described above. Participants allocated to the practiced, but not the unpracticed, group played an extra practice session of the slot-machine game in a quiet testing room. Participants were told that the amounts they won in the game would be exchanged for real money and form part of their total experiment payment. Participants were given £10 credit at the start of the game. Each play cost 25p. This practice session contained 120 game plays and 16 control plays. Overall, 20 plays ended with winning outcomes, 24 ended with near-miss outcomes and 76 plays ended with losing outcomes, all of which were delivered in a pseudo-random order. This schedule determined that every participant finished the game with £4 credit (i.e. they lost £6 during the course of the game).

The game played in the practice session had identical event structures to the fMRI version of the game, except that the blank display interval between plays was shortened to between 1 and 4 seconds (mean=2.5 seconds, Poisson distributed). The button-clicking, reel-spinning and outcome delivery were each accompanied by distinctive sound effects. The practice game also contained 16 control plays, arranged in a way that 5 occurred in a row after the first 30 game plays, another 5 occurred after the next 30 game plays, and the rest occurred after the 90th game play. Finally, following instructions on how to play the game, participants were given 7 introductory plays before playing the game proper.

On study visit 2, participants arrived at the Oxford Centre for Clinical Magnetic Resonance Imaging (OCMR) to play the slot-machine game inside the fMRI scanner. Game displays were back-projected onto a screen at the head-end of the scanner bore which participants viewed via a mirror positioned directly above their eyes and approximately one meter from the screen. The scan version of the game consisted of 60 slot-machine plays and 10 control plays. Overall, ten slot-machine plays ended with winning outcomes, 12 ended with near-miss outcomes and 38 ended with losing outcomes, all of which were delivered in a pseudo-random order. Participants were given £5 credit to start with, and each play cost 25p. All participants ended with £2 (i.e. they lost £3 during the course of the game). The control plays were arranged such that 5 occurred in a row after the first 20 game plays and another 5 after the next 20 game plays. All participants completed 7 introductory plays before being moved into the scanner.

Functional image acquisition Participants were scanned at 3 Tesla with a Siemens MAGNETUM Trio scanner (Siemens Medical Solutions, Erlangen, Germany) while performing the slot-machine game. Functional data were collected as T2-weighted echo planar images, optimized for blood-oxygen-level-dependent (BOLD) signal contrast in orbitofrontal cortex (voxel size: 3×3×3 mm; TE: 30ms; TR: 3 seconds; 45 slices angled at 30° al ong anterior-posterior axis). A preparation pulse (1ms; 2mT/m) was used in the slice selection to compensate for through-plane susceptibility gradients when imaging orbitofrontal and medial temporal lobe regions (Deichmann et al., 2003). A 176

slice anatomical T1-weighted data set was also acquired with a slice thickness of 1mm for co-registration with the EPI data.

Pre-processing Image pre-processing analysis was carried out with FEAT (FMRI Expert Analysis Tool) v.5.98 (Oxford Centre for Functional Magnetic Resonance Imaging of the Brain; www.fmrib.ox.ac.uk/fsl). Images were high-pass filtered and realigned to correct for motion artefacts using MCFLIRT (Jenkinson et al., 2002). Each volume was corrected for timing of slice acquisition and was smoothed with a Gaussian filter (full width half maximum=5mm). The skull and non-brain matters were removed from the brain using BET (Smith, 2002). Compensation for geometric distortion and signal loss was carried out by measuring field inhomogeneities with a fieldmap sequence and using this information to geometrically unwarp the EPI images and apply a cost-function masking in registrations to ignore areas of signal losses (Jenkinson, 2003). Individual timeseries were also examined using a model-free independent component analysis implemented in MELODIC (Multivariate Exploratory Linear Optimized Decomposition into Independent Components) (Beckmann and Smith, 2004), in order to check for unexpected remaining artefacts.

Data analysis Single-subject General Linear Model (GLM) results were estimated using FEAT (FMRI Expert Analysis Tool v.5.43; www.fmrib.ox.ac.uk/fsl) (Woolrich et al., 2001) and transformed, after spatial normalization, into standard (MNI152) space (Jenkinson et al., 2002). Modelled

events were convolved with a gamma hemodynamic response function (HRF). As suggested by Friston et al. (1998), temporal derivatives of the blurred original waveform were included. High-pass temporal filtering was also applied to the model. Higher-level analysis was carried out with FLAME (FMRIB's Local Analysis of Mixed Effects) (Woolrich et al., 2004). Z (Gaussianized T/F) statistical images were thresholded using clusters at $Z>3.09$ for the main effects of outcomes and a whole-brain corrected cluster significance threshold of $P<0.05$.

Identified activation clusters that would allow comparisons between BOLD signals for the unpracticed and the practiced groups were extracted from functional regions of interest (ROIs) based on the contrast between winning and losing outcomes, intersected with the anatomical definitions of these regions extracted from the Harvard-Oxford cortical and subcortical structural atlases (Havard Center for Morphometric Analysis) (Figure 2). These included i) the midbrain incorporating bilateral ventral tegmental area (VTA) and substantia nigra (SN); ii) bilateral caudate nucleus; iii) bilateral ventral striatum including the nucleus accumbens; iv) bilateral amygdala; v) bilateral anterior cingulate cortex (ACC); vi) bilateral dorsomedial prefrontal cortex (DMPFC, including the medial superior frontal gyrus) and vii) bilateral insular cortex.

Model Winning outcomes and their values, near-miss outcomes and their values and losing outcomes were all modelled as 1-second impulses of neural activity. The value of near-misses was determined as the value of the first two

fruits. For example, the symbol sequence “grape-grape-pear” was modelled with the value of £2 as this was the prize for winning on 3 grapes. The reel spins were modelled in two ways. First, we modelled the start of reel spins as 1-second impulses, with separate regressor for reel spins following previous winning, near-miss and losing outcomes (these were included to test whether different game outcomes influenced signals elicited while watching the 3 reels spin on subsequent plays of the slot machine; there were no such effects so these regressor are not discussed further). Second, we modelled the extended anticipatory activity associated with waiting for the game outcome to appear as the whole jittered duration of the reel spins, this time collapsing across spins following different types of previous play outcomes.

Timeseries analysis The timecourse of signals across the reel spin and the outcomes are shown for illustrative purposes only within ROIs identified above using a cluster-corrected threshold of $P<0.05$. To obtain signal changes within ROIs evoked during game-play, we performed a series of hemo-dynamic deconvolutions across each play of the game. BOLD amplitudes—expressed as % signal changes—were fit by hemodynamic response functions (HRFs) using GLM. We separated and resampled participants’ timeseries data to align them into two phases of the slot-machine plays: i) reel spins which started after participants’ click responses at time 0 and ii) play outcomes which appeared after the reels stopped spinning at time 7s. The resampling resolution was 0.1 seconds.

Timeseries data and model fits were plotted separately for the practiced and unpracticed participants, and separately for plays ending with different types of outcomes. We tested two hemodynamic models. In the first model, BOLD responses were modelled by regressors consisting of a 1-second impulse of phasic activity at the start time of the reel spins and play outcomes convolved with the HRF. In the second model, the BOLD signals were explained by regressors consisting of tonic activity that lasted for the entire duration of the reel-spins and play outcomes, again convolved with the HRF. We compared these models using the sum of square errors (SSE) between the model and the data. Overall, the impulse model provided a better fit to the data and is the one used here.

Matching analysis for participants Matching for age, trait positive affect negative affect (PANAS), depressive symptomology (BDI), gambling problems (SOGS), impulsivity (I-7) and verbal IQ (NART) was performed using one-way analyses of variance (ANOVA) with the 2 between-subjects factors of group (practiced vs. unpracticed) and gender.

Behavioural and BOLD data analysis Mean reaction times (in milliseconds) for click responses to start new slot-machine plays were tested with repeated-measures ANOVA with the between-subjects factors of group (practiced vs. unpracticed) and gender, and the within-subjects factor of the immediately previous play outcome (win, near-miss or loss). Trait impulsivity scores (I-7) were also added as a covariate. Participants' BOLD signals (β-values obtained

from data modelling, see **Timeseries analysis** above) were analysed using one-sample t-tests, univariate ANOVAs and omnibus multi-factorial repeated-measures ANOVA (see Results).

Results

Participant characteristics The practiced and unpracticed groups of participants were closely matched for gender, age and scores on questionnaires measuring mood; the 2 groups were also matched on impulsivity trait as measured by the I-7 Impulsiveness scale, SOGS scores and verbal IQ (all Fs (1, 41)<1.29) (Table 1).

The reaction times (RT) of slot-machine play First, we looked at participants' reaction times in starting new plays of the slot-machine game. The practiced participants overall showed smaller RTs than the unpracticed participants ($F(1, 38) = 6.372$, $p<.05$).

An overview of analysis on neural signals Our analysis on BOLD amplitudes was conducted in three stages. Our principle focus involved structures innervated by mesolimbic dopamine pathways, especially the ventral striatum and amygdala, which have been shown to support reinforcement learning (Schultz, 2010; Hollerman and Schultz, 1998; Galvan et al., 2005); however, we

also wished to test the effects of game practice in other frontostriatal sites that might be involved in the representation of slot machine play and outcomes. Therefore, in the first stage of our analysis, we identified limbic, striatal and cortical regions of interest (ROIs) that showed significant BOLD signals in the comparison between winning and losing outcomes. These ROIs were identified using a Z-score of 3.09 and a cluster-corrected threshold of $p<.05$ (Figure 2 and Table 2), and were orthogonal to our planned comparisons involving practiced and unpracticed participants, thus avoiding the problem of circularity when selecting statistical tests in fMRI (Kriegeskorte et al., 2009).

In the second stage, we modelled the BOLD amplitudes elicited by the slot-machine reel spins, and winning, near-miss and losing outcomes within these ROIs. One-sample t-tests over the resultant β-values were used to test the significance of BOLD responses against baseline. Testing our central hypotheses involved demonstrating opposing effects of prior game-play experience upon the BOLD amplitudes evoked by the reel spins (signal increases) and winning outcomes (signal decreases). Therefore, the third part of our analysis used an omnibus repeated-measures analysis of variance (ANOVA) over the β-values, with the between-subjects factors of practice, gender, impulsivity (high vs. low) and the within-subjects factors of game event (reel spins vs. winning outcomes) and ROI (see below). Impulsivity was entered as a between-subjects factor as this trait had previously been shown to predict problematic gambling behaviours (Steel and Blaszczynski, 1998). High impulsivity (HI) (10 practiced participants, 9 unpracticed participants) and low impulsivity (LI) (11 practiced participants, 13 unpracticed participants) groups

were identified using the median split of participants' I-7 scores, with the LI group scoring equal or lower than 7 and the HI group scoring higher than 7 (Clarke, 2006). The effects of practice upon the BOLD amplitudes within individual ROIs of *a priori* interest were tested with univariate ANOVAs. These ROIs include mesolimbic, mesostriatal and mesocortical dopaminergic regions such as the midbrain, ventral striatum, the amygdala and the caudate nucleus.

Collapsing across the practiced and unpracticed participants, winning outcomes were associated with significant increases in BOLD amplitudes compared to losing outcomes within the midbrain (VTA/substantia nigra), ventral striatum, caudate nucleus, amygdala, anterior cingulate cortex (ACC), dorsomedial prefrontal areas (dmPFC), and the anterior insular cortex (Figure 2 and Table 2). As expected, winning outcomes evoked positive BOLD signals against the timeseries baseline within each of these ROIs, ts (41)>5.32, p<.001 (Figure 3). However, the experience of near-miss outcomes was not associated with significant signal changes relative to losing outcomes within any of the ROIs (ts (41)<1.4), with the exception of the dorsomedial prefrontal area in the unpracticed group, t (21) = 2.48, p<.05. This signal was significantly reduced in the practiced group (t (41) = -2.29, p<.05).

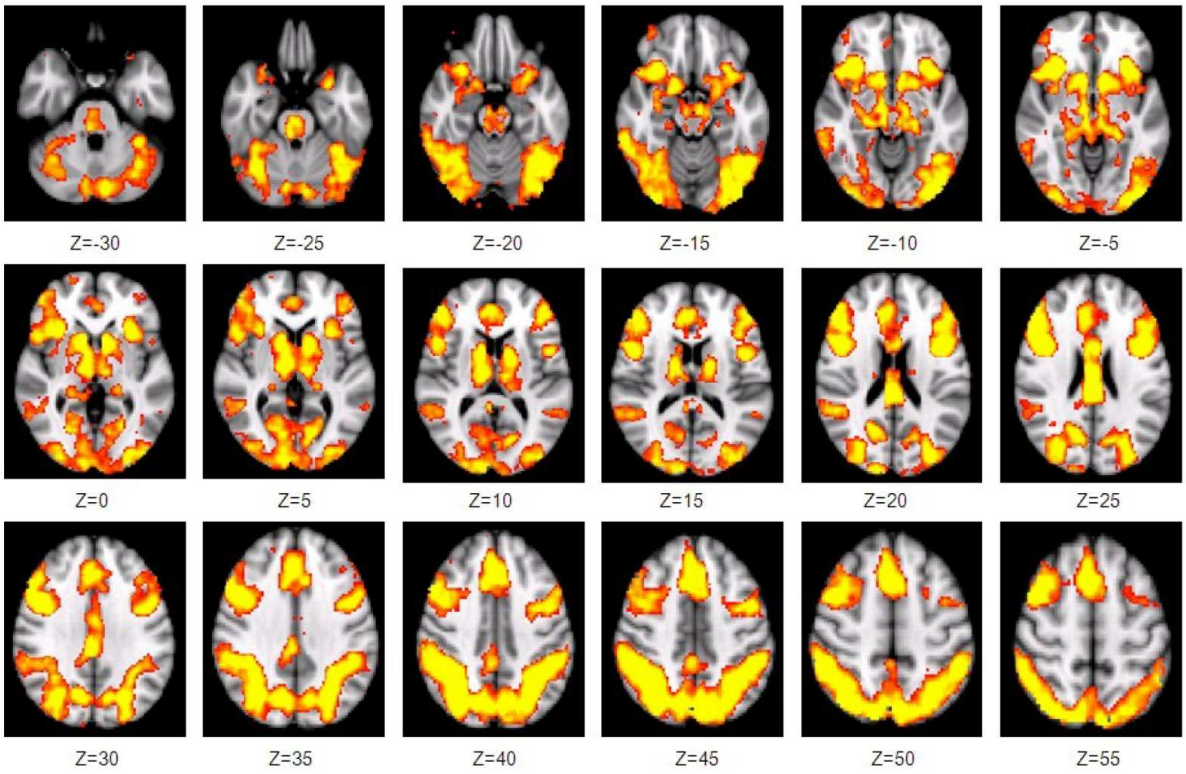


Figure 2. Activation map for blood-oxygenation-level-dependent 1 (BOLD) amplitudes evoked by delivery of winning compared to losing outcomes during play of a simulated slot machine game in 43 healthy adults (collapsing across practiced and unpracticed groups). Signals were thresholded at Z= 3.09, whole-brain cluster-based corrected at $p < 0.05$, and then rendered onto the MNI (Montreal Neurological institute) 'MNI152_T1_2mm' brain (see Methods). Contrast-dependent regions of interest (ROIs) identified included the midbrain (VTA/SN), ventral striatum, caudate nucleus, amygdala, anterior cingulate cortex (ACC), dorsomedial prefrontal cortex (dmPFC) and anterior insular cortex.

Area	Side	Max Z	X	Y	Z
Midbrain (VTA/SN)		5.57	8	-28	-24
Ventral Striatum	L	6.77	-8	10	-4
	R	6.37	10	10	-4
Ventral Putamen	L	5.96	-14	8	-4
	R	6.11	16	10	-2
Caudate Nucleus	L	7.18	-10	8	0
	R	6.60	12	8	6
Amygdala	L	4.64	-22	0	-16
	R	5.37	20	2	-16
Anterior Cingulate	L	5.90	-2	26	40
	R	6.66	6	20	48
Posterior Cingulate	L	6.67	-2	-32	24
	R	7.23	2	-30	26
Superior frontal gyrus	L	6.70	-2	26	40
	R	7.43	6	20	48
Middle frontal gyrus/sulcus	L	6.34	-42	14	22
	R	6.65	44	14	26
Insular cortex	L	7.31	-30	24	-8
	R	7.74	34	22	-8
Thalamus	L	6.01	-12	-2	8
	R	7.36	10	-14	6
Primary visual cortex	L	4.80	-2	-96	6
	R	5.88	12	-96	8
Inferior parietal sulcus	L	7.43	-32	-56	42
	R	7.86	40	-54	46

Table 2 (for Figure 2). Group maximum Z-scores and MNI (Montreal Neurological Institute) 'MNI152_T1_2mm' brain coordinates of BOLD amplitudes identified by the comparison between winning outcomes and losing outcomes, thresholded at $Z>3.09$ and cluster-corrected at $p<0.05$. VTA= ventral tegmental area; SN= substantia nigra.

The omnibus multi-factorial ANOVA on BOLD responses β-values obtained from the GLM modelling of timeseries signals (see Methods) were tested with a repeated-measures ANOVA described above, with the between-subjects factors of group (practiced vs. unpracticed), gender, impulsivity (high vs. low) and the within-subjects factors of game event (reel spins vs. winning outcomes) and ROIs (midbrain, ventral striatum, caudate nucleus, amygdala, ACC, dmPFC and anterior insular cortex). Practice produced different effects on the BOLD signals evoked by slot reel spins compared to the winning game outcomes, as evidenced by the significant 2-way interaction between practice and game event, $F (1, 35) = 6.88$, $p<.05$. Analysis of the simple effects demonstrated that practice reduced signals evoked by the winning outcomes, $F (1, 35) = 6.021$, $p<.05$, but enhanced the signals evoked by the reel spins, $F (1, 35) = 4.03$, $p<.05$.

These distinctive effects of practice were not reliably more or less pronounced in any of the 7 ROIs listed above, as evidenced by the non-significant 3-way interaction between practice, game event and ROI, $F (6, 210) = 1.12$. Univariate ANOVA analyses over the BOLD amplitudes revealed smaller signals evoked by winning outcomes in the practiced compared to the unpracticed participants in the ventral striatum, $F (1, 35) = 9.093$, $p<.05$, and the caudate nucleus, $F (1, 35) = 5.399$, $p<.05$, with a similar trend in the midbrain, $F (1, 35) = 3.134$, $p=.085$ (Figure 3). BOLD signals evoked by winning outcomes were also reduced after practice within a region of the dmPFC, $F (1, 35) = 8.71$, $p<.05$. By contrast, prior experience with the slot-machine game significantly increased the BOLD signals evoked by the reel spins within the ventral striatum, F (1, 35)

= 4.339, p<.05, and the amygdala, F (1, 35) = 6.193, p<.05 (Figure 3). Comparable practice effects were evident in ROIs extracted from the dmPFC and anterior insula, thought *not* the ACC.

We performed the same omnibus repeated-measures ANOVA on BOLD signals elicited by the near-miss outcomes, this time found no significant effect of the practice × game event (reel spin vs. near-miss outcomes) interaction (p>.1). In addition, the 3-way interaction of practice × game event × ROI was non-significant (p>.1). Thus, we found no evidence that practice with the slot-machine game changed the signals evoked by reel spins and near-miss outcomes in different directions.

To test the claim that practice had larger effects upon BOLD responses to winning outcomes compared to near-miss and losing outcomes, we also performed an ANOVA analysis with the between-subjects factors of practice, gender, impulsivity and the within-subjects factors of game outcomes (wins, near-misses, losses) and ROI. This analysis generated a marginally significant 2-way interaction between practice and game outcome, F (2, 70) = 3.10, p=.05.

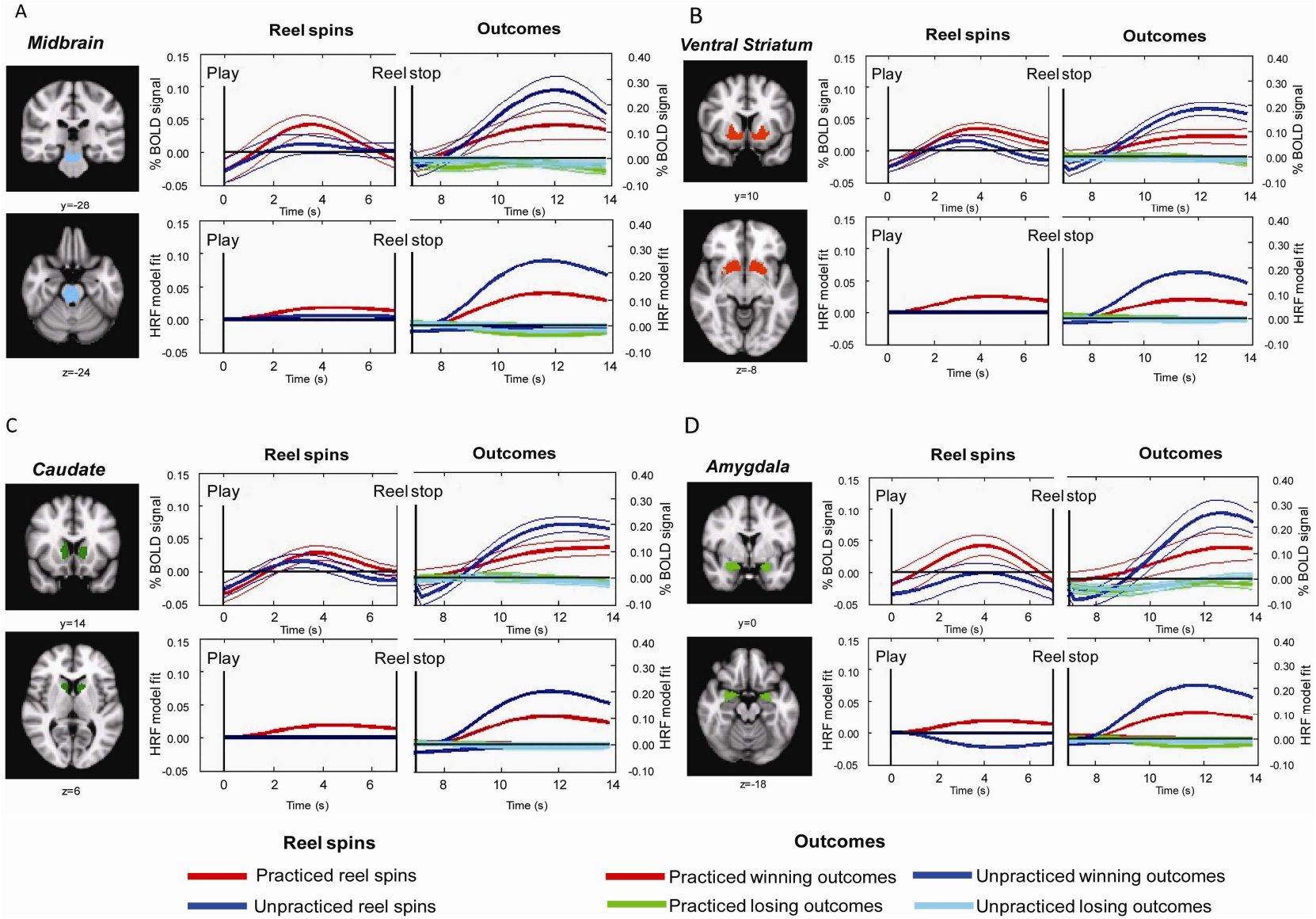

A
Midbrain
y=-28
z=-24
Reel spins
Outcomes
Play
Reel stop
% BOLD signal
HRF model fit
Time (s)
B
Ventral Striatum
y=10
z=-8
C
Caudate
y=14
z=6
D
Amygdala
y=0
z=-18
Reel spins
Practiced reel spins
Unpracticed reel spins
Outcomes
Practiced winning outcomes
Unpracticed winning outcomes
Practiced losing outcomes
Unpracticed losing outcomes

Figure 3. Timeseries plots of BOLD signals within 4 regions of interests (ROIs) constructed using the comparison between winning and losing outcomes (thresholded at Z=3.09, whole-brain cluster-corrected at p< .05). Coronal and axial slices are shown for each of the ROIs. MNI (Montreal Neurological institute) y coordinates are provided below the coronal slices and z coordinates below the axial slices. Upper plots: % BOLD signal changes while watching the game reels spin (displayed for a mean of 7s following 'Play') and the winning outcomes of the game (displayed for 7s following 'Reel stop'). For the reel spins, plays completed by the practiced participants are indicated by the red lines and plays completed by the unpracticed participants are indicated by blue lines. For the outcomes, plays completed by the practiced participants are indicated by red (win) and green lines (loss), and those completed by the unpracticed participants are indicated by blue (win) and cyan (loss) lines. Means % signal values (relative to baseline) are shown together with standard errors. Lower plots: hemodynamic response function (HRF) gamma model used to fit the BOLD % signals. An 'impulse' or phasic HRF and mean response latency of 6s was adapted for the model. The midbrain (including the ventral tegmental area/substantia nigra) is marked in cyan (**A**); the ventral striatum is marked in red (**B**); the caudate nucleus is marked green (**C**); the amygdala in light green (**D**).

Testing the effects of infrequency: wins vs. near-misses It is possible that our finding that prior experience with slot-machine play increased the BOLD signals evoked by reel spins but reduced the signals evoked by winning outcomes may reflect enhanced anticipation of infrequent, or otherwise salient, events but diminished processing of their delivery. One (partial) test of this possibility is to compare the effects of practice on BOLD responses to winning outcomes with the responses to the marginally more frequent near-miss outcomes (10 vs. 12). Two previous investigations suggested that near-misses evoke BOLD signals within the ventral striatum (Chase and Clark, 2010; Clark et al., 2009). Therefore, we confined our tests to this brain structure using an ANOVA with the between-subjects factors of practice, gender, impulsivity and the within-subjects factor of outcome (win vs. near-miss). This analysis showed that practice had a significantly larger effect upon BOLD responses to winning compared to near-miss outcomes ($F(1, 35) = 5.16$, $p<.05$). Univariate analysis confirmed that practice reduced the BOLD signals elicited within the ventral

striatum by winning outcomes, F (1, 35) = 9.09, p<.05, but not by near-miss outcomes, F (1, 35) = 2.27.

Testing anatomical specificity: BOLD signals in posterior areas The practice-related changes in reinforcement signalling while playing our slot-machine game showed some degree of anatomical specificity, being most clearly expressed within dopaminergic reinforcement sites compared to posterior cortical regions. To explore this issue, we examined BOLD amplitudes within 2 posterior ROIs centred around the intra-parietal sulcus and the primary visual area (incorporating the calcarine fissure) (Figure 4). These ROIs were also identified using the original contrast between the winning and losing outcomes (thresholded at Z=3.09 and whole-brain cluster-corrected at p<.05). Overall, there was no indication that prior game experience influenced the BOLD responses evoked by the winning outcomes differently from the BOLD responses evoked by the reel spins in these regions, as evidenced by a non-significant 2-way interaction between practice and game event, F (1, 35) = 0.18. Testing the effects of practice on signals elicited by the winning outcomes and by the reel spins directly (and separately) did not yield significant main effects, F (1, 35) = 0.10 and F (1, 35) = 0.06, respectively (Figure 4).

We also *compared* the BOLD responses evoked by the reel spins and winning outcomes within the intra-parietal sulcus and ventral striatum, using an ANOVA with the between-subjects factors of practice, gender and impulsivity and within-subjects factors of game event and ROI (intra-parietal sulcus vs. ventral

striatum). This analysis showed that prior game experience influenced participants' BOLD responses to the two game events differently within these 2 regions, as evidenced by a significant 3-way interaction between practice, game event and ROI, $F(1, 35) = 4.57$, $p<.05$. Analysis of the simple interaction effects showed that practice reduced the BOLD responses to winning outcomes but increased BOLD signals to reel spins within the ventral striatum as indicated by a significant 2-way interaction between practice and game event, $F(1, 35) = 10.06$, $p<.05$. However, the same simple interaction effect was not significant in the intra-parietal sulcal area, $F(1, 35) = 0.53$ (Figure 4).

As one last test of the anatomical specificity, we compared directly the BOLD responses to the winning outcomes and reel spins of the slot-machine game within anterior ROIs of the forebrain that are richly innervated by the ascending dopamine pathways against the posterior ROIs that have more limited dopaminergic innervations. We did this by averaging the β-values across the midbrain, ventral striatum, caudate nucleus, amygdala and ACC, and then averaging the β-values across the 2 remaining primary visual area and intra-parietal sulcal area. These averages were then used to construct a new within-subjects factor of region (anterior vs. posterior). Prior experience with the slot-machine game influenced participants' BOLD responses to the winning outcomes and reel spins differently within the anterior and posterior sites, as evidenced by a significant 3-way interaction between practice, game event and region, $F(1, 35) = 4.27$, $p<.05$. Analysis of the simple interaction effects showed that practice reduced signals elicited by winning outcomes but increased signals elicited by reel spins within the anterior dopamine-enriched sites, as indicated

by a significant 2-way interaction between practice and game event, F (1, 35) = 6.67, p<.05. This simple interaction was not significant within the posterior ROIs, F (1, 35) = 0.18.

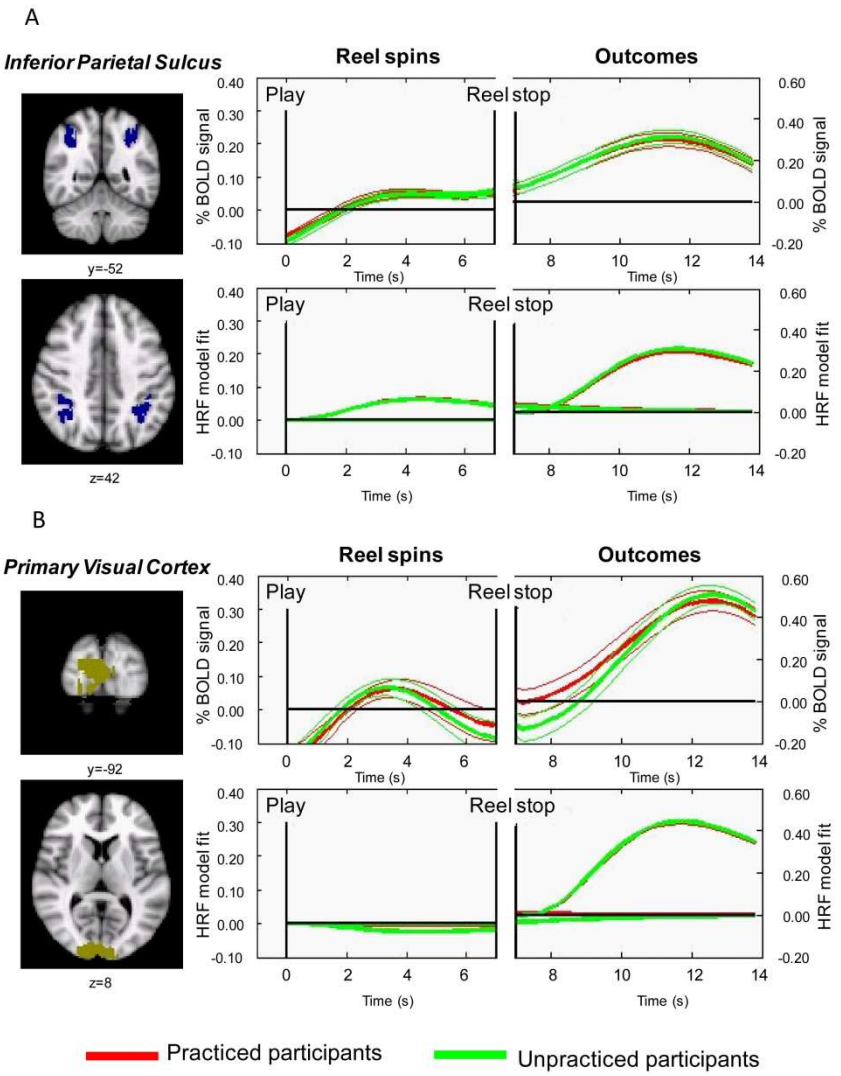


Figure 4. Timeseries plots of BOLD signals during performance of a simulated slot-machine game within the 2 posterior regions of interests (ROIs) identified using the contrast between winning and losing outcomes (see above). Signals were thresholded at Z= 3.09, whole-brain cluster-based corrected at p < 0.05, and then rendered onto the MNI (Montreal Neurological institute) 'avg152 brain' (see Methods). Coronal and axial slices are shown for each of the ROIs. MNI (Montreal Neurological institute) y coordinates are provided below the coronal slices and z coordinates below the axial slices. Upper plots: % BOLD signal changes while watching the game reels spin (modelled for 7s following 'Play') and winning outcomes of the game (displayed for 7s following 'Reel stop'). Signals arising from plays completed by the practiced participants are indicated by red lines; plays completed by the unpracticed participants are indicated by green lines. Means % signal values (relative to baseline) are shown together with standard errors. Lower plots: hemodynamic response function (HRF) gamma models used to fit % BOLD signals. 'Impulse' or phasic HRFs with mean response latencies of 6s were used. The intra-parietal sulcus is marked in blue (**A**) and the primary visual cortical region is shown in yellow (**B**).

Testing BOLD signals evoked by the control game The patterns of BOLD amplitudes evoked by the events in our slot-machine game in the practiced and unpracticed participants were not attributable to the game's gross visual and motor features. Participants also completed a 'control' game, which involved similar visual displays and identical motor commands, except that all fruit and credit symbols were replaced by coloured hashes ('#'). The event-structure and timings of the control game were identical to those of the slot-machine game. In general, the BOLD amplitudes elicited by the reel spins and, in particular, the outcomes of the control game were weak and statistically unreliable within those mesolimbic and striatal ROIs that were responsive to the winning outcomes and reel spins of the slot-machine game (Figure 5). While BOLD amplitudes elicited by the winning outcomes of the slot-machine game, collapsing across the practiced and unpracticed participants, were all positive and significant in these ROIs (all mean β-values between 2.47 and 4.17), the amplitudes elicited by those of the control game were small, negative and non-significant (β-values between -0.72 and -0.19). The only exception was the significant negative responses to control outcomes within the ACC, β-value = -1.14, $t(42) = -2.99$, $p<.05$.

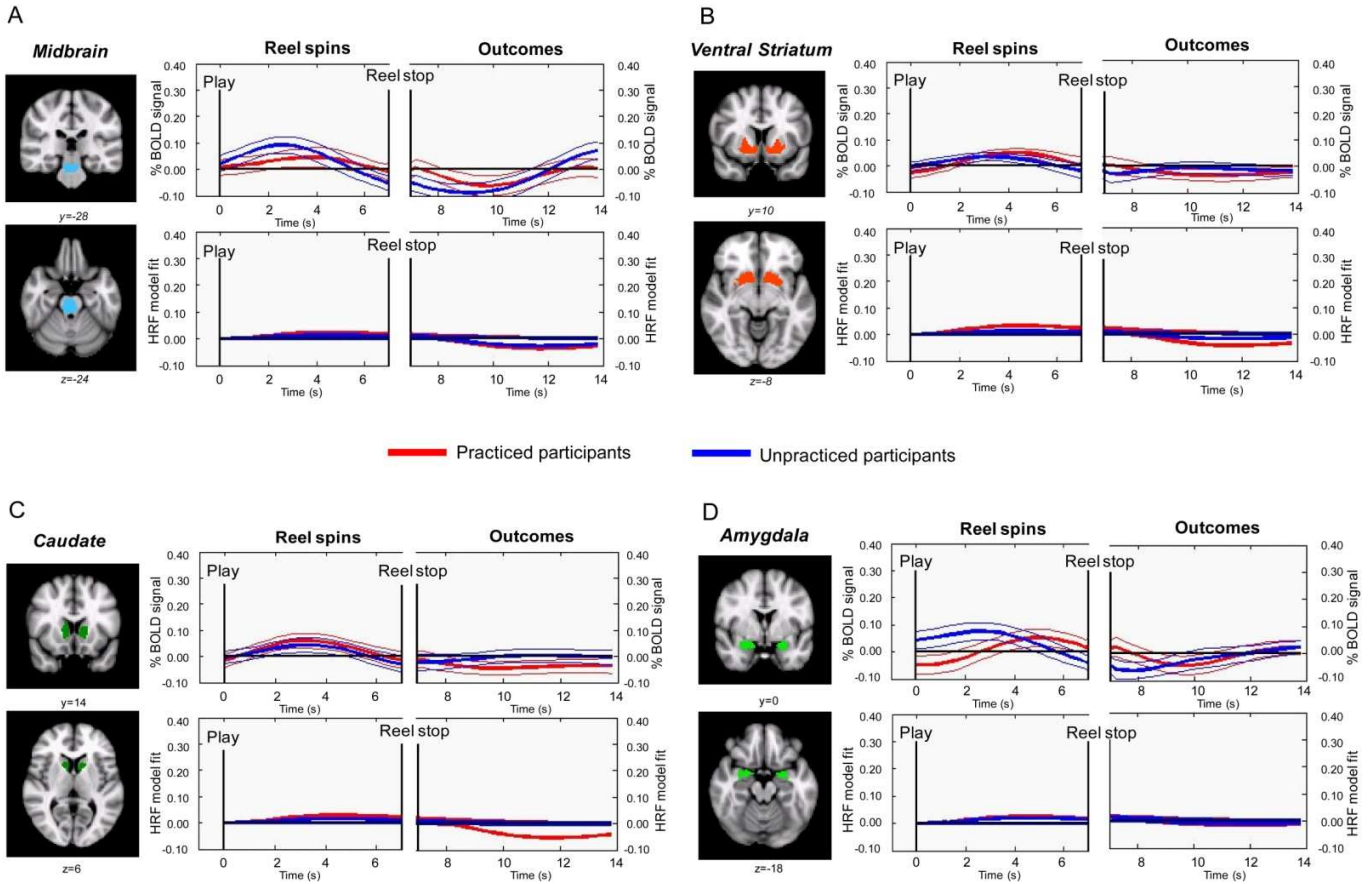


Figure 5. Timeseries plots of BOLD signals during performance of our control game within the same regions of interests (ROIs) identified using the contrast between winning and losing outcomes of the slot-machine game. Coronal and axial slices are shown for each of ROIs. MNI (Montreal Neurological institute) y coordinates are provided below the coronal slices and z coordinates below the axial slices. Upper plots: % BOLD amplitudes while watching the control game reels spin (displayed for 7s following 'Play') and outcomes (displayed for 7s following the 'Reel stop'). Signals from plays completed by the practiced participants are indicated by red lines and those completed by the unpracticed participants are indicated by blue lines. Means % signal values (relative to baseline) are shown together with standard errors. Lower plots: hemodynamic response function (HRF) gamma models used to fit % BOLD signals. The midbrain is marked in cyan (A); the ventral striatum is marked in red (**B**); the caudate is marked in green (**C**); and the amygdala is shown in light green (**D**).

Outcome value analysis We also investigated BOLD signals which encoded the monetary value of winning outcomes. Two brain regions, the anterior cingulate cortex and the ventromedial prefrontal cortex incorporating the rostral cingulate cortex adjacent to the genu, showed significant activations which correlated with the value of winning events (thresholded at Z=3.09, uncorrected). Losing outcomes were associated with reduced signals within this area of the ACC ($t(41) = 3.22$, $p<.05$). Both near-miss and losing outcomes also showed near-significant associations with reduced BOLD signals within this area of the ventromedial prefrontal cortex/rostral cingulate cortex ($t(41) = -1.78$, $p=0.083$ and $t(41) = -1.9984$, $p=0.052$, respectively).

Discussion

The results from Experiment 1 indicate that a single episode of slot-machine play engages well-characterised reinforcement learning mechanisms mediated by mesolimbic and mesostriatal dopamine pathways, as suggested by previous eletrophysiological studies using animals and research on humans employing the indirect fMRI technique (Hollerman and Schultz, 1998; O'Doherty et al., 2003), in order to shift reinforcement signalling from game outcomes to their preceding anticipatory states. Instantiating what is known about how the dopamine system supports reinforcement learning (Schultz, 2010), and the involvement of striatal sites in the consolidation of reinforcement learning over periods of days (Lansink et al., 2008), these results are consistent with the proposal that a single episode of slot-machine play diminishes the positive reward value of winning outcomes but enhances the value of the game events

that precede them. Our findings link these shifts in reward value to the representation of positive prediction errors by dopamine pathways and their efferent mesolimbic, striatal and amygdala targets (Hollerman and Schultz, 1998; O'Doherty et al., 2003), to clinical evidence of dysfunction with dopamine pathways in pathological gamblers (Reuter et al., 2005; Zack and Poulos, 2004, 2007), and to preliminary evidence that altered D2 receptor activity mediates problematic EGM play (Tremblay et al., 2011). Our findings suggest that slot machines, and other EGMs that share common structural features, engage dopaminergic mechanisms to mediate the transition from exploratory to more regular machine play.

Further experiments are needed to establish the precise psychological correlates of the enhanced signals within the ventral striatum and amygdala evoked by watching the reels spin following prior game experiences. However, we consider 3 possibilities here. First, phasic activity of the VTA in the midbrain and its target sites in the ventral striatum signal both the magnitude and probability of rewards against their variances in a way that represents expected value (Fiorillo et al., 2003; Schultz, 2007; Tobler et al., 2005). Corresponding signals reflecting linear and nonlinear subjective probabilities of reward can also be detected in the human striatum using fMRI (Knutson et al., 2005; Hsu et al., 2005; Kable and Glimcher, 2007; Haruno et al., 2004), representations possibly mediating human gambling behaviours (Hsu et al., 2009; Tobler et al., 2008). Similarly, activity within the amygdala appears to code the presence of partial or incomplete information about reward probabilities (Schultz et al., 2008). Therefore, increased activity within the ventral striatum and amygdala in

response to reel spins in association with prior experience with the slot-machine game may reflect learning that links the game's reel spins to their likely expected reinforcement value in terms of the frequency of positive versus negative outcomes.

On the other hand, the enhanced BOLD signals within the ventral striatum and amygdala observed during the reel spins of our slot-machine game are unlikely to reflect reward uncertainty *per se*. Winning outcomes in our game were delivered according to a variable-ratio of 6 or, on average, once in every 6 plays. Uncertainty about whether individual plays would terminate in winning outcomes would have been maximal in participants playing the game for the first time, predicting that BOLD signals within the ventral striatum and amygdala evoked by watching the game reels spin should have been increased in the *unpracticed* compared to the practiced participants. Here, we found the opposite pattern of signal changes (Figure 3).

Second, other evidence suggests that activity of the VTA and its dopaminergic targets code the incentive salience (Bromberg-Martin et al., 2010; McClure et al., 2003; Berridge, 2007), as well as the physical salience (Schultz, 2010), of environmental stimuli, with indications that salience signals can be detected in the human striatum using fMRI (Zink et al., 2003; Jensen et al., 2007). Clinical reports suggest that habitual slot-machine players find that the reel spins, and the configuration of visual and auditory stimuli that accompany them, capture attention and encourage further play (Griffiths, 1993a); these game features

may even drive dissociative states (Distin and Hodgins, 2001). The heightened activity we observed within the ventral striatum and amygdala may signal the enhanced salience of the slot reel spins in the practiced players.

Relatedly, substantial evidence indicates that the amygdala plays a significant role in coding the reinforcement value of stimuli that predict rewards including those that form the basis for addictive behaviours (Volkow et al., 2002), and that amygdala activity allows these stimuli to sustain reward-seeking behaviours (Volkow et al., 2002; Everitt et al., 1999). Thus, our data are also consistent with the proposal that the incentive and conditioned values of the reel spins and other visual-auditory features of slot machines are passed from the amygdala to ventral striatum via efferent projections (Fudge et al., 2002), perhaps promoting continued play.

In contrast to Clark et al. (2009)'s findings, in Experiment 1 we observed no reliable signal increases or decreases in response to near-miss slot-machine outcomes in any of the 7 ROIs investigated. In addition, there was no indication that BOLD signals evoked by near-miss events, if any, were modulated by prior game experience. The absence of near-miss activations across a range of reinforcement circuitries was surprising in light of previous research reporting near-miss outcomes stimulate persistent play (Cote et al., 2003; Kassinove and Schare, 2001) and activate overlapping brain regions as wins (Clark et al., 2009; Chase and Clark, 2010). The discrepancy in results might have arisen for a number of reasons. On methodological grounds, it might be that the slot-

machine game employed by Clark et al. involved an element of personal control (in one game condition, participants could choose the ‘winning’ play icons). However, this is unlikely to be the case as Rogers et al. (in submission) demonstrated positive signal changes within the midbrain, striatal and cingulate sites using a slot machine similar to the one used in the present experiment. Alternatively, previous experiments that have demonstrated that near-misses prolong slot-machine play and/or are positively reinforcing tended to employ reinforcement schedules with high return rates (e.g. Cote et al., 2003) or generous payoff (Clark et al., 2009). In Experiment 1, we implemented a more stringent, but commercially realistic payoff schedule and found that the positive effects of near-misses on neural activity vanished, suggesting that they may be conditional on high game returns. Thus, our findings from Experiment 1 raised questions about the reliability and generality of the near-miss effect in producing positive reinforcement signals during gambling activities.

In summary, the data from Experiment 1 show, for the first time, that prior experience with slot-machine games were associated with shifts of positive reinforcement signalling away from the game outcomes themselves towards the reel spins that precede them. These data delineate the neural pathways that mediate the transfer of value away from positive outcomes towards the temporally earlier anticipatory states. At a clinical level, our data suggested that the anticipatory, or reel spin, phase of the slot-machine game can be important in inducing arousal, excitement and even dissociative states which are frequency reported among individuals with gambling problems (Jacobs, 1988). Thus, findings from Experiment 1 shed lights on understanding how gambling

experiences shape the neural mechanisms underlying the progression from casual to regular gambling, which has both important theoretical and clinical implications.

Chapter III–Experiment 2

Neural response to slot-machine play: the influences of impulsivity and illusions of control

Introduction

Many previous studies have found an association between impulsivity and gambling problems (e.g. Alessi and Petry, 2003; Nower et al., 2004), as well as other addictive behaviours (Petry et al., 1998). Impulsivity levels were found to be elevated in both social gamblers (Clarke, 2006) and pathological gamblers (Steel and Blaszczynski, 1996; Petry, 2001) and may compromise treatment outcome in the latter population (Leblond et al., 2003). There is also evidence that impulsivity, as measured by neuro-cognitive tasks, predicts relapse in pathological gamblers after treatments (Goudriaan et al., 2008). In one longitudinal study, high impulsivity scores at early adolescence predicted development of gambling problems 3-4 years later (Vitaro et al., 1999). Yet, research examining influences of impulsivity among people with little gambling involvement is lacking, making it difficult to understand the basic relationship between this aspect of personality and gambling behaviour, as well as complicating the interpretation of research findings on clinical samples of problem gamblers.

Recent evidence suggests that heightened impulsivity and drug self-administration are mediated by altered dopamine transmission and/or D2/D3 receptor availability within mesolimbic dopamine circuitries (Besson et al., 2010; Dalley et al., 2007; Diergaarde et al., 2008; Buckholtz et al., 2010). Also, damage to parts of the mesolimbic dopamine pathway such as the nucleus accumbens and the amygdala leads to heightened impulsivity (Cardinal et al., 2001; Winstanley et al., 2004), supporting the associations between mesolimbic dopamine transmissions and impulsivity. In addition, dopamine treatment led to more impulsive choice behaviours in Parkinson's disease patients with pathological gambling or compulsive shopping problems (Voon et al. 2010). Moreover, both behavioural and clinical expressions of impulsivity, as well as impulsivity as measured by self-report questionnaires, enhance neural responses to delivered rewards within the ventral striatum (Bjork et al., 2008, Hariri et al., 2006; Forbes et al., 2009), perhaps reflecting altered D2 receptor expression (Buckholtz et al., 2010).

Other evidence links pathological gambling to altered dopamine transmission levels in the brain (Zack and Poulos, 2004, 2007). Administration of d-amphetamine was found to increase desire to gamble in the pathological gamblers, but not in controls (Zack and Poulos, 2004), and the dopamine D2 receptor antagonist haloperidol increased subjective rewarding effect of gambling and improved reading speed of gambling words in the pathological gambler, but not control, group (Zack and Poulos, 2007). Also, dopamine release during the Iowa gambling task was associated with worse performance among pathological gamblers but better performance in controls (Linnet et al.,

2011), implicating underlying differences in dopaminergic function. In addition, a subset of patients with Parkinson's disease treated with dopamine therapy later develops problematic gambling behaviours (Dodd et al., 2005; Bandini et al., 2007). In addition, abnormal dopamine receptor activity may predispose the development of problem gambling later in life. Consistent with this, Comings et al. (1996) found that a much higher proportion of gamblers carry the A1 allele of the dopamine D2 receptor gene, which is associated with reduction in D2 receptor density. However, there might be other changes in dopamine transmission. For example, Bergh et al. (1997) found that pathological gamblers show altered levels of dopamine metabolites in the cerebrospinal fluid compared to controls.

Therefore, in Experiment 2 we tested whether individual differences in impulsivity among non-gambler participants were associated with altered signalling within reinforcement sites—in particular, the ventral striatum—in response to slot-machine outcome events. We hoped that the data would improve our understanding of the association between impulsivity and gambling and identify the neural basis of this association. Also, by examining the influence of impulsivity on neural responses to winning and near-miss outcomes, we were able to test the 'mini-win' theory of the near-miss effect (Reid, 1986). If near-miss outcomes are processed similarly to winning outcomes by the dopaminergic reinforcement system, we would then expect impulsivity to exert similar influence on neural signals to winning and to near-miss outcomes within the mesolimbic dopamine circuitries. More specifically, if impulsivity increased ventral striatal activities to winning outcomes, as suggested by previous studies

(Bjork et al., 2008; Hariri et al., 2006; Forbes et al., 2009), people who score higher on this trait would also show more positive signals in the ventral striatum in response to near-miss outcomes.

While individual differences in personality traits are likely to play important roles in the development of problem gambling, certain types of cognitive biases and erroneous thinking have also been considered as 'common factors' leading to regular involvement in gambling activities (Blaszczynski, 2000). One of these cognitive biases, namely the illusion of control, has received much attention from researchers in consequence of its capacity in promoting persistent gambling behaviours (Griffiths, 1994).

As noted in Chapter 1, illusions of control occur when people hold non-veridical beliefs about his/her ability to influence probabilistic events and secure winning outcomes in essentially chance situations (Langer, 1975). Within the context of slot-machine play, there is evidence that regular gamblers consider the game as more skill-oriented than irregular gamblers (Griffiths, 1994). Illusions of control have also been observed in many other gambling activities such as roulette (Oldman, 1974; Dixon et al., 1998), video poker (Dixon et al., 2007), lottery (Langer, 1975; Rogers, 1998) and sport-betting (Gadboury and Ladouceur, 1988; Gilovich and Douglas, 1986). Important evidence exists suggesting that the levels of illusions of control people endorse are related to how severe their gambling problems might be (Carol and Huxley, 1994; Griffiths, 1990; Ladouceur, 2004), with the more problematic (Myrseth et al., 2010) and

heavily-involved gamblers showing greater illusions of control than non-problematic or infrequent gamblers (Strickland et al., 2006).

There is recent evidence that people who hold a stronger skill-oriented view about gambling report greater subjective desire to play following near-miss slot-machine outcomes, supporting the idea that near-miss outcomes foster illusions of control (Billieux et al., 2011). In addition, a recent fMRI study examined the influence of personal control on neural responses to a slot-machine-like game (Clark et al., 2009). These authors found that near-miss outcomes elicited positive BOLD signals in a region of the anterior cingulate cortex (ACC) only when the player had the opportunity to choose the 'winning' symbol. One possible explanation of Clark et al.'s findings was that the influence of near-miss outcomes on players' neural responses was mediated by illusions of control, which were heightened when some levels of perceived control were available (i.e. choosing the winning symbol). The anterior cingulate cortex is considered to code action-value relationships and to play a major role in integrating recent reinforcement histories (Walton et al., 2007). It is also well-positioned to influence reinforcement processing within the striatum (Rushworth et al., 2004). Thus, this brain structure might be a candidate region where illusions of control exert effects on the neural processing of gambling actions and outcomes during slot-machine play.

Therefore, in Experiment 2 we also tested the influence of illusions of control on non-gambler participants' neural responses to slot-machine outcomes. Based

on the findings of Clark et al. (2009), we focused on examining the association between illusions of control and neural signals to near-miss outcomes. Different from Clark et al. (2009), our slot-machine game was constructed using a more commercially realistic reinforcement schedule(http://www.gamblingcommission.gov.uk/shared_content_areas/gaming_machines_technical_stan.aspx) and involved a structural layout that more closely resembled conventional slot machines (see Methods).

Methods

They study was approved by the National Health Service Oxfordshire Research Ethics Committee C. All participants provided fully-informed written consents.

Subjects Experiment 2 used the same sample of participants as Experiment 1. See Table 1, Chapter 2 for demographic and psychometric details of participants. The screening procedures were also identical to those employed in Experiment 1.

Psychometric assessments Impulsivity was measured using the I-7 Eysenck Impulsiveness Scale (Eysenck and Eysenck, 1985), which was shown previously to discriminate between pathological and non-pathological gamblers (Nower et al., 2004) and to correlate with the severity of gambling problems among a non-clinical sample (Clarke, 2006). Participants also completed the Gamblers' Beliefs Questionnaire (GBQ) (Steenbergh et al., 2002). Table 1 shows these scores for the practiced and unpracticed participants.

GBQ The GBQ contains 21 items grouped into 2 factors. The first factor (luck/perseverance) assesses cognitive biases such as overestimation of the winning chance, overconfidence and gamblers' fallacy (e.g. 'In the long run, I'll win more money than I'll lose gambling'), and the second factor (GBQ-IoC) measures illusions of control (e.g. 'My knowledge and skill in gambling contribute to the likelihood that I will make money'). Respondents rate the degree to which they agree with each of the statements on a Likert scale ranging from 1 ('strongly agree') to 7 ('strongly disagree'). Total score ranges from 21 to 147, with lower scores indicating stronger cognitive distortions. In order to make higher scores indicative of greater cognitive biases, we reversely coded participants' responses on the GBQ in Experiment 2 and in all the other experiments that employed this questionnaire (Experiment 3-5) in this thesis. The 2 subscales of the GBQ are highly correlated and both show high levels of internal consistency and test-retest stability (Steenbergh et al. 2002). Both subscales of GBQ have also been shown to discriminate between pathological and non-pathological gamblers (Steenbergh et al., 2002; Mackillop et al., 2006), and to correlate with gambling frequencies (Strickland et al., 2006). There is also evidence that gamblers who prefer chance games report stronger biases on the first GBQ factor and those preferring skill-based games show stronger biases on the second factor (Myrseth et al., 2010).

	I-7	GBQ	
		Luck/perseverance	Illusion of control
Practiced	7.10±0.88	28.24±2.91	23.52±2.44
Unpracticed	7.18±0.98	26.68±2.20	27.09±1.98
Total	7.14±0.65	27.44±1.80	25.35±1.57

Table 1. Gambling-related personality trait and psychometric scores of 43 healthy adult participants who completed a simulated slot-machine game as part of a standard fMRI protocol. Twenty one participants had prior experience of the game before being scanned while 22 players had no prior experience. Impulsivity (I-7) = Eysenck Impulsiveness Scale (Eysenck and Eysenck, 1985); GBQ=Gamblers' Beliefs Questionnaire (Steenbergh et al. 2002). See texts for more details.

Design, game structure and procedure These were all identical to Experiment 1 (Chapter 2).

Image acquisition and data analysis Technical details of Echo Planar Image (EPI) and structural brain image acquisition, as well as fMRI data processing and analysis, were included in the Methods section of Chapter 2. Z (Gaussianized T/F) statistical images were thresholded using clusters at $Z>2.3$ for the covariate effects of impulsivity and GBQ illusions of control scores (see below) and a whole-brain corrected cluster significance threshold of $P<0.05$.

Model Participant-level analyses included the reel-spin and outcome event-related variables (EVs) and were exactly as those described in the Methods section of Chapter 2. However, at the group level, participants' scores on the I-7 questionnaire and the illusion of control subscale of the GBQ were entered as covariate of signal changes in separate analyses. When testing the main effects of covariates, the raw psychometric scores were demeaned across the practiced and unpracticed participants. When the covariate analyses were performed for practiced and unpracticed participants separately, the raw scores were demeaned within each group.

Timeseries analysis The covariate analysis of the main effect of I-7 scores identified brain areas including the ventral striatum and caudate nucleus bilaterally and left amygdala in the comparison between signals evoked by

winning and near-miss outcomes (thresholded at Z>2.3, whole-brain cluster-corrected at p<.05). The analysis of the main effect of the GBQ illusion of control subscale (GBQ-IoC) isolated activity within regions of the cingulate cortex and the insular cortex in the comparison between signals elicited by reel spins following winning and losing outcomes (thresholded at Z>2.3, whole-brain cluster-corrected at p<.05). The covariate effects of I-7 and GBQ-IoC scores on neural responses to slot-machine events were plotted as regression coefficients.

Behavioural and neural signal analysis Mean reaction times (in milliseconds) for click responses to start new slot-machine plays were tested with repeated-measures ANOVA with the between-subjects factors of group (practiced vs. unpracticed) and gender, and the within-subjects factor of the immediately previous play outcome (win, near-miss or loss). Participants' I-7 impulsivity and illusion of control scores were added as covariates of interest in order to test whether variations in these scores influenced the speeds of starting new plays following different slot-machine outcomes. Participants' BOLD signals, expressed as β values from data modelling, were analysed using one-sample and independent-samples t-tests. The covariate effects of trait and cognitive bias scores, expressed as regression coefficients, were also analysed using one-sample and independent-samples t-tests where appropriate (see Results).

Results

Participant characteristics The practiced and unpracticed groups of participants scored similarly on all of the gambling-related psychometric measures (all Fs (1, 41) < 2.5) (Table 1).

The reaction times (RT) of slot-machine play Participants with high I-7 scores were significantly faster to start new plays following winning outcomes compared to near-miss and losing outcomes ($F(2, 76) = 7.14$, $p<.05$). In general, high I-7 scores were associated with faster responses to start new plays following winning outcomes ($r(43) = -.314$, $p<.05$), but not following near-miss ($r(43) = .015$) or losing outcomes ($r(43) = -.057$), confirming that the reinforcing effects of successful plays were selectively enhanced in high-impulsive participants.

Impulsivity influences BOLD signals to wins and near-misses Next, we entered participants' I-7 scores as a covariate of interest into the general linear model (GLM) of the BOLD timeseries data to identify ROIs that showed impulsivity-dependent signals, thresholded at $Z>2.3$ and cluster-corrected at $p<.05$. This isolated activity within the ventral striatum and caudate nucleus bilaterally and left amygdala in the comparison between amplitudes evoked by winning and near-miss outcomes (Figure 1 and Table 2). Analysis of the timeseries data revealed that high I-7 scores enhanced the positive signals evoked by winning outcomes within the ventral striatum and amygdala but diminished the signals evoked in the same structures by near-miss outcomes (Figure 2).

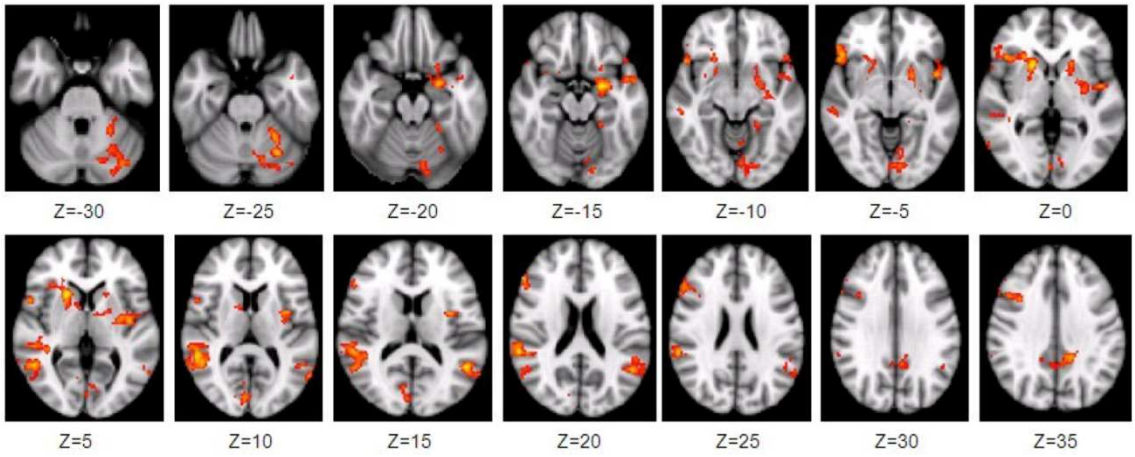


Figure 1. Activation map for impulsivity-dependent BOLD signals in the comparison between winning and near-miss outcomes during performance of a simulated slot-machine game, collapsed across the 21 practiced healthy adult participants and the 22 unpracticed participants of the experiment. Signals were thresholded at Z= 2.3, with cluster-based correction at $p < 0.05$, and then rendered onto the MNI (Montreal Neurological institute) 'MNI152_T1_2mm' brain (see Methods). Contrast-dependent regions of interest (ROIs) identified included the ventral striatum, the amygdala and the caudate nucleus (see main text for details).

Area	Side	Max Z	X	Y	Z
Ventral striatum	L	3.18	-18	6	-4
	R	4.10	20	16	2
Amygdala	L	3.94	-22	-4	-16
Caudate nucleus	L	3.04	-18	18	0
	R	4.18	18	18	2
Insular cortex	L	3.56	-34	-2	12
	R	3.12	38	22	0
Inferior frontal gyrus	L	2.90	-50	22	-12
	R	3.55	54	30	18
Middle temporal gyrus	L	3.41	-50	-54	12
	R	4.02	50	-54	6
Angular gyrus	L	3.95	-50	-54	14

Table 2 (for Figure 1). Z-scores and MNI (Montreal Neurological 1 institute) 'MNI152_T1_2mm' coordinates of BOLD amplitudes associated with the positive covariate of I-7 scores on the winning minus near-miss outcomes contrast (Figure 1) (Z>2.3, cluster-correlated at p<0.05).

To further characterize the influence of impulsivity on the near-miss signals within the ventral striatum and amygdala, we examined the timecourse of BOLD responses elicited in high-impulsive (HI, n=19) and low-impulsive (LI, n=24) participants. These were classified based on a median split of I-7 scores, with the LI group scoring equal or lower than 7 and the HI group scoring higher than 7 (see Results section of Chapter 2). We then identified ROIs using our original (and orthogonal) comparison of winning and losing outcomes, thresholded at $Z>3.09$ and cluster-corrected at $p<.05$. Recently, Clark and colleagues reported enhanced BOLD amplitudes within a region of the putamen following the delivery of near-miss compared to other losing outcomes (Clark et al., 2009). Therefore, we also extracted an additional ROI from the same comparison in this region of the putamen posterior and lateral to the nucleus accumbens (Figure 3) to see whether near-miss signals within this ROI were modulated by impulsivity.

Among LI participants, and consistent with previous reports (Clark et al., 2009; Chase and Clark, 2010), near-miss slot-machine outcomes evoked significant or near-significant positive BOLD signals within the ventral striatum ($t(23) = 1.7438$, $p=0.0945$), putamen ($t(23) = 2.0959$, $p<.05$) and amygdala ($t(23) = 2.89$, $p<.05$) (Figure 3). However, these positive signals were significantly reduced among HI participants in all 3 sites ($t(41) = 2.6206$, $p<.05$, $t(41) = 2.6711$, $p<.05$ and $t(41) = 3.0201$, $p<.05$, respectively) (Figure 3). This confirmed that impulsivity diminished, rather than enhanced, the neural signals previously linked to near-miss outcomes (Clark et al., 2009; Chase and Clark, 2010).

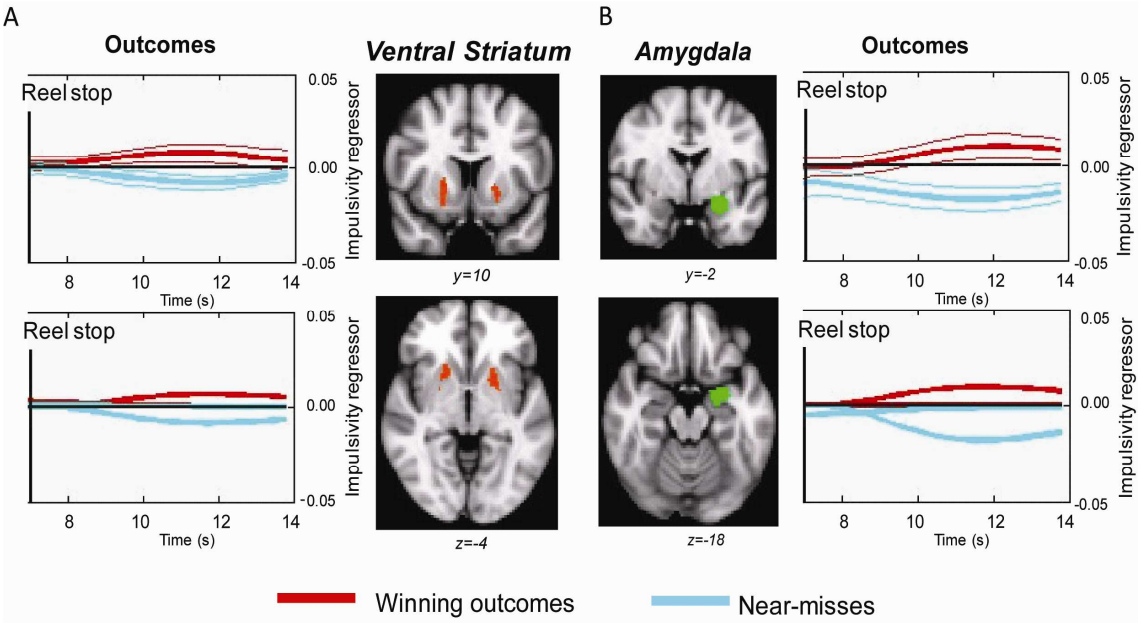


Figure 2. Timeseries plots of BOLD signals within 2 regions of interests (ROIs) constructed using I-7 scores as a covariate in the comparison between winning outcomes and near-misses (thresholded at Z=2.3, whole-brain cluster-corrected at p< .05). Timecourse signals show influence of I-7 score against the baseline on the BOLD responses to winning outcomes and near-misses. Coronal and axial slices are shown for both ROIs. MNI (Montreal Neurological institute) y coordinates are provided below the coronal slices and z coordinates below the axial slices. Upper plots: the regression coefficients of I-7 scores on % BOLD signal changes evoked by winning outcomes (indicated in red) and near-miss (indicated in cyan) outcomes (displayed for 7s following 'Reel stop'). Coefficient values are shown together with standard errors. Lower plots: the regression coefficients of I-7 scores on BOLD signals fitted to the HRF gamma model. An 'impulse' or phasic HRF and mean response latency of 6s was used. The ventral striatum is marked in red (**A**); the amygdala is marked in light green (**B**).

Furthermore, there was little evidence that the effects of impulsivity on the neural coding of winning and near-miss outcomes were significantly modulated by practice in either the ventral striatum or amygdala (Fs(1, 39) <=0.7) (Figure 4). This implied that the divergent coding of winning and near-miss outcomes represented a relatively stable feature of the way that game outcomes were encoded within reinforcement sites among high-impulsive individuals, rather than something that is only apparent during the early acquisition of slot-machine games.

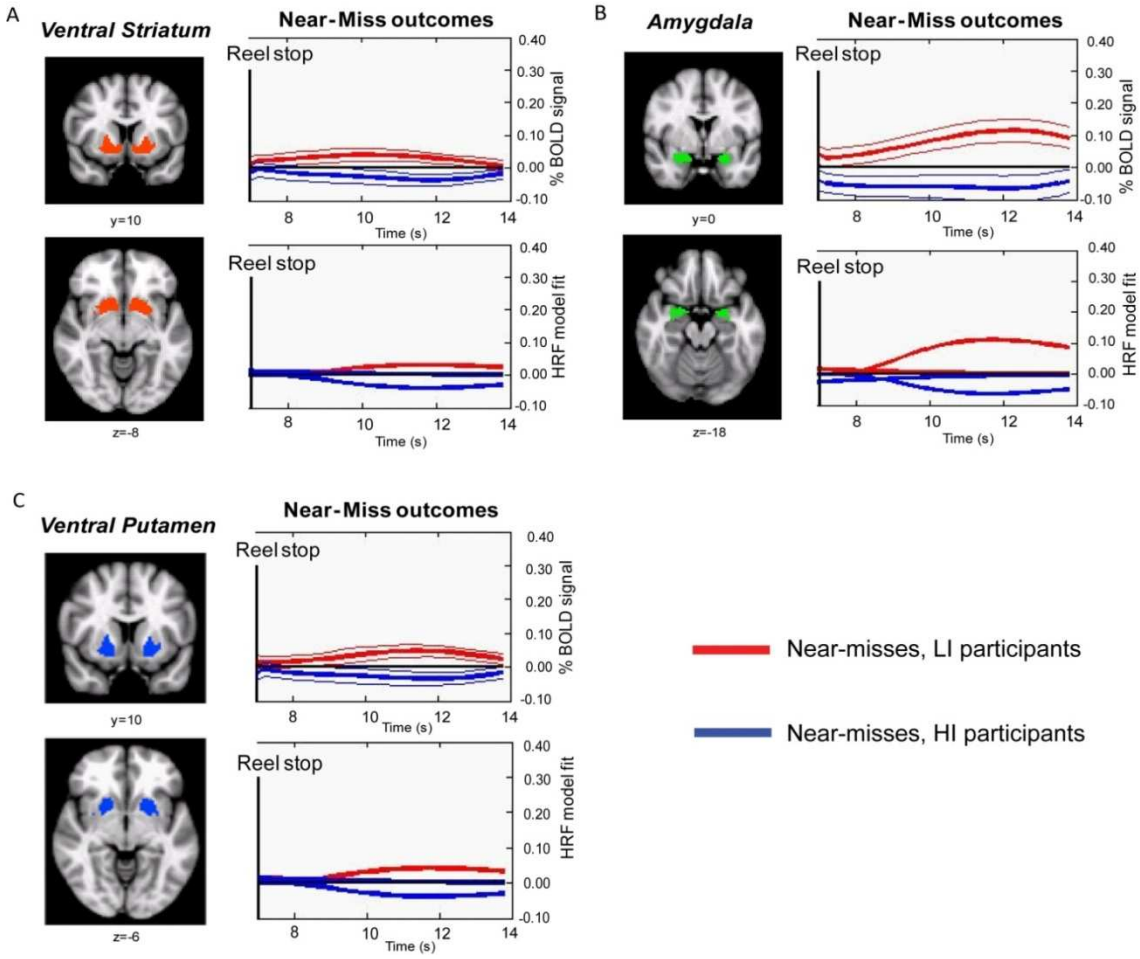


Figure 3. Timeseries plots of BOLD signals evoked by near-miss outcomes within the ventral striatum, amygdala and putamen among low-impulsive (LI) participants (11 practiced; 13 unpracticed) with I-7 scores equal or lower than 7 and in high-impulsive (HI) participants with scores higher than 7 (10 practiced; 9 unpracticed). The ROIs were identified using the orthogonal comparison of winning outcomes versus losing outcomes (Z-score> 3.09, cluster-thresholded at p< 0.05). Coronal and axial slices are shown for all 3 ROIs. MNI (Montreal Neurological institute) y coordinates are provided below the coronal slices and z coordinates below the axial slices. Upper plots: % BOLD signal changes evoked by near-miss outcomes (indicated in red for LI and blue for HI participants). Means % signal values (relative to baseline) are shown with standard errors. Lower plots: hemodynamic response function (HRF) gamma model used to fit the BOLD % signals. An 'impulse' or phasic HRF and mean response latency of 6s was used. The ventral striatum is marked in red (**A**); the amygdala in light green (**B**) and putamen in blue (**C**).

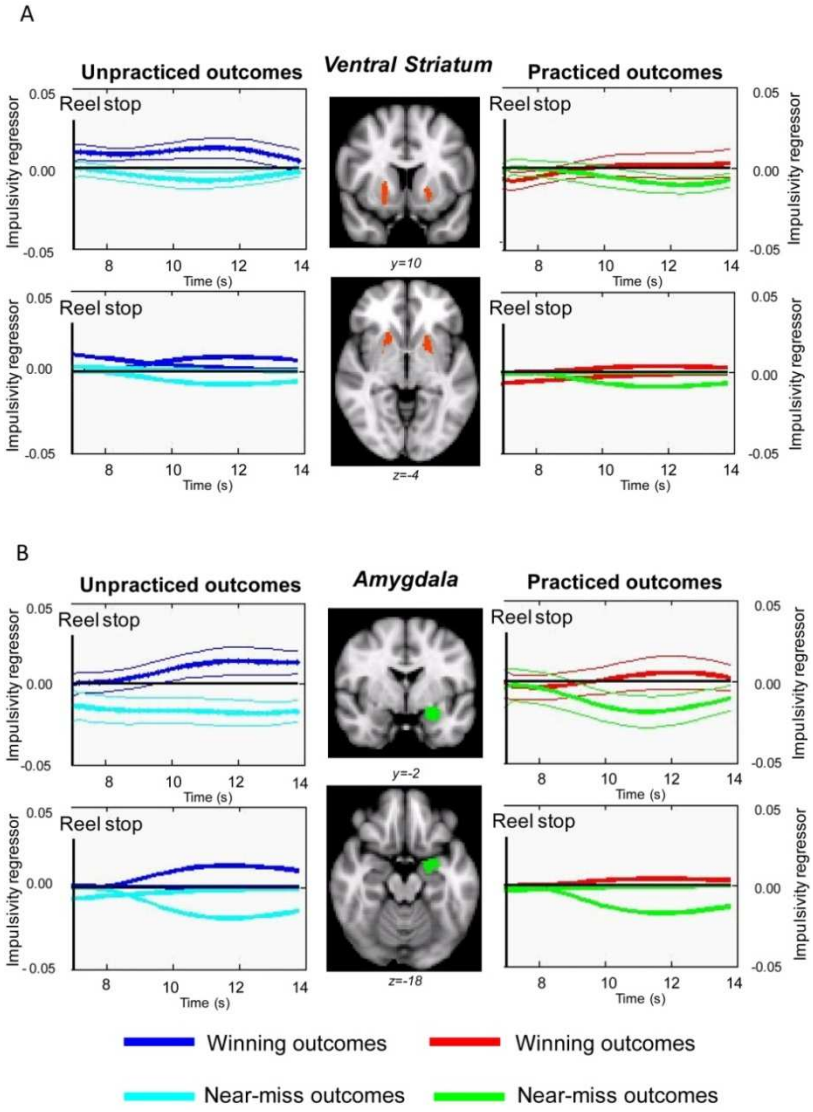


Figure 4. Timeseries plots of BOLD signals within 2 regions of interests (ROIs) constructed using the I-7 score (5, 6) as a covariate in the comparison between winning outcomes and near-misses (thresholded at Z= 2.3, whole-brain cluster-corrected at p< .05). Positive and negative signals show the influence of I-7 score on the BOLD signals associated with winning outcomes and near-misses, plotted separately for the 21 practiced and 22 unpracticed participants. MNI (Montreal Neurological institute) y coordinates are provided below the coronal slices and z coordinates below the axial slices. Upper plots: regression coefficients of I-7 scores on % BOLD signal changes evoked by winning (blue for unpracticed; red for practiced) and near-miss outcomes of the game (cyan for unpracticed and green for practiced participants) (7s duration following 'Reel stop'). Regression coefficients are shown with standard errors. Lower plots: the regression coefficients of I-7 scores on % BOLD signals fitted to the hemodynamic response function (HRF) gamma model. An 'impulse' or phasic HRF and mean response latency of 6s was used. The ventral striatum is marked in red (**A**); the amygdala is marked in light green (**B**).

Illusions of control, practice and near-misses We tested the effects of illusions of control, indicated by scores on the GBQ-IoC scale, on BOLD signals elicited during game play. GBQ-IoC scores had no influence over the average speeds at which participants initiated new plays ($F(1, 38) = 0.352$), and no interactive effects with previous outcome types ($F(2, 76) = 0.222$). The most apparent influence of GBQ-IoC scores on neural responses involved BOLD amplitudes elicited by the reel spins of the game immediately following winning outcomes compared to those following losing outcomes. This contrast identified a region of the anterior cingulate cortex (ACC) and bilateral insular cortex (thresholded at $Z>2.3$, cluster-corrected at $p<.05$) (Figure 5). Thus, the anticipatory signals within these regions after participants had just won compared to those after they had just lost showed positive correlation with participants' self-reported illusions of control, and we tested the influence of this cognitive bias on neural responses to slot-machine outcome events within these two brain structures.

We found a positive influence of the GBQ-IoC scores on the BOLD signals evoked by near-miss outcomes within the ACC among practiced participants only ($t(41) = 2.064$, $p<.05$) (Figure 5). In addition, the influence of GBQ-IoC scores on BOLD signals elicited by near-miss outcomes within the insular cortex was more positive in the practiced compared to the unpracticed group ($t(41) = 2.036$, $p<.05$) (Figure 5). Thus, greater illusions of control potentiated neural responses to near-miss outcomes among participants with more experience with the game compared to those without such experience in both the anterior cingulate cortex and the insular cortex.

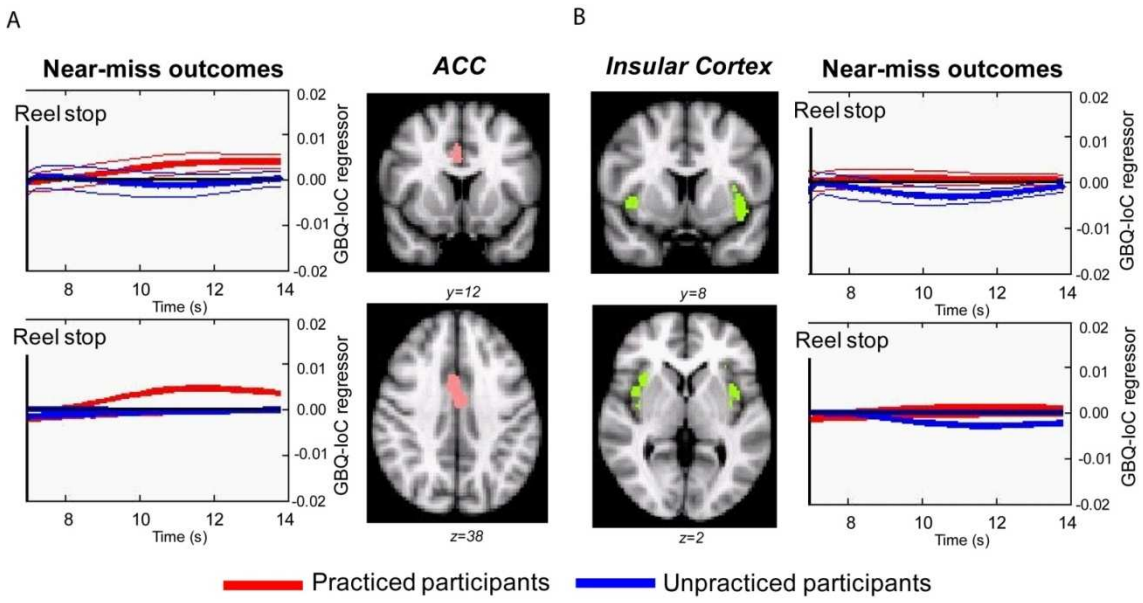


Figure 5. Timeseries plots of BOLD signals within 2 regions of interests (ROIs) constructed using GBQ-IoC scores as a covariate in the comparison between reel spins following winning outcomes and losing outcomes (thresholded at Z=2.3, whole-brain cluster-corrected at p< .05). Timecourse signals show influence of GBQ-IoC score against the baseline on the BOLD responses to near-miss outcomes. Coronal and axial slices are shown for both ROIs. MNI (Montreal Neurological institute) y coordinates are provided below the coronal slices and z coordinates below the axial slices. Upper plots: the regression coefficients of GBQ-IoC scores on % BOLD signal changes evoked by near-miss outcomes among the practiced (indicated in red) and unpracticed (indicated in blue) participants (displayed for 7s following 'Reel stop'). Coefficient values are shown together with standard errors. Lower plots: the regression coefficients of GBQ-IoC scores on BOLD signals fitted to the HRF gamma model. An 'impulse' or phasic HRF and mean response latency of 6s was used. The anterior cingulate cortex (ACC) is marked in pink (**A**); the insular cortex is marked in light green (**B**).

Discussion

In Experiment 2 we tested whether personality traits, such as impulsivity, and cognitive biases such as illusions of control, influenced neural responses while playing a slot-machine game. We found that impulsivity was associated with divergent coding of winning and near-miss outcomes within dopaminergic reinforcement circuitries, enhancing the positive signals elicited by winning

outcomes but suppressing signals evoked by near-miss outcomes within the ventral striatal areas and the amygdala. Stronger illusions of control were associated with greater BOLD responses to near-miss outcomes in regions of the ACC and the insular cortex among the practiced group compared to the unpracticed group.

Impulsivity influences BOLD signals to game outcomes Previous research show that high levels of impulsivity are associated with heightened gambling involvement (Steel and Blaszczynski, 1996), more severe gambling problems (Alessi and Petry, 2003) and worse treatment outcomes among pathological gamblers (Leblond et al., 2003). There is also evidence that high impulsivity at early adolescence predicts onset of gambling problems 3-4 years later (Vitaro et al., 1999). Moreover, other evidence suggests that there is a dopaminergic basis for both impulsivity and problem gambling (Dalley et al., 2007; Winstanley et al., 2004; Zack and Poulos, 2004, 2007).

However, little is known about how impulsivity influences behavioural responses to electronic gaming machine (e.g. slot-machine) outcomes, or their neural coding within reinforcement circuitries. Previous studies on slot-machine play suggest that response latencies following winning outcomes are longer than those following losing outcomes (Schreiber and Dixon, 2001). In Experiment 2, we found that high I-7 scores speeded the initiation of new slot-machine plays following winning outcomes, suggesting that impulsivity counteracts ‘post-reinforcement pauses’ in play (Delfabbro and Winefield, 1999) and facilitate

subsequent gambling participation by enhancing the reward value of gambling successes.

Impulsivity is linked to heightened BOLD responses to monetary rewards within the ventral striatum (Bjork et al., 2008; Hariri et al., 2006) and to the representation of delayed rewards within the amygdala (Winstanley et al., 2004). In rats, heightened levels of impulsivity and cocaine self-administration are associated with reduced dopamine transmission in the ventral striatum (Dalley et al., 2007), with additional evidence that infusion of dopamine antagonist into the shell and core subregions of the ventral striatum increases and decreases impulsivity, respectively (Besson et al., 2010). In humans, reduced midbrain D2/D3 receptors are associated with heightened psychometric scores of impulsivity and increased dopamine release following amphetamine challenge (Buckholtz et al., 2010). Our finding that impulsivity enhanced BOLD responses within the ventral striatum and amygdala, and speeded new game plays, following winning outcomes suggests that impulsivity enhances the reward value of gambling successes within mesolimbic dopamine systems, possibly promoting play in individuals vulnerable to gambling problems and cormorbid addictions (Potenza, 2008; Petry, 2001).

Our findings that impulsivity modulated BOLD responses to near-miss outcomes within the ventral striatum and amygdala are more challenging but still advance our understanding of the neural basis of slot-machine play in several ways. In Chapter 2, we concluded that near-miss outcomes in our slot-

machine game did not lead to significant positive BOLD signals within reinforcement circuitries, which finding was at odds with previous research showing that near-miss outcomes elicit activations in the ventral striatum (Clark et al., 2009; Chase and Clark, 2010). The results of Experiment 2, however, suggest that among the low-impulsive individuals, the experience of almost-winning can elicit positive BOLD signals (against baseline) within the ventral striatum and the amygdala (Clark et al., 2009). Our data also demonstrate that the positive reinforcement signals elicited by near-miss outcomes can be observed even in simple slot-machine games with relatively little player involvement that might foster 'illusions of control'. However, it is unlikely that near-miss outcomes operate simply or solely as 'mini-wins' or signals for imminent winning outcomes (Griffiths, 1991; Reid, 1986). If they did, impulsivity would have enhanced the positive signals evoked by their presentation, just as it did for winning outcomes. Here, we obtained the opposite finding that high impulsivity was associated with reduced BOLD responses to near-miss outcomes within the ventral striatum and amygdala.

There are several possible explanations for these observations. First, clinical reports suggest that near-miss outcomes prolong gambling episodes by inducing negative affective states such as frustration or cognitive regret (Reid, 1986; Clark et al., 2009). These states can be markedly enhanced in impulsive individuals such as those vulnerable to gambling problems (Griffiths, 1995b). One possibility is that aversive states triggered by near-miss outcomes are signalled by decreased activity within the reinforcement systems in high-impulsive individuals. On the other hand, aversive states have been linked to

heightened activity within the striatum and amygdala (Coricelli et al., 2005; Nitschke et al., 2006; Goldin et al., 2008). Aversive signals within the amygdala can also be diminished by cognitive re-appraisal (Goldin et al., 2008). Continued gambling frequently depends upon the ability of players to rationalise away gambling losses to legitimize further play (Toneatto, 1999; Raylu and Oei, 2004). Therefore, the attenuation of ventral striatum and amygdala signals following near-miss outcomes in high-impulsive participants may reflect the cognitively-mediated attenuation of aversive states or emotional reactions following near-miss outcomes.

Second, it is natural to suppose that players attempt to predict the occurrence of different game outcomes, including near-misses alongside winning outcomes, as part of the process of understanding the reinforcement contingencies underlying any given slot machine. Indeed, there is evidence that mistaken beliefs about such contingencies are more strongly held in problem slot-machine players (Delfabbro and Winefield, 2000). Other data indicate that salient aversive events generate positive BOLD signals within the ventral striatum, perhaps encoding the prediction errors that mediate aversive learning (Seymour et al., 2004), while monetary losses and their associated prediction errors may be encoded within the amygdala (Yacubian et al., 2006). This raises the possibility that impulsivity is linked to attenuated positively-signed prediction errors evoked by near-misses within the ventral striatum and amygdala, again potentially facilitating continued play.

It is also worth noting that there is recent evidence suggesting an inverted U-shaped relationship between novelty-seeking as measured by the Zuckerman Personality Scale (Zuckerman and Kuhlman, 2000) that was considered as closely related to impulsivity (Zuckerman, 1996), and dopamine receptor availability in striatal areas (Gjedde et al. 2010). This raises the possibility that there may exist a similar non-linear relationship between impulsivity and dopaminergic transmissions in the brain, under which scenario our findings on the influence of impulsivity on mesolimbic activities to winning and near-miss outcomes may not generalize to populations with more serious gambling problems whose impulsivity scores are likely to fall in the higher range compared to our current sample of non/infrequent gamblers (e.g. Alessi and Petry, 2003).

Illusions of control potentiate near-miss signals after practice Individuals who report heavy involvement in gambling, as well as gambling problems, frequently adopt a skill-oriented approach to gambling (Carol and Huxley, 1994; Griffiths, 1994), implicating high levels of illusions of control. Regular slot-machine gamblers also tend to perceive themselves as being more skilful on the game which is not supported by objective measures of performance (Griffiths, 1994). In this context, it is striking that findings of Experiment 2 show that participants who endorse higher levels of illusions of control, as measured by the GBQ-IoC scale, exhibit more positive signals to near-miss outcomes in a region of the ACC, provided that they had prior experience with the game. No influence of illusions of control was found in the same brain structure on neural responses to near-miss outcomes among participants who played the game for

the first time. Similarly, practiced participants showed more positive influence of illusions of control on BOLD signals elicited by near-miss outcomes in a region of the insular cortex compared to the unpracticed participants.

The ACC is widely connected with cortical and subcortical structures implicated in reinforcement learning and goal-directed behaviours, such as the striatum (Balleine, 2007) and the amygdala (Hampton et al., 2007). Functions that have been attributed to different sub-regions of the ACC include voluntary response selection (Frith et al., 1991; Walton et al., 2004), response-conflict resolving (Potenza et al., 2003a), action-outcome monitoring (Walton et al., 2004; Bush et al., 2002) and reward prediction-error signalling (Montague et al., 2004). It has also been suggested that the ACC plays important roles in integrating recent reinforcement histories in order to guide actions (Kennerley et al., 2006), and that it might be involved in deciding whether an action is worth taking based on its value and cost (Rudebeck et al., 2006). These roles of ACC may help to mediate decision-making in gambling contexts, whereby players constantly make decisions based on recent histories of winning (rewarding) and losing (punishing) outcomes.

The insular cortex has reciprocal connections with both amygdala and ventral striatum (Reynolds and Zahm, 2005), as well as the ACC. Paulus and Stein (2006) suggested that the insular cortex relays interoceptive information to the ACC which is influenced by the values of perceived stimuli. Both the ACC and the anterior insular cortex are activated when people evaluate the value of

current choices and decide upon subsequent actions (Hampton et al., 2006). In Clark et al. (2009), participants who are overall more susceptible to gambling biases as measured by the GRCS, and who report greater desires to continue playing following near-miss outcomes, show greater activations to near-misses within the anterior insular areas. It seems likely that, within the context of slot-machine gambling, the insular cortex plays a role in processing interoceptive emotional information in association with desires and urges to engage in further play behaviours.

We speculate that individuals who hold strong beliefs about control in gambling may also consider the near-miss outcomes positively reinforcing either as a result of learning erroneous associations between near-misses and wins through conditioning from previous play experience (Kassinove and Schare, 2001), or because they erroneously interpret near-miss outcomes as signalling improvements in play skill and imminent wins (Reid, 1986). In both cases, previous experience of game play is required, either to provide opportunities for the associative learning to take place, or to provide basis on which the false perception of skill improvement is formed. The activation of the ACC, in response to near-miss outcomes among practiced participants with strong illusions of control, might be the neural basis for the influence of this cognitive bias on participants' overestimation of the value of near-misses, which may, in real-life scenarios, influence people's gambling behaviours. Similarly, the insular cortex, which is reciprocally connected with the ACC and was found to represent action values (Hampton et al., 2006) and the associated interoceptive emotional information (Paulus and Stein, 2006; Clark et al., 2009), might assist

with the process underlying the influence of illusions of control through representing emotional arousals consequent to near-miss game outcomes.

In summary, the data from Experiment 2 show that impulsivity is associated with divergent coding of winning and near-miss outcomes, in particular attenuating the neural responses evoked by the experience of almost-winning in the ventral striatum and amygdala. Illusions of control had positive influence on neural responses to near-miss outcomes within the ACC only when participants had previous experience with the game. Practiced participants also showed more positive influence of illusions of control on BOLD signals evoked by near-miss outcomes in the insular cortex compared to the unpracticed participants. Collectively, these data demonstrate how personality traits and cognitive biases that confer vulnerability for gambling problems may interact with structural features of EGMs to enhance the likelihood of further play.

Experiment 3-5

The effects of winning and near-miss frequencies and their interaction on people's valuations of slot-machine games

Chapter IV–Experiment 3

Introduction

Among the different types of gambling activities, Electronic Gaming Machines (EGMs) such as slot machines have been identified as a kind that might be associated with heightened risks of harm, possibly relating to the games' structural characteristics (Griffiths, 1993a, 1995a). One of the most salient features of EGMs, in terms of their potential to increase gambling-related harm, is the delivery of 'near-miss' game outcomes, or a special kind of loss that is close to a win (Reid, 1986).

The near-miss effect on gambling As reviewed in Chapter 1, some experimental evidence suggests that the delivery of near-miss outcomes during gambling can facilitate continued play (Cote et al., 2003), at least when occurring at certain frequencies (Kassinove and Schare, 2001). Cote et al. (2003) found that participants played 33% more games on a slot-machine which delivered 25% of near-miss outcomes than on another machine which delivered no near-misses, even though neither machine delivered any wins. Kassinove and Schare (2001) took a step further by allocating participants to one of three

slot machines each delivering a different frequency of near-miss outcomes (15%, 30% or 45%). An inverse U-shaped relationship was observed between the frequency of near-miss outcomes and persistence of play, such that participants who played the 30% near-miss game showed the greatest persistence in a subsequent extinction phase involving no winning outcomes.

Near-misses act as 'mini-wins' There are several possible explanations for the near-miss effect. According to one view, near-miss outcomes may produce some of the excitement of wins and have the same kind of conditioning effect on behaviours as actual winning outcomes (Reid, 1986). Evidence consistent with this theory was reported by Griffiths (1991), who found that winning and near-winning outcomes produce similar elevations in arousal levels among pathological fruit machine gamblers.

It might be that near-miss outcomes naturally 'look like' wins because they bear great similarities to wins in appearance (i.e. stimulus generalization) (Pearce, 1987). As such, they are perceived as 'mini-wins' and have similar hedonic and motivational effects as real wins. If this was the case, people would perceive near-miss outcomes as close to wins without the need to make connections between them either through conditioning or through verbal association (see below).

Alternatively, near-miss outcomes might become conditioned to wins following sufficient pairing in previous play (Kassinove and Schare, 2001). According to the latter authors, the frequency of near-miss outcomes needs to be high enough to be paired with wins sufficiently often, but not too high so that the player realizes that near-miss outcomes have no real predictive value. Yet a third possibility is that people perceive near-miss outcomes as close to wins as a result of verbal associative processes. While studies have showed that recreational and regular gamblers rate near-miss slot-machine outcomes as closer to wins than losses (Dixon and Schreiber, 2004; Dixon et al., 2009; Habib and Dixon, 2010), such appraisal of near-miss outcomes could be altered through verbal association training, in which text materials such as ‘almost’ and ‘lost’ are associated with visual displays of slot-machine losing and near-miss outcomes, respectively (Dixon et al., 2009). This latter finding has the implication that the processing of near-miss outcomes is verbal, which might be acquired outside of gambling contexts (Daugherty and MacLin, 2007).

Some convergent evidence for the claim that near-miss outcomes act as appetitive cues is available from experiments on rats. Food-collecting responses were observed following near-miss outcomes delivered by a slot-machine-like device, despite that food stimuli were only delivered following wins. The response latencies following near-miss outcomes were also more similar to those following wins than other losses (Peters et al., 2010). In another recent study, rats responded to a series of three flashing lights, analogous to the reels of a slot machine (Winstanley et al., 2011). Rats showed higher frequency of food-collecting responses following both when two and three lights were lit,

which behaviour was influenced by the administration of the D_2 receptor agonist quinpirole, suggesting that the capacity of near-miss outcomes to potentiate gambling depends upon the dopaminergic neural reinforcement circuitries.

Near-misses induce negative affect and frustration According to another theory, near-misses may encourage further play by producing frustration and cognitive regret (Loftus and Loftus, 1983). Players tend to experience near-miss outcomes as both encouraging and frustrating (Reid, 1986), and Clark et al. (2009) observed on a simulated slot-machine game that near-miss outcomes were generally rated by recreational gamblers as aversive events that increased motivation to play. However, there is evidence that consecutive losing and frustration in gambling can indeed lead to termination rather than continuation of gambling activities (Dickerson et al., 1991), particularly among low-frequency gamblers (Dickerson, 1993), suggesting again that the particular frequency of near-miss outcomes is important in determining their effects on gambling behaviours.

Near-misses potentiate illusions of control According to a third theory, a near-miss may be taken as an encouraging sign, confirming the player's strategy and raising hopes for future success (Reid, 1986). This view is closely related to the concept of illusions of control (Langer, 1975), that the gambler experiences almost-winning as evidence for an improvement in personal skill (Griffiths, 1994) or perceived luckiness (Daugherty and MacLin, 2007). Although some researchers (e.g. O'Connor and Dickerson, 2003) argue that illusions of

control play a less role in games such as slot machines which are not traditionally considered as skill-based, others (e.g. Griffiths, 1994) suggest that regular slot machine players tend to consider the game as skill-oriented. For example, regular slot-machine players often have their ‘favourite’ machines and claim they can predict when the machine is going to pay out (Dickerson, 1993; Parke and Griffiths, 2006). Apparently, players also need to experience occasional wins for illusions of control to persist (Dickerson, 1993), consistent with the role of near-miss outcomes in highlighting future success. On this view, the near-miss outcomes encourage further play through acting as instrumental conditioned reinforcers, leading the players to believe future wins are imminent. This is different from the theory we described earlier, which proposes that near-miss outcomes act as appetitive cues after being paired (or conditioned) to wins through Pavlovian processes.

In Experiment 2 described in chapter 3, we found that participants’ scores on the illusions of control subscale of the Gamblers’ Beliefs Questionnaire were positively associated with BOLD signals in the anterior cingulate cortex and the insular cortex in response to near-miss slot-machine outcomes among practiced participants compared to unpracticed participants. We speculated that previous experience with the slot-machine game boosted the player’s sense of ‘knowing’ the game, and possibly their sense of control (either active or passive) (Langer, 1975), thus increasing the special predictive value of near-miss outcomes (Reid, 1986).

Testing the illusion of control effect on gambling behaviour As mentioned above, the illusion of control bias may play important roles in both EGMs and other forms of gambling activities. Illusion of control is defined as 'An expectancy of a personal success probability inappropriately higher than the objective probability would warrant' (Langer, 1975). Langer (1975) identified several factors which influence people's perceived illusions of control, such as personal choice, stimulus/response familiarity, involvement and competition. Players who experienced more wins in earlier phases of a gambling episode also tended to show stronger illusions of control than those experiencing similar numbers of wins in later phases (Langer and Roth, 1975).

Although a number of studies have been carried out previously on the effects of illusions of control on gambling behaviours (e.g. Dixon et al., 2007; Martinez et al., 2011), there remains a lack of well-controlled experiments on this phenomenon among samples of individuals with limited involvement in gambling activities. Specifically, at least three factors need to be controlled for when designing tasks for studying the effects of illusions of control. First, care needs to be taken to exclude any element of real control. While real opportunities to control gambling outcomes may be non-existent or negligible in certain types of gambling activities such as lottery play and dice-throwing, some levels of real skills and control may be present in games such as poker and sports betting. When studying the effects of illusory control, it is essential that the task is designed so that no real skill or control exists.

Secondly, when examining people's gambling behaviours under conditions affording different levels of perceived control, it is important to ensure that the conditions differ as little as possible on all other aspects. For example, in lottery play, some people might prefer the numbers they chose themselves over 'lucky-dip' because the numbers have special meanings for them, not because they believe that these numbers are associated with higher chances to win.

Thirdly, previous research has used different measures to assess the effects of illusions of control, such as verbal report (e.g. Griffiths, 1994), gambling-cognition questionnaires (e.g. Myrseth et al., 2010) and behavioural measures (e.g. Dixon et al., 2007), the latter further divided into betting behaviours (e.g. Martinez et al., 2011) and other types such as throwing dices softly for lower numbers and hardly for higher numbers (Henslin, 1967). It is thus important, when selecting the experimental measures, to ensure that they have face validity over illusions of control.

Based on the above discussions, we constructed 3 goals in Experiment 3. First, we wished to test how non-problem gamblers' valuations of a simple EGM, in this case a simple slot machine, are influenced by the frequencies of winning and near-miss outcomes in the most recent history of play. To date, no research has investigated how the influence of near-miss slot-machine outcomes on people's play behaviours depends on the reinforcement environment i.e. the frequency of winning outcomes. One way to study this is to ask participants to play a number of game rounds, each delivering certain numbers (and

frequencies) of winning and near-miss outcomes. Following each round, participants were invited to decide how many optional plays they wished to buy. We tested the hypothesis that near-miss outcomes would only increase players' valuations of the game, as indicated by the number of optional plays bought, if they occurred at certain frequencies and were accompanied by winning outcomes i.e. that there would be an interaction between the numbers of winning and near-miss outcomes on participants' valuations of the slot-machine game.

Second, previous experiments have looked at the effects of near-miss outcomes on gambling behaviour among non-problem gamblers (e.g. Cote et al., 2003) and pathological gamblers (e.g. Griffiths, 1991). However, relatively few studies have examined the psychometric correlates of the near-miss effect in contexts of slot-machine play. Thus, in Experiment 3 we tested whether participants' self-reported gambling-related cognitive biases and behavioural patterns predicted the influence of recent near-miss outcomes on their game valuations. In particular, we examined the associations between the influence of near-miss outcomes and illusions of control. We did this in 2 ways. First, we looked at whether the influence of near-miss outcomes on participants' valuations of the slot-machine game was associated with participants' scores on psychometric measures of illusions of control. We focused on 4 scales which measured cognitive constructs closely related to illusions of control: the illusion of control subscale of the Gamblers' Beliefs Questionnaire (GBQ) (Steenbergh et al., 2002), the predictive control, the illusion of control and the interpretative bias subscales of the Gambling-Related Cognitions Scale (GRCS) (Raylu and

Oei, 2004). Second, we tested whether the influence of near-miss outcomes was associated with participants' betting behaviours on a separate card-guessing game designed to assess illusions of control (see below).

Third, in Experiment 3 we aimed to develop a well-controlled gambling game which measures the effects of illusions of control. Our new game involves asking participants to find, among a row of 4 covered cards, a given card that was previously selected by either the player or the computer. In the condition which allowed a higher degree of perceived control (the 'self-choose' condition), the player chose the to-be-found card and decided which of the 4 covered cards would be that card. In the other condition (the 'computer-choose' condition), both these selections were performed by the computer. We used players' bet sizes as the behavioural measure for two reasons. First, the illusion of control bias is, by definition, related to players' confidence in winning the game and the amounts of money they would wager (Langer, 1975). Second, bet size is an important index of gambling that is closely related to the amount of total expenditure and chasing behaviours (O'Connor and Dickerson, 2003). Also, risk-taking in general is associated with a greater affinity for gambling and more gambling-related problems (Lejuez et al., 2002).

When testing the influences of near-miss and winning outcomes on participants' valuations of the slot-machine game, we focused upon not only the analyses of the *means*, but also the *trend* effects. This was because we were interested in examining the *broader pattern* of the influence of winning and near-miss

frequencies on people's game valuations, as expressed in their purchase of optional plays, which seemed to us an important step towards further understanding the relationship between EGM play and the game's structural features. In addition, individual participants' game valuations sometimes showed considerable variations within the play session due to factors other than the ones of primary research interests, thus increasing the total residual variance and making it difficult to obtain a significant effect upon the means.

Methods

This study was approved by the Central University Research Ethics Committee. All participants provided fully-informed written consent.

Subjects Forty-one adults (22 females) recruited from the University of Oxford and local community participated. Participants' mean age was 26.59 ± 1.32 years (range 19-55 years). The screening included assessment with a semi-structured SCID-I interview to ensure that none of the following exclusion criteria were met: i) major physical illnesses; ii) current or previous DSM-IV major mood or psychotic disorders; iii) current or previous DSM-IV substance abuse disorders. Participants were assessed with the National Opinion Research Centre DSM-IV Screening for Gambling Problems (NODS) and the South Oaks Gambling Screening Questionnaire (SOGS) to establish that none had any history of DSM-IV pathological or problem gambling episodes.

All participants were paid £25 plus travelling expenses, which amount comprised of base payments plus winnings from the task games (see below). Table 1 presents the demographic information and psychometric scores of participants.

	Age	SOGS	GBQ[1]	
			Luck/perseverance	Illusion of control
Males	26.58 ± 1.99	0.42 ± 0.14	30.42 ± 1.92	28.53 ± 1.85
Females	26.59 ± 1.82	0.00 ± 0.00	22.09 ± 1.75	21.91 ± 1.83
Total	26.59 ± 1.32	0.20 ± 0.07	25.95 ± 1.44	24.98 ± 1.39

	I-7	CHQ		
		Win-chasing	Loss-chasing	Near-miss-chasing
Males	7.95 ± 0.62	12.26 ± 1.11	9.11 ± 0.67	4.32 ± 0.30
Females	7.55 ± 0.83	9.05 ± 0.72	6.32 ± 0.14	3.18 ± 0.25
Total	7.73 ± 0.52	10.54 ± 0.68	7.61 ± 0.38	3.71 ± 0.21

	GRCS				
	Gambling Expectancy	Illusion of Control	Predictive Control	Inability to Stop	Interpretative Bias
Males	8.58 ± 1.11	5.95 ± 0.67	15.00 ± 1.24	5.53 ± 0.30	10.47 ± 0.87
Females	6.14 ± 0.72	5.27 ± 0.51	10.64 ± 1.01	5.36 ± 0.28	7.36 ± 1.04
Total	7.27 ± 0.66	5.59 ± 0.41	12.66 ± 0.85	5.44 ± 0.20	8.80 ± 0.72

Table 1. Demographic and psychometric scores (mean and standard error) of male and female participants. SOGS: South Oaks Gambling Screening (Lesieur and Blume, 1987). GBQ: the Gamblers' Beliefs Questionnaire (Steenbergh et al., 2002). CHQ: the Chasing Questionnaire (O'Connor and Dickerson, 2003). GRCS: the Gambling Related Cognitions Scale (Raylu and Oei, 2004).

Psychometric assessments Participants completed the South Oaks Gambling Screening Questionnaire (SOGS) (Lesieur and Blume, 1987) (range: 0-2, mean=0.20±0.07). Verbal IQ was assessed with the National Adult Reading Test (Nelson, 1982) (range: 105-125, mean=117.41±0.77). The present sample of participants no or very limited past or present involvement in gambling activities. Participants' scores on SOGS were mostly 0 and 1, with no one scoring higher than 2. Impulsivity was measured using the I-7 Impulsiveness

[1] Scores on the GBQ were inversely coded. See Methods section of Chapter 3.

scale (Eysenck and Eysenck, 1985). Participants were also assessed with the Gambling-Related Cognitions Scale (GRCS) (Raylu and Oei, 2004), the Chasing Questionnaire (CHQ) (O'Connor and Dickerson, 2003) and the Gamblers' Beliefs Questionnaire (GBQ) (Steenbergh et al., 2002) (Table 1). Detailed descriptions of the GBQ were included in chapter 3 earlier. The inter-correlations of participants' scores on these gambling-related questionnaires are presented in Table 2.

CHQ The chasing questionnaire measures a composite of cognitive (e.g. 'I thought I would like to continue betting'), emotional (e.g. 'I felt an urge to continue betting') and behavioural (e.g. 'I continued betting ') components of chasing in relation to heavy wins and losses (O'Connor and Dickerson, 2003). The questionnaire also includes assessment of chasing behaviours following near-miss outcomes. Respondents rate the extent to which the statement describes how they feel on a 5-point Likert scale ranging from 1 ('Occasionally') to 5 ('Almost Always'). Higher scores indicate more chasing-related thoughts, urges and/or behaviours. Chasing in EGM players as measured by CHQ was related to their total gambling expenditure and time spent on gambling, as well as impaired control among these gamblers (O'Connor and Dickerson, 2003). In particular, chasing after near-misses was shown to strongly correlate with impaired control in EGM gamblers (O'Connor and Dickerson, 2003).

GRCS The GRCS is a 23-item questionnaire comprised of five subscales, each measuring a different aspect of gambling cognition: *gambling expectancy* that

assesses positive expectations about the effects and consequences of gambling (e.g. ‘Gambling makes me happier’), *illusions of control* that assesses erroneous beliefs about control in gambling based on superstitious rituals and special objects (e.g. ‘Praying helps me win’), *predictive control* that assesses beliefs in the ability to predict future gambling events (e.g. ‘Losses when gambling are bounded to be followed by a series of wins’), *inability to stop* that assesses cognitive dysfunctions reflecting difficulties in stopping gambling (e.g. ‘I can’t function without gambling’) and *interpretative bias* that assesses the tendency to interpret gambling successes to personal skills/knowledge and losses to external factors (e.g. ‘Relating my winnings to my skill and ability makes me continue gambling ‘) (Raylu and Oei, 2004). Respondents indicate how much they agree with each item or statements by giving ratings on a 7-point Likert scale ranging from 1 (‘strongly disagree’) to 7 (‘strongly agree’). Higher scores indicate greater gambling-related cognitive biases. All the subscales of the GRCS show good internal consistency (Raylu and Oei, 2004). However, evidence for test-retest reliability of the GRCS was relatively lacking (Raylu and Oei, 2004). Each subscale of the GRCS also correlates significantly with all other subscales and the total score, which might be accounted for by some higher-order factor of ‘gambling cognition’ (Raylu and Oei, 2004). Both the total score and the subscales of GRCS predicted scores on SOGS (Oei et al., 2008), and GRCS scores predicted relapse among gambling anonymous members (Oei and Gordon, 2008).

	I-7	SOGS	GB1	GB2	LCW	LCL	LCNM	GRCS-GE	GRCS-IC	GRCS-PC	GRCS-IS	GRCS5-IB
I-7	1	.149	.145	.057	.271	.194	.069	.148	-.101	-.008	-.105	-.063
SOGS	.149	1	.429*	.423*	.447*	.178	.304	.527*	.31	.292	.221	.31
GB1	.145	.429*	1	.759*	.478*	.206	.426*	.491*	.528*	.584*	.347*	.529*
GB2	.057	.423*	.759*	1	.423*	.202	.321	.38*	.299	.473*	.354*	.388*
LCW	.271	.447*	.478*	.423*	1	.474*	.671*	.286	.113	.403*	.24*	.334*
LCL	.194	.178	.206	.202	.474*	1	.681*	.17	-.07	.197	.139	.245
LCNM	.069	.304	.426*	.321	.671*	.681*	1	.237	.019	.384*	.228	.541*
GRCS1-GE	.148	.527*	.491*	.38*	.286	.17	.237	1	.588*	.472*	.403*	.53*
GRCS2-IC	-.101	.31	.528*	.299	.113	-.07	.019	.588*	1	.474*	.515*	.468*
GRCS3-PC	-.008	.292	.584*	.473*	.403*	.197	.384*	.472*	.474*	1	.231	.752*
GRCS4-IS	-.105	.221	.347*	.354*	.24*	.139	.228	.403*	.515*	.231	1	.257
GRCS5-IB	-.063	.31	.529*	.388*	.334*	.245	.541*	.53*	.468*	.752*	.257	1

Table 2. The correlation matrix of participants' scores on the gambling-related psychometric measures. SOGS: South Oaks Gambling Screening (Lesieur and Blume, 1987). GB1: the luck/perseverance subscale of the Gamblers' Beliefs Questionnaire (Steenbergh et al., 2002). GB2: the illusion of control subscale of the Gamblers' Beliefs Questionnaire. LCW: the win-chasing scales of the Chasing Questionnaire (O'Connor and Dickerson, 2003). LCL: the loss-chasing scales of the Chasing Questionnaire. LCNM: the near-miss-chasing scales of the Chasing Questionnaire. GRCS-GE: the gambling expectancy subscale of the Gambling Related Cognitions Scale (Raylu and Oei, 2004). GRCS-IC: the illusion of control subscale of the Gambling Related Cognitions Scale. GRCS-PE: the predictive control subscale of the Gambling Related Cognitions Scale. GRCS-IS: the inability to stop subscale of the Gambling Related Cognitions Scale. GRCS-IB: the interpretability bias subscale of the Gambling Related Cognitions Scale.

Design All participants completed 2 games. The first game was a simple 3-reel slot machine with 1 pay-line. The slot machine game consisted of a total of 60 rounds. Each round consisted of 2 parts: i) 6 compulsory plays with a variable-ratio (VR) of 6 for winning outcomes and a VR of 5 for near-miss outcomes and ii) optional plays in which the VRs for winning and near-miss outcomes were also set as 6 and 5, respectively. Participants paid 90 credits per play, or a total of 32,400 credits for all the compulsory plays, and won back 30,000 credits in total from those plays (a return-to-player of 92.6%). The second game was an illusion-of-control card-guessing game consisted of 60 plays in total, out of which 16 ended with winning outcomes (VR = 3.75) (see below).

Computer-simulated slot-machine game The slot-machine game was designed and implemented using Presentation v. 14.5 software (Neurobehavioral Systems, San Pablo, USA). As in conventional slot-machine games, the display consisted of 3 horizontal reels showing fruit symbols (Figure 1). Players' credits were displayed at the top; they started each round of the game with 1200 credits. The prizes associated with different reel combinations were also shown towards the right side of the display. In this game, all winning outcomes gave a standard prize of 500 credits. Players completed 60 rounds of 6 plays. Each round contained 0, 1 or 2 winning outcomes and 0, 1 or 2 near-miss outcomes, forming 9 different types of round structures, plus 1 extra type containing 1 winning outcome and 3 near-miss outcomes. This latter type was added to make the variable ratios for winning and near-miss outcomes 6 and 5,

respectively, as described above. Each type of rounds was repeated 6 times, and the rounds were presented in random orders (Figure 1).

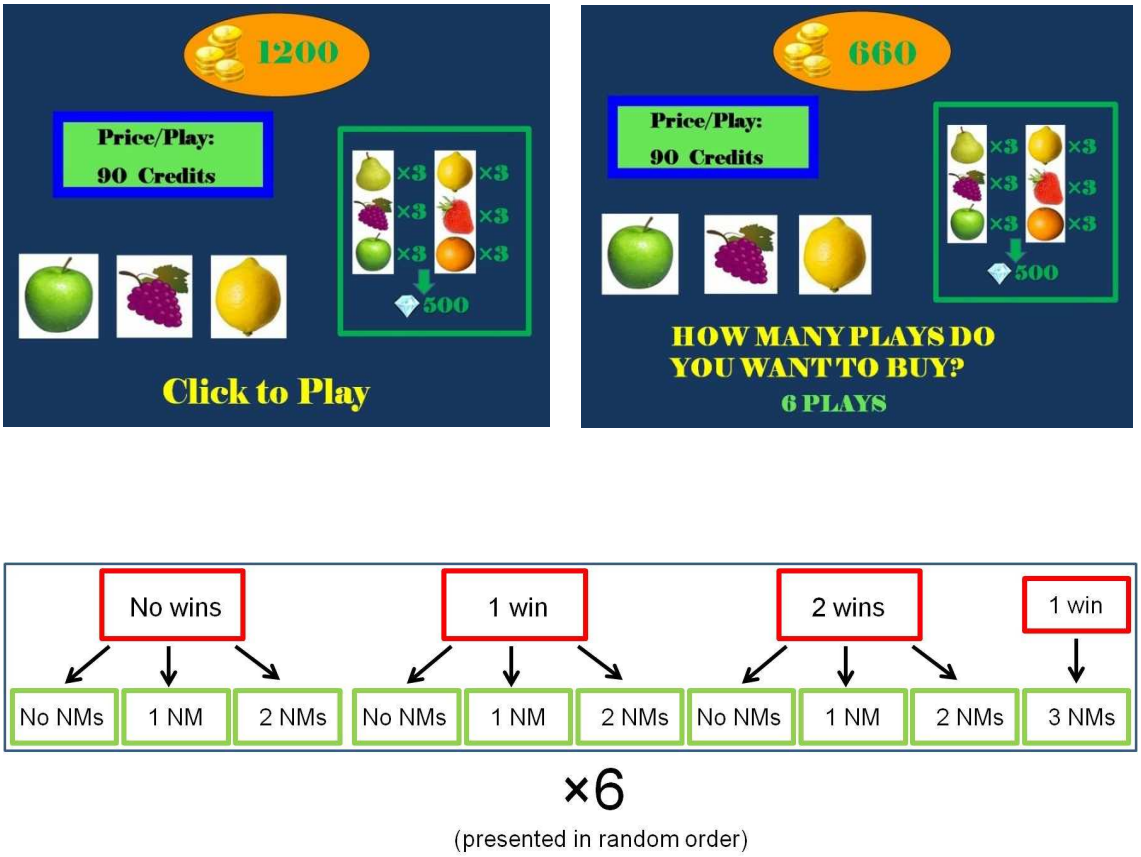


Figure 1. **The computer-simulated slot-machine game**. Upper left: The game display showed the remaining credits for the current round, the price for each play, the winning combinations of fruits symbols, the three fruit reels and the text “Click to play”. After a clicking response was made on the left mouse button, the reels started to spin at a frequency of 20Hz. The reels stopped sequentially from left to right with a variable latency of 1-1.5 seconds between each stop and reveal the outcome, which held on the screen for a fixed 3 seconds for wins, or a fixed 1 second for near-misses and losses. The next play immediately followed the outcome of the previous play. Upper right: In each round after completion of the 6 compulsory plays, participants were provided with the opportunity to decide how many optional plays to buy (ranging from 0 to 6), indicated by pressing the space bar for buying 0 or one of the number keys from 1 to 6 on the keyboard. After a buying response was made, it appeared briefly on the bottom of the screen. Participants then either proceeded straight to the next round (if the decision was to buy 0 optional plays) or continued with the optional plays (if the decision was to buy more than 0 plays) before going into the next round. Bottom: The round structure of the slot-machine game based on the factorial design investigating the effects of winning, near-miss outcomes and their interaction on participants’ game valuations. NM: near-miss outcomes. See text for more information.

Participants pressed the left mouse button with their right hand to start each reel spin, following which the fruit symbols in all 3 reels changed randomly with a frequency of 20Hz (i.e. each fruit held its position for 50ms during spin). The reels stopped sequentially from left to right with variable latencies of 1-1.5 seconds between each stop and revealed the outcome. If the reels displayed 3 identical fruits in a row, participants won a standard reward of 500 credits (all 6 fruit symbols were shown with an equal probability). Near-miss outcomes were implemented as those in which the first two reels showed the same fruit while the third reel showed a different fruit. All other outcomes were counted as losses (near-miss outcomes in the forms of ABB or ABA never occurred, so all losing outcomes involved 3 different symbols). Winning outcomes were displayed on the screen for 3s. Near-miss and loss outcomes were shown for 1s. Each play outcome was followed immediately by the next play display.

Following the completion of 6 compulsory plays in each round, participants were offered the opportunity to ‘bank’ the remaining credits and proceed straight to the next round, or to use some of those credits to buy some optional plays with the hope of winning more prize (Figure 1). If participants decided not to buy any optional plays (by pressing the space bar on the keyboard), then all the remaining credits in the current round would be transferred to the ‘bank’ and added to the player’s total score which was to be cashed at the end of experiment. If the player decided to buy some numbers of optional plays (by pressing the number key 1, 2, 3, 4, 5 or 6), the cost of these plays at 90 credits per play would be subtracted from the remaining credits, and participants gained the chance of completing the optional plays before proceeding to the

next round. Participants were informed that the whole game would finish after a fixed (unknown) number of rounds. They were also told that the total score at the end of game, comprised of the credits in the ‘bank’ and the total prize sum, would be converted to real money based on comparison with other players and paid to them as part of their experimental fee. During the course of the game, this accumulated credit score was not visible to the player.

Computer-simulated card-guessing game The card-guessing game was designed and implemented using Presentation v. 14.5 software (Neurobehavioral Systems, San Pablo, USA) (Figure 2). Each game display consisted of two rows of cards and an array of keys for placing bets on the outcomes. Participants were given 1,300 credits at the start of game and completed a total of 60 plays, each randomly allocated to 1 of 2 different conditions (see below). Participants were told that both rows consisted of the same four cards. However, the cards in the top row were always visible and their relative spatial positions did not change, whereas the cards in the lower row may appear in different positions as participants moved from play to play, and through shuffling (see below).

On the self-choose plays, participants first selected one card as the target from the top row, which would then be marked with a green border. Card selection was achieved by moving the mouse cursor to the card and clicking the left

mouse button. The player then shuffled the lower row of face-down cards by pressing down the left mouse button for as long as he/she wanted the shuffling to last, and releasing the button when he/she wanted to terminate the shuffle. Card shuffling was displayed as an animation in which neighbourhood cards constantly swapping their positions. Next, participants picked one card from the lower row to match the card that was selected from the top row, and this card was also marked with a green border. Next, participants decided how many points to bet on the outcome by pressing the arrow buttons to increase or decrease their stake. Stakes ranged from a minimum of 3 points to a maximum of 60 points. Each arrow-button pressing led to an increase or decrease of 6 points. Finally, participants clicked the 'OK' button to reveal the outcome, which was displayed for 2s.

The number of points won with successful card matches was normally 6 times the stake, and the number of points lost with unsuccessful matches was twice the stake. However, there were 4 'bonus' plays in which the winning amounts were doubled (i.e. 12 times the stake) while losses remained the same. This was to measure players' behaviours in situations that were potentially more profitable, and offered a further test of the validity of the game. Bonus plays were inserted at fixed times in the game, and were notified to the player by a 'beep' sound and the text 'BONUS' in red displayed on the top-right of the screen. Unknown to participants, the self-choose plays delivered 8 winning outcomes, which were distributed randomly across the play sequence.

On the computer-choose plays, participants saw a similar game display, but one card from the top row was already marked by the green border, indicating the target card chosen by the computer. Participants then clicked this marked card to start the shuffle of the lower row of face-down cards. After the shuffle was completed, the computer chose one card from the lower row marked again with the green border, and participants had to follow this by clicking that card. The only decision that the participants made in this condition was the bet, with the stake and pay-offs bearing exactly the same values as in the self-choose condition. The computer-choose condition also contained 4 bonus plays and delivered 8 winning outcomes.

Participants were told that the total number of points they finished up with would be converted to real money based on comparisons with other players and paid to them as part of the total experimental fee. Unknown to participants, however, they were always paid £25 which covered the prize money for both the slot-machine game and the card game. Participants' updated total points were displayed on the upper-left of the screen throughout the card game.

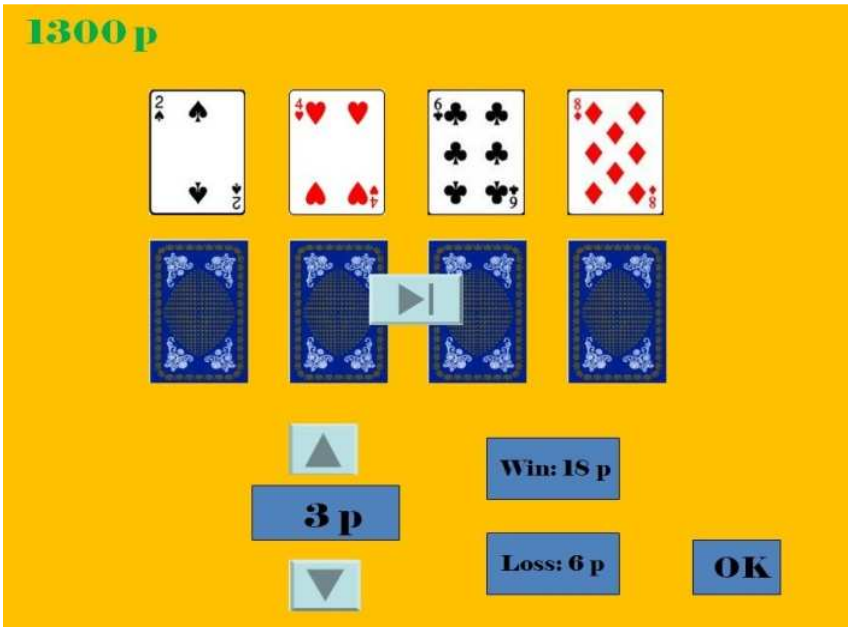


Figure 2. The computer-simulated card-guessing game. The game display consisted of two rows of cards (a spade 2, a heart 4, a club 6 and a diamond 8 in the top row, 4 covered cards in the middle row with an overlaid arrow button) and a lower part with buttons where bets were placed. In the self-choose condition, players chose one card from the top row, shuffled the middle row and picked one card from the middle row to match the card chosen from the top row. In the computer-choose condition, the computer decided which cards were selected from the top and the middle rows and performed the shuffling. The player always decided how many points to bet (the stake), either on their own decisions or on the computer's, using the arrow buttons to increase or decrease the stake. Points that were won or lost were fixed multiples of the stake. See text for more information.

Procedure On study day, Participants arrived at the University Department of Psychiatry and completed the screening as described above. Following the completion of the psychometric tests, participants were taken into the computer room and played the two games. All participants played the shorter card game first (about 20 mins) before the longer slot-machine game (about 50 mins). This was to minimize possible fatigue effects on participants' play behaviours. After both games were completed, participants were debriefed and filled out a payment form before leaving.

Statistical analyses Experiment 3 was intended to test how the (relative) frequency of winning and near-miss outcomes in slot-machine game rounds influenced players' valuations of the game, as indicated by their purchasing of optional plays, and whether these effects were associated with psychometric and laboratory measures of gambling-related cognitive biases and behavioural patterns, in particular illusions of control.

Slot-machine data analyses The analyses of slot-machine data were completed in 2 stages. First, the numbers of optional plays bought were analysed using a repeated-measures ANOVA with the numbers of winning (0, 1 or 2) and near-miss (0, 1 or 2) outcomes as within-subjects factors and gender as a between-subjects factor. Simple-effects ANOVAs were performed to test individual contrasts where applicable. Second, at the single-participant level, the numbers of optional plays were regressed against the numbers of winning and near-miss outcomes, plus their interaction term (win × near-miss)[2]. The sequence number of individual rounds (1 to 60) was also included as a predictor variable in order to account for effects due to participant fatigue and boredom. At the group level, participants' regression coefficient beta values were then regressed against their gambling-related psychometric scores, controlling for potentially confounding variables such as age and IQ. Moreover, in order to seek for common constructs underlying participants' play behaviours on both games, the regression coefficient beta values obtained from slot-machine data

[2] In a linear regression model with variables win, near-miss and their interaction term win × near-miss, the unstandardized coefficient beta value for win is the estimate of the influence of win when the number of near-miss equals 0, provided that the data set includes instances where the number of near-miss indeed equals 0. The same principle applies for the coefficient value of near-miss (Everitt, 1997).

analyses were also regressed against participants' betting ratios in the card game (see below).

Because the win × near-miss interaction term naturally correlate positively with both individual variables of winning and near-miss frequencies at the single-participant level, the coefficient beta values associated with the influence of win × near-miss interaction would often correlate negatively with the beta values associated with the individual influences of winning or near-miss frequency at the group level. This would mean that, at the group level**, the relationships between the beta values associated with the interactive effect of winning and near-miss frequencies and participants' psychometric scores would often be of the opposite sign to the relationships between the beta values associated with the individual influences of winning or near-miss frequency and the psychometric scores.** Since the coefficient values for the win × near-miss interactive effect contain overlapping information about how participants' buying behaviours were influenced by different outcomes as the coefficient values for the individual effects of winning or near-miss frequency, **we only focused on the association between the interactive effect and participants' psychometric scores in the group-level analyses.** Similar approaches were adopted when analysing data from Experiment 4 and 5 (see Results section of Chapter 5 and 6).

Card-game data analyses Participants' bet sizes in the self- and computer-choose conditions were analysed using a repeated-measures ANOVA with

condition (self-choose vs. computer-choose) and bonus (2 levels) as within-subjects variables and gender as a between-subjects variable. We also compared participants' bet sizes in the 2 game conditions by performing one-sample t-tests on the betting ratios, calculated as the player's averaged bet size in the self-choose condition divided by the averaged bet size in the computer-choose condition. Betting ratios that were significantly greater than 1 suggested overall larger bet size in the self-choose compared to the computer-choose condition.

Finally, regression analyses were performed between the betting ratios and participants' gambling-related psychometric scores, and between the betting ratios and the regression coefficient beta values obtained from the slot-machine data analyses (see above). Significance level was set as $p<.05$ for all statistical tests.

Results

Psychometrics Details of participants' scores on the gambling-related questionnaires are shown in Table 1. In general, participants reported only infrequent and limited involvement in gambling activities, which were confined to poker/card games, sports-betting, horse-betting, slot machines, lottery/scratch card, and occasional visits to the casino.

Slot-machine buying behaviour

ANOVA Five participants (2 females) were excluded from the slot machine data analyses due to zero optional play buying following every game round, leaving 36 participants. The mean number of optional plays bought showed considerable inter-subject variability, ranging between 0.45±0.19 and 4.63±0.11. Figure 3 shows the numbers of optional plays participants decided to buy, expressed as integers from 0 to 6 and averaged across all participants, following the 9 different combinations of winning and near-miss outcomes (0, 1 or 2 wins × 0, 1 or 2 near-misses). This figure also shows the standard error of the difference on the means, calculated according to the formula $\sqrt{MSE/n}$, where MSE = mean square of the error term and n equals the total sample size (i.e. 36) (Cochran and Cox, 1957). Overall, neither the frequency of winning outcomes or near-miss outcomes significantly influenced the *mean* number of optional plays bought, ($F(2, 68) = 2.248$, $p>.1$ and $F(2, 68) = 0.02$, $p>.1$, respectively). There was also no significant interactive effect of the numbers of winning and near-miss outcomes on the *mean* number of optional plays bought ($F(4, 136) = 1.22$, $p>.1$).

However, within-subjects contrasts tests showed that the influence of winning and near-miss outcome frequency on participants' purchasing behaviour followed different trends, characterised by a significant linear trend for near-miss frequency overlaid with a significant quadratic trend for win frequency ($F(1, 34) = 6.064$, $p<.05$). Inspection of Figure 3 indicates that while 1 or 2 near-miss outcomes led to larger numbers of optional plays bought than 0 near-miss

outcome in game rounds with 1 winning outcome, no such positive effect of near-miss outcomes was present for game rounds with either none or 2 winning outcomes. Analyses of simple effects confirmed that the number of near-miss outcomes had a significant linear trend effect on the number of optional plays bought when the round contained 1 winning outcome ($F(1, 34) = 4.822$, $p<.05$), but not when it contained 0 or 2 winning outcomes (ps>.1).

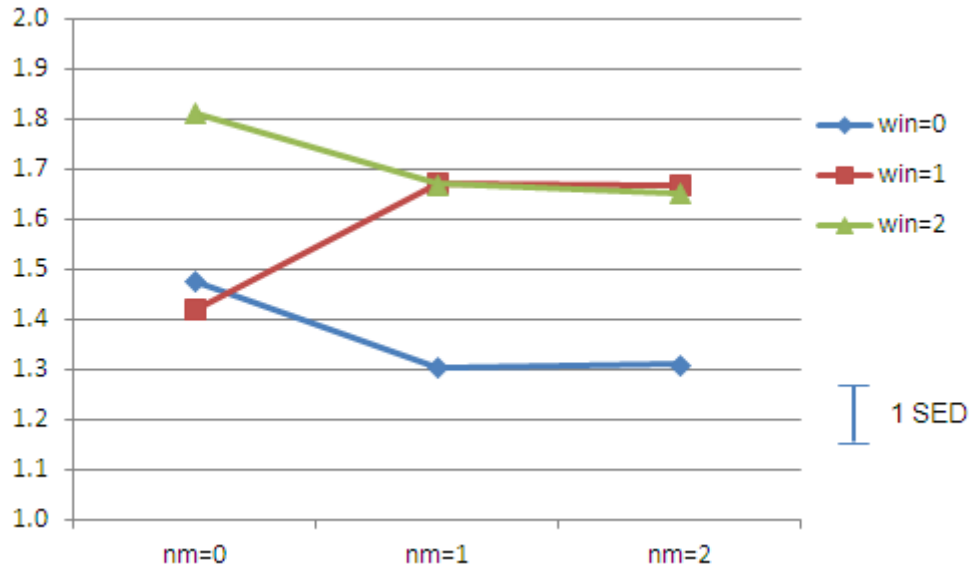


Figure 3. The number of optional plays participants chose to buy immediately following rounds containing different numbers of winning (0, 1 or 2) and near-miss (0, 1 or 2) outcomes. nm: near-miss outcome. 1 SED represents one standard error of the difference on the means for the win × near-miss interaction effect, calculated according to the formula √MSE/n, where MSE = mean square of the error term and n equals the total sample size (i.e. 36) (Cochran and Cox, 1957).

Multiple linear regression analyses Unstandardized coefficient beta values were obtained by regressing the numbers of optional plays bought against the frequencies of winning, near-miss outcomes and their interaction. Some of these beta values (see below) were then regressed against participants' gambling-related psychometric scores, controlling for factors of age and IQ.

Particular attention was paid to the illusion of control subscale of GBQ and the illusion of control, predictive control and interpretative bias subscales of GRCS. As explained in the Methods section, we focused on the associations between beta values representing the interactive influence of winning and near-miss frequencies upon purchasing behaviour and participants' psychometric scores.

The interactive effects of the frequencies of winning and near-miss outcomes were positively associated with the strength of participants' beliefs that gambling success could be predicted as measured by the GRCS predictive control subscale (β=.026, $t(32) = 2.242$, $p<.05$) (Figure 4). This association remained significant even after controlling for the additional factor of the numbers of gambling activity types participants had previously engaged in (β=.025, $t(31) = 2.086$, $p<.05$). The extent to which the influence of near-miss outcomes depended positively on the frequency of winning outcomes also showed near-significant positive association with participants' levels of illusion of control as measured by the illusion of control subscale of GBQ (β=.015, $t(32) = 1.801$, $p=.081$). The win × near-miss interactive effects were not associated with participants' scores on the illusion of control or interpretative bias subscales of GRCS ($p>.1$).

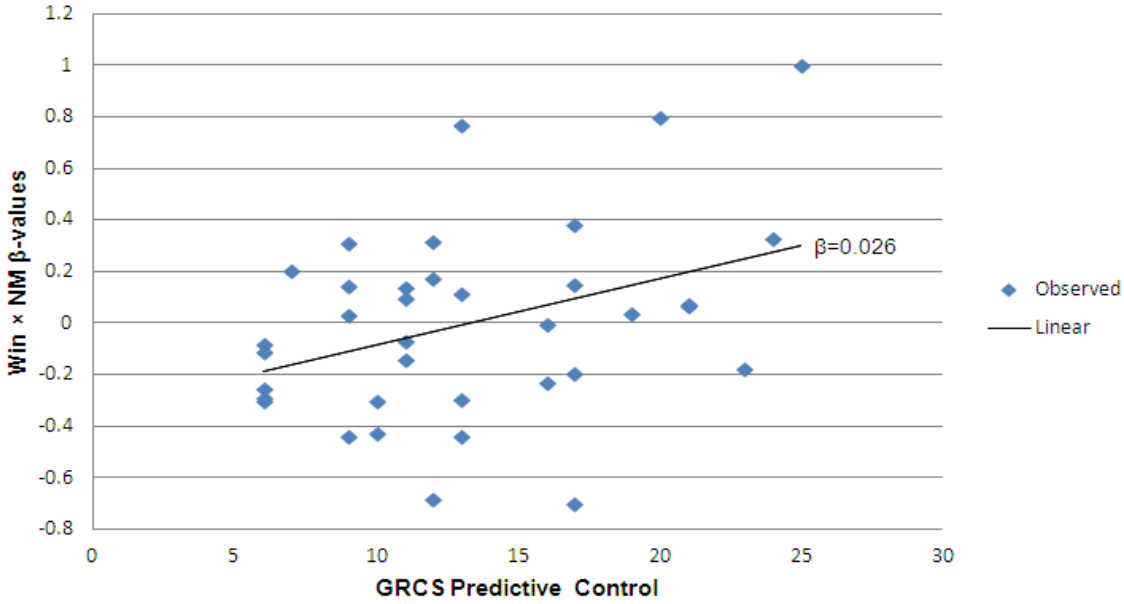


Figure 4. The association between the influence of win × near-miss interaction on the number of optional plays bought, expressed as unstandardized regression coefficient beta values, and participants' scores on the predictive control subscale of GRCS. NM: near-miss outcomes.

Card-game betting behaviour

ANOVA All 41 participants were included in the card game data analyses. Participants' averaged bet sizes in the self- and computer-choose conditions of the card game are shown in Table 3. Bet sizes are shown separately for the bonus and the non-bonus plays. Participants placed significantly larger bets when they were allowed to choose the cards compared to when the computer made the card choices ($F(1, 39) = 7.126$, $p<.05$). They also betted higher amounts in the bonus plays compared to the non-bonus plays ($F(1, 39) = 25.614$, $p<.05$).

Similar results were obtained using one-sample t-tests on the betting ratios, calculated by dividing participants' bet sizes in the self-choose condition by their

bet sizes in the computer-choose condition. We found betting ratios that were significantly greater than 1 in both the bonus (mean = 1.17, SE = 0.07, t (40) = 2.437, p<.05) and non-bonus (mean = 1.27, SE = 0.08, t (40) = 3.468, p<.05) plays, and in all plays combined (t (40) = 3.483, p<.05).

	All Plays	Bonus Plays	Non-bonus plays
Self-choose	15.81 ± 2.04	26.82 ± 3.13	14.33 ± 2.04
Computer-choose	13.58 ± 1.97	25.09 ± 3.13	12.05 ± 1.98

Table 3. Participants' bet sizes in different types of plays (bonus vs. non-bonus) and in different control conditions (self-choose vs. computer-choose). Both the means and the SEs are shown.

Regression analyses We performed similar regression analyses between participants' betting ratios in the card game and their gambling-related psychometric scores, controlling for potentially confounding variables of age and IQ. Illusions of control, expressed as the betting ratio in the self-choose compared to the computer-choose condition, showed near-significant positive association with participants' scores on the interpretative bias subscale of GRCS (β=.024, t (37) = 1.832, p=0.075), but no significant associations with scores on the illusion of control subscale of GRCS, the predictive control subscale of GRCS or the illusion of control subscale of GBQ (ps>.1). The betting ratios based on bonus plays only also showed near-significant positive association with participants' scores on the interpretative bias subscale of GRCS (β=.029, t (37) = 1.932, p=0.061).

Finally, in order to establish a link between participants' buying behaviours on the slot-machine game and their betting behaviours on the card game, we regressed the coefficient beta values from the slot-machine data against the betting ratios from the card game. Participants for whom the influence of near-miss outcome frequency on purchasing behaviour depended more positively on the frequency of winning outcomes showed a near-significant tendency to place much larger bets when they chose the cards compare to when computer chose the cards in the card game (β=.302, t (32) = 1.799, p=.082).

Discussion

An overview of results In Experiment 3, we tested whether the frequency of near-miss slot-machine outcomes interact with the frequency of winning outcomes to jointly influence participants' valuations of the game. In doing so we focused upon not only the analyses of the *means*, but also the *trend* effects, as we were particularly interested in testing the overall *pattern* of influence of winning and near-miss frequencies on participants' valuations of the game, as expressed in their purchase of optional plays. We also looked at the association between the interactive influence of the winning and near-miss frequencies on game valuation on the one hand, and participants' self-reported gambling-related cognitive biases on the other hand. Furthermore, we aimed to develop a well-controlled gambling game which measures the effects of illusions of control on participants' betting behaviours.

Contrary to our expectations, we found no effect of the frequency of winning or near-miss outcomes on the *mean* numbers of optional plays bought. However, we did find that the frequency of near-miss outcomes exerted positive linear trend effect upon participants' valuations of the slot-machine game, indicated by the number of optional plays bought, provided that 1 winning outcome was also delivered. No positive effects of near-miss outcome frequency were observed when either 0 or 2 winning outcomes were delivered in a 6-play round. Moreover, the extent to which the influence of near-miss frequency on participants' buying behaviours depended positively on the frequency of winning outcomes was positively associated with participants' beliefs in predictive control in gambling. We also found that our card game was successful in eliciting betting behaviours indicative of illusions of control, the degree of which showed some relationship with participants' tendencies to interpret gambling outcomes in biased ways.

Near-misses interact with wins to influence game valuations In this experiment, we tested the hypothesis that the positive reward value of near-miss slot-machine outcomes depends upon the presence of winning outcomes in the game (Kassinove and Schare, 2001). We did not find any direct evidence for this hypothesis based on the analyses of the *mean* number of optional plays purchased. However, Experiment 3 did provide some subtle statistical evidence that the delivery of near-miss outcomes in a simple 3-reel slot-machine game led participants to form more positive valuations of the game, provided that 1 winning outcome was also delivered in a 6-play round. When the previous round contained 1 winning outcome, participants chose to buy larger numbers

of optional plays following either 1 or 2 near-miss outcomes, compared to 0 near-miss outcome. However, participants' buying behaviours were not under any positive influence of near-miss outcomes when either 0 or 2 winning outcomes were delivered (Figure 3). These joint influences of near-miss and winning frequencies were characterised by a linear trend effect of near-miss frequency that was modulated in a quadratic manner by the frequency of wins. Thus, near-miss and winning outcome frequencies interact in a non-linear manner to influence the valuation of the slot-machine game, suggesting that the capacity of the former type of outcome to serve as positive reinforcement signal depends upon the reinforcement environment of play, that is, the frequency of winning outcomes.

Existing accounts of near-miss outcomes have different strength in explaining our findings. Our results are incompatible with the theory that near-miss outcomes are associated with success through simple Pavlovian conditioning processes following sufficient pairings in previous play (Reid, 1986; Kassinove and Schare, 2001). Conditioning might explain why we found no positive influence of near-miss outcomes in rounds containing no winning outcomes. However, it cannot easily explain why no positive near-miss influence was observed following the delivery of 2 winning outcomes, under which condition the pairing between these outcomes would have been more frequent within the round. According to a slightly different perspective, near-miss outcomes have positive value by sharing commonalities in appearance with winning outcomes (e.g. Dixon and Schreiber, 2004; Dixon et al., 2009). However, this account also

does not explain why the near-miss influence on game valuations was non-linearly dependent on the frequency of winning outcomes.

Similarly, our findings might be incompatible with the verbal association theory, which proposes that the perception of near-miss outcomes as close to wins has a verbal origin (Dixon et al., 2009; Daugherty and MacLin, 2007). The verbal association theory may not easily explain, by itself, the absence of positive near-miss influence in the presence of 0 or 2 winning outcomes.

By contrast, our findings from Experiment 3 might be explained by the negative affect theory of the near-miss effect, according to which almost-winning experience encourages further play by producing frustration and cognitive regret (Loftus and Loftus, 1983; Reid, 1986; Clark et al., 2009). On this view, we found no positive influence of near-miss outcomes on participants' buying behaviours following 2 winning outcomes because the frustration elicited by near-miss outcomes was counteracted by the frequent winning outcomes. However, this remains speculative since we did not include any measures of affect in Experiment 3. Moreover, other evidence suggests that excessive negative affect and frustration resulting from consecutive gambling losses may lead to termination rather than continuation of gambling behaviours (Dickerson et al., 1991), particularly among low-frequency gamblers (Dickerson, 1993). This might account for the absence of a positive influence of near-miss frequency when no winning outcomes were delivered.

Finally, an illusion of control theory of the near-miss effect suggests that a near-miss outcome may be taken as an encouraging sign, confirming the efficacy of the current game strategy and raising hopes for future success (Reid, 1986). In other words, near-miss outcomes encourage further play through acting as instrumental conditioned reinforcers, leading the players to believe future wins are imminent. Thus, we observed no positive influence of near-miss frequency when no winning outcomes were delivered, because participants needed to experience occasional success to maintain beliefs in control or strategy (Dickerson, 1993). However, the view that near-misses acquire positive value by signalling forthcoming success is difficult to reconcile with our finding of Experiment 2 that impulsivity had opposite influence on BOLD signals to winning and near-miss outcomes. In addition, this theory might also have difficulties in explaining why the frequency of near-miss outcomes had no positive influence on game valuations when 2 winning outcomes were delivered. However, it might also be argued that near-miss outcomes have much less value as predictors of future success when high numbers of winning outcomes were also delivered (i.e. the positive value of near-miss outcomes in predicting future wins were overpowered by the frequent winning outcomes that co-occurred).

The interactive influence of near-miss and winning frequencies was associated with predictive control One clue to understanding the above results of Experiment 3 might be provided by the observation that participants who scored higher on the predictive control subscale of the GRCS, and were thus holding stronger beliefs that positive gambling outcomes could be

predicted (Raylu and Oei, 2004), were more positively influenced by the number of near-miss outcomes on game valuations if a high frequency of winning outcomes was also delivered (Figure 4). This finding suggests that people who believe more strongly that future success in gambling can be predicted, based on a variety of information sources, tend to ascribe greater predictive values to near-miss outcomes if they had just experienced a high frequency of success in the game. This suggests that these individuals were trying to build mental models of the game's outcome structure based on the recent history of both success (winning outcomes) and almost-success (near-misses), which were then used to valuate future (optional) plays.

By contrast, we found only limited evidence that participants who scored higher on the illusion of control subscale of the GBQ showed buying behaviours which were more positively dependent on the frequency of near-miss outcomes when a high frequency of winning outcomes was also delivered. The reason that this association was not as strong as that involving scores on the predictive control subscale of GRCS (see above) might be that our slot-machine game contained little element that could be perceived as skill-based (e.g. participants had no control over the durations of reel-spins). Rather, the only way that participants could influence the final score of the game was to decide the numbers of optional plays to buy, which was mainly based on the prediction of future outcomes using information from previous play experience.

Participants' betting behaviours in the card-guessing game Experiment 3 was successful in demonstrating behavioural manifestation of illusions of control in our novel card-guessing game. In designing the game, we ensured that there was no element of actual control over the outcomes. Participants had to place bets on the matching of 2 cards, each of which was selected either by participants or by the computer from a row of 4 cards. There were no skills that participants could employ to predict the outcome of the matching, which was wholly determined by a pseudo-random pre-programmed sequence. In addition, the two game conditions that provided different levels of perceived control were very similar in all the other aspects, including winning schedule, visual and auditory stimuli, and motor responses. We used participants' bet sizes as the behavioural measure to assess illusions of control for 2 reasons. First, the illusion of control bias is often closely related to participants' confidence in winning the game and the amount of money wagered (Langer, 1975). Second, bet size is an important index of gambling behaviours in other contexts (O'Connor and Dickerson, 2003), and risk-taking in general is associated with more serious gambling problems (Lejuez et al. 2002).

As expected, Experiment 3 demonstrated that participants placed significantly larger bets when they were allowed to choose their own cards, compared to when the computer chose both cards, despite the chances of winning being identical in the 2 conditions. This pattern of betting behaviour was observed in both the ordinary plays and the bonus plays which offer 'double' prizes. Thus, participants' betting behaviours on our card game illustrates a typical manifestation of illusions of control (Martinez et al., 2011).

According to Langer (1975), the influence of illusions of control on people's behaviours depends on several factors, including the freedom to choose, stimulus and/or response familiarity, involvement, competition and the history of gambling outcomes (Langer and Roth, 1975). Our findings indicate the importance of choice in fostering illusions of control. It is unlikely that factors of stimulus/response familiarity and involvement contributed overly to participants' betting behaviours, as the self-choose and computer-choose conditions of our card game differ very little on visual or auditory stimuli, motor response or behavioural involvement. Also, the betting patterns shown by our participants were not due to the factor of competition, which was present to the same degree in the 2 choose conditions. Finally, it was unlikely that participants' betting patterns were caused by history of gambling outcomes, which were controlled by pseudo-random pre-programmed sequences that were identical across the 2 choose conditions.

However, as against the above observations, we found only marginal evidence that participants' betting behaviours in the card game were associated with their scores on the psychometric measurements of illusions of control (Steenbergh et al., 2002; Raylu and Oei, 2004). One reason for this might be that illusions of control as manifested in game-play behaviours are not the same as those measured by self-report questionnaires. For example, Dickerson (1993) argued that beliefs in illusions of control are often context-specific, being expressed only during game play. When gamblers are questioned outside of the game-

play setting, they often express beliefs of no control in gambling (Dickerson, 1993). This is indeed one reason why we need to be careful in selecting which measures to use when designing experiments to test illusions of control.

There was also only marginal evidence that participants whose buying behaviours in the slot-machine game were more positively influenced by the interaction of winning and near-miss frequencies also chose to bet much larger stakes in the card game when they chose the cards compared to when computer chose the cards. Although this association is interesting, it was not statistically significant and we will examine it again in the subsequent experiments.

A summary of results and an outline of Experiment 4 In summary, Experiment 3 did not provide significant evidence that the frequency of winning or near-miss slot-machine outcomes influenced the *mean* number of optional plays participants were willing to buy. However, we did find some subtle statistical evidence that the frequency of near-miss slot-machine outcomes interacted with the frequency of winning outcomes to jointly influence participants' buying of optional plays. The delivery of 1 or 2 near-miss outcomes led participants to buy more optional plays if they co-occurred with 1 winning outcome, but no such positive influence of near-miss outcomes was observed when 0 or 2 winning outcomes were delivered. This finding is consistent with the idea that near-misses acquire positive values through acting as predictive cues for imminent wins as players seek to build mental models of the game's

outcome structures. Consistent with this, the extent to which the influence of near-miss frequency on participants' buying behaviours depended positively on the frequency of winning outcomes showed positive association with participants' scores on the predictive control subscale of the GRCS. We also found that our card game was successful in eliciting betting patterns that were indicative of illusions of control at a behavioural level, which were mostly unrelated to participants' scores on questionnaires assessing this cognitive bias in gambling.

In the following experiment, we aimed to develop the methodology introduced in Experiment 3 by making several changes to the slot-machine game and the participant sample. First, the number of plays contained in each individual round was increased, so that participants were provided with sufficient play experience to form adequate valuations of the game in order to guide purchasing behaviour. Second, participants' purchasing decisions about the number of optional plays to buy in Experiment 3 could be influenced by the fatigue associated with completing those extra plays. Therefore, we changed this aspect of the game so that participants did not need to actually complete the additional plays bought. Third, in order to further understand the cognitive and emotional mechanisms of the near-miss effects in gambling, we added questions following each round of play about participants' feelings of enjoyment and perceived luckiness. Last, we wanted to compare our findings on people who gamble very little to those obtained from individuals who gamble more often, so our next experiment involved an additional group of frequent gamblers.

Chapter V–Experiment 4

Introduction

Experiment 3 provided preliminary evidence that the trend effects of near-miss frequency on participants' buying decisions depended on the frequency of co-occurring winning outcomes. In addition, the modulatory influence of winning frequency on the trend effect of near-miss frequency was characterised by a quadratic, not linear, trend. Specifically, having experienced 1 or 2 near-miss outcomes in the preceding 6-play round led participants to buy more optional plays than having experienced no near-miss outcomes, but only when participants had also experienced 1 winning outcome in that round. The experience of near-miss outcomes did not encourage players to buy more optional plays if either 0 or 2 winning outcomes were delivered in the preceding round. These results suggest that the near-miss effect in the context of slot-machine play may be more fragile than researchers had previously proposed; that is, it requires the co-occurrence of other types of outcome events (i.e. winning outcomes) at particular frequencies.

One limitation of Experiment 3 was that each game round delivered only 6 plays. This might have meant that the number of plays was not sufficient for the player to form adequate valuations of the game. Learning about EGMs may take place over more extended course of outcomes, and the valuations participants made following individual rounds in Experiment 3 may have been based on explicit

memory of recent events rather than more implicit evaluations of the game. Even if players' buying behaviours were based on implicit learning about the game, it is difficult to ascertain whether they were learning from play experiences extending further back in time than the immediately preceding game round.

Consequently, we decided to make a few alterations to our slot-machine game in Experiment 4. First, we increased the length of the game rounds from 6 plays to 12 plays. This meant that the numbers of winning and near-miss outcomes in every round were doubled, but their relative proportions remain unchanged: each game round delivered either 0, 2 or 4 winning outcomes and either 0, 2 or 4 near-miss outcomes at equal frequencies, leading to a variable ratio of 6 for both these 2 types of events.

Second, instead of making the participants complete the optional plays they chose to buy, we only asked them to indicate how many optional plays they 'would like' to buy if given the opportunity. These plays were not actually completed. The reason for this change was to reduce fatigue associated with completing the optional plays. Thus, in Experiment 4, participants were asked to imagine a scenario in which they had the opportunity to use the remaining credits from the previous round to purchase some numbers of optional plays, but were also told explicitly that these plays would not be completed.

Third, we asked the participants to rate their enjoyment of playing each game round and their perceived luckiness following each round. We conjectured that these rating questions might help us understand the cognitive and emotional mechanisms of near-miss effects on gambling behaviour. For example, the experience of near-miss outcomes might be pleasant and positively-reinforcing, as predicted by the stimulus generalization and the conditioning theories (Reid, 1986); or they might be experienced as unpleasant and frustrating that in turn motivate further play, as predicted by the negative affect theory of near-miss effect (Reid, 1986; Clark et al., 2009). There is also some evidence suggesting that players' perceived luckiness is influenced by the type of slot-machine outcomes they recently experienced (Daugherty and MacLin, 2007). For example, one study found that participants who almost suffered a big loss rated themselves luckier than those who almost won a big prize (Wohl and Enzle, 2003). Therefore, we wanted to test in Experiment 4 whether and how recent experience of near-miss and winning outcomes influenced participants' feelings of enjoyment and perceived luckiness.

Lastly, in Experiment 4 we recruited both frequent and infrequent gamblers. Although a continuum model of gambling (e.g. Griffiths, 1993b) claims that data collected on the non-gambler part of the population spectrum could be used to deduce the psychological correlates of behaviours among social gamblers, problems gamblers and even pathological gamblers, there still remains a possibility that the psychological correlates of near-miss effect are different among individuals with different levels of gambling participation (Sharpe, 2002). Therefore, we included both frequent and infrequent gamblers in Experiment 4.

Inspection of differences between these 2 groups could tell us more about how gambling-related cognitive biases, such as illusions of control, among frequent and infrequent gamblers influence their valuations of EGMs as a function of the frequencies of recent game outcomes.

Methods

This study was approved by the Central University Research Ethics Committee. All participants provided fully-informed written consents.

Subjects Twenty-five frequent gamblers (3 females) and twenty-six infrequent gamblers (4 females) recruited from the University of Oxford and from the local community participated. Participants' mean age was 27.04 ± 1.04 years (range 18-46 years). The screening included assessment with a semi-structured SCID-I interview to ensure that none of the following exclusion criteria were met: i) major physical illnesses; ii) current or previous DSM-IV major mood or psychotic disorders; iii) current or previous DSM-IV substance abuse disorders.

Participants were also assessed with the National Opinion Research Centre DSM-IV Screening for Gambling Problems (NODS) and the South Oaks Gambling Screening Questionnaire (SOGS) in order to identify any gambling problems. Participants who scored 5 or above on both the NODS and the SOGS were excluded as pathological gamblers based on the DSM-IV criteria (APA, 1994).

Participants were divided into the frequent gambler and the infrequent gambler groups based on their gambling frequencies during the past year. Individuals who reported gambling once or more per week were classified as frequent gamblers (mean frequency = 3.63 ± 0.46 times/week). The remaining participants who engaged in gambling less often were considered as infrequent gamblers (mean frequency = 0.13 ± 0.03 times/week). The type of gambling activities reported by participants included poker, sports or horse betting, bingo, roulette, slot machines, currency trading, betting on video game plays and lottery/scratch cards. Gambling activities typically took place at casinos, betting shops, on-line websites, pubs and race-tracks. We excluded individuals who met the criteria for frequent gamblers on gambling frequency but were engaged in lottery play only, as lottery gambling can be motivated by diverse factors and its frequency does not indicate wider gambling involvement (Rogers, 1998).

All participants were paid £25 plus travelling expenses, which amount comprised of base payments plus winnings from the task games (see below).

Psychometric assessments

Participants completed the South Oaks Gambling Screening Questionnaire (SOGS) (Lesieur and Blume, 1987) (range: 0-10, mean=1.29 ± 0.30). Verbal IQ was assessed with the National Adult Reading Test (Nelson, 1982) (range: 100-124, mean=114.88±0.80). Impulsivity was measured using the I-7

Impulsiveness Scale (Eysenck and Eysenck, 1978, 1985) (range: 0-20, mean=8.47±0.65).

Participants were also assessed with the Gambling-Related Cognitions Scale (GRCS) (Raylu and Oei, 2004), the Chasing Questionnaire (CHQ) (O'Connor and Dickerson, 2003) and the Gamblers' Beliefs Questionnaire (GBQ) (Steenbergh et al., 2002) (Table 1). Detailed descriptions of these questionnaires were included in chapter 3 earlier. Independent t-tests confirmed that compared to infrequent gamblers, frequent gamblers scored higher on NODS ($t(49) = 4.453$, $p<.05$), SOGS ($t(49) = 3.395$, $p<.05$), I-7 ($t(49) = 3.004$, $p<.05$), GBQ luck/perseverance ($t(49) = -2.181$, $p<.05$), GBQ illusion of control ($t(49) = -2.311$, $p<.05$), loss-chasing ($t(49) = 3.056$, $p<.05$), near-miss chasing ($t(49) = 2.612$, $p<.05$), GRCS gambling expectancy ($t(49) = 3.867$, $p<.05$), GRCS predictive control ($t(49) = 2.052$, $p<.05$), GRCS inability to stop ($t(49) = 3.151$, $p<.05$) and GRCS interpretative bias ($t(49) = 2.947$, $p<.05$). The frequent gamblers also scored marginally higher than the infrequent gamblers on win-chasing ($t(49) = 1.991$, $p=.052$). Overall, not surprisingly, our frequent gambler group reported heavier gambling involvement, more serious gambling problems, stronger gambling-related cognitive biases and higher levels of impulsivity than the infrequent gamblers. The frequent and infrequent gambler groups were, however, not different on IQ scores as measured by NART ($t(49) = 0.882$, $p>.1$).

	Age	SOGS	GBQ[3]	
			Luck/perseverance	Illusion of control
Frequent gamblers	28.64 ± 1.60	2.24 ± 0.52	37.26 ± 2.22	34.15 ± 1.95
Infrequent gamblers	25.50 ± 1.31	0.38 ± 0.18	29.73 ± 2.63	28.08 ± 1.77
Total	27.04 ± 1.04	1.29 ± 0.30	33.42 ± 1.79	31.05 ± 1.37

	I-7	CHQ		
		Win-chasing	Loss-chasing	Near-miss-chasing
Frequent gamblers	10.32 ± 0.89	13.48 ± 1.00	10.84 ± 0.84	5.16 ± 0.41
Infrequent gamblers	6.69 ± 0.82	10.65 ± 1.00	7.19 ± 0.40	3.81 ± 0.32
Total	8.47 ± 0.65	12.04 ± 0.73	8.59 ± 0.50	4.47 ± 0.27

	GRCS				
	Gambling Expectancy	Illusion of Control	Predictive Control	Inability to Stop	Interpretative Bias
Frequent gamblers	12.20 ± 1.21	6.48 ± 0.55	17.60±1.20	9.56 ± 1.13	14.04 ± 1.04
Infrequent gamblers	7.15 ± 0.83	5.92 ± 0.64	13.73±1.44	5.77 ± 0.41	9.54 ± 1.12
Total	9.63 ± 0.74	6.20 ± 0.42	15.63±0.97	7.63 ± 0.64	11.75 ± 0.82

Table 1. Demographic and psychometric scores (mean and standard error) of frequent gambler and infrequent gambler groups. SOGS: South Oaks Gambling Screening (Lesieur and Blume, 1987). GBQ: the Gamblers' Beliefs Questionnaire (Steenbergh et al., 2002). I-7: The Eysenck Impulsiveness Questionnaire (Eysenck and Eysenck, 1985). CHQ: the Chasing Questionnaire (O'Connor and Dickerson, 2003). GRCS: the Gambling Related Cognitions Scale (Raylu and Oei, 2004).

Design In this experiment, all participants completed 2 games. The first game was a simple slot machine similar to that described in Experiment 3 and was constructed with a variable ratio of 6 for both winning and near-miss outcomes. The player paid £0.90 for each play, and each win delivered a prize of £5.00. The overall return-to-player (RTP) rate was 92.6% i.e. overall players won back 92.6% of the credits they paid to play. The whole game consisted of 54 rounds, each comprised of 12 plays. There were a total of 9 different types of rounds, based on the number of winning outcomes (0, 2 or 4) and near-miss outcomes

[3] Scores on the GBQ were inversely coded. See Methods section of Chapter 3.

(0, 2 or 4) in the round. Each type of round occurred 6 times presented in random order.

Computer-simulated slot-machine game The slot-machine was designed using the Lua programming language version 5.1(http://www.lua.org/) and implemented using the LOVE flash software version 7.2 (http://love2d.org/) (Figure 1). As in conventional slot-machine games, the display showed 3×3 fruit reels with the middle horizontal line as the pay line. The winning combinations of symbols and their associated prizes were shown at the top of display. In this game, all winning outcomes gave a standard prize of £5.00. Participants started each game round with £20 credits, and their remaining credits and the prize won in each round were displayed towards the top left of the screen.

Participants pressed the left mouse button with their right hand to start each reel spin, which lasted for between 1.2s and 1.5s before the reels stopped sequentially from left to right. Participants won a standard prize of £5.00 if the reels displayed 3 identical symbols on the pay line. Viewed from left to right on the pay line, if the first 2 reels showed the same symbol but the third reel showed a different symbol (i.e. AAB), then it was a near-miss outcome. All other outcomes were counted as losses (symbol combinations in the forms of ABA or ABB never occurred, so losing outcomes always consisted of 3 different symbols). Following the presentation of each outcome, participants pressed the left mouse button again to initiate the next play.

Following the completion of each game round, participants were directed to a question screen asking how many optional plays they would like to buy with the remaining credits from the previous round, which could be answered by typing in any number between 0 and 10. Participants were explicitly told that the question was hypothetical; that no optional plays would be completed for real and no credits would be taken to pay for them.

Two other questions asked participants' levels of enjoyment from playing the previous game round ('How much did you enjoy playing the last round?') and their perceived luckiness at that moment ('How lucky do you feel right now?'). Participants were required to indicate their responses on a sliding visual analogue scale with 'Not at all' on the left end and 'Very much' or 'Very lucky' on the right end. Participants were required to answer all 3 questions before clicking on the 'Submit' button at the bottom of the screen, which would take them to the next round.

Participants were told that the whole game consisted of an unknown number of rounds, and that a fraction of the total amount of credits they accumulated over the course of the game would be converted to real money and paid to them as part of their total experimental fees. During the game, the overall accumulated credit scores were not displayed on the screen except those won in the round played at the time.

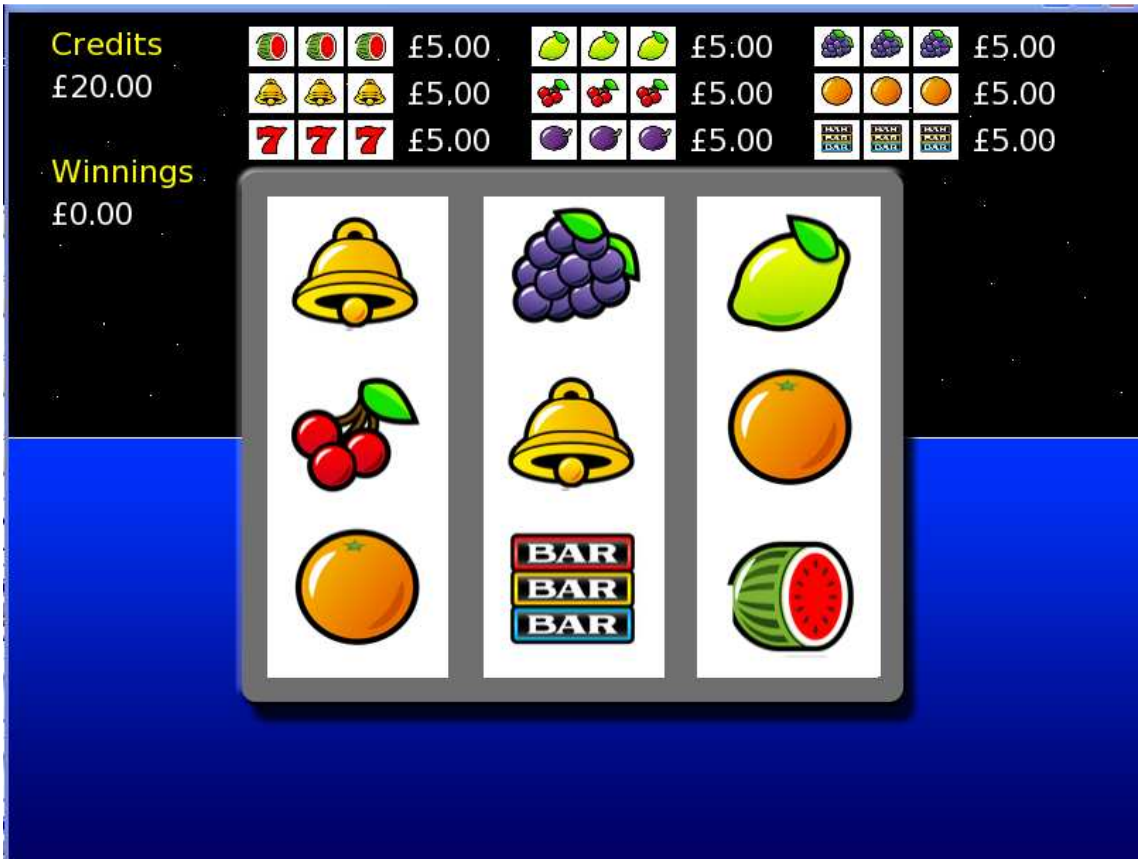


Figure 1. The computer-simulated slot-machine game. Participants started each round with £20 credits. Each spin cost £0.90 credits. Players started each reel spin by pressing the left mouse button, after which all three reels simultaneously started spinning and stopped sequentially from left to right. After all reels stopped spinning, if three identical symbols showed up on the middle line (the pay line), the player won a fixed prize of £5 credits. Otherwise the player won nothing. Each game round contained 12 individual plays, followed by questions on optional-play buying, enjoyment rating and luckiness rating. See text for more details.

Computer-simulated card-guessing game The second game was a card-guessing game measuring illusions of control which was exactly the same as that used in Experiment 3. The game consisted of 60 plays in total and delivered 16 winning outcomes (a VR of 3.75). Detailed descriptions of the game displays and structures were presented in the method section of Chapter 4.

Procedure Participants arrived at the University Department of Psychiatry and completed the screening as described above. Once the psychometric tests were completed, participants were taken into a quiet computer room and played the 2 games. All participants played the shorter card game first before the slot-machine game. After both games were completed, participants were debriefed and filled out a payment form before leaving.

Statistical analyses The main focus of the analyses was to test how the frequencies of winning and near-miss outcomes in individual rounds of a slot-machine game influenced players' valuations of the game (the number of optional plays bought), their enjoyment feelings and perceived luckiness, and how the interactive influence of winning and near-miss frequencies was associated with individual differences in gambling-related psychometric scores among the frequent and infrequent gambler groups.

Slot-machine data analyses The analyses of slot-machine data consisted of 2 parts. In the first part, we examined how participants' optional-play buying and their ratings of enjoyment and luckiness were influenced by the frequencies of winning and near-miss outcomes. Thus, the data were analysed with a repeated-measures ANOVA with group (frequent vs. infrequent gamblers) as the single between-subjects factor and number of winning (0, 2 or 4) and near-miss (0, 2 or 4) outcomes as 2 within-subjects factors. Simple-effects ANOVAs and paired-sample t-tests were carried out to test individual contrasts where

applicable. As in Experiment 3, we carried out analyses of both the effects upon the means and the trend effects.

Second, we looked at how the influence of the interaction between winning and near-miss frequencies on participants' optional-play buying was associated with participants' gambling-related psychometric scores[4]. At the single-participant level, the number of optional plays bought was regressed against the numbers of winning and near-miss outcomes, plus their interaction (win × near-miss). The sequence number of individual rounds (1 to 54) was also included as a predictor variable in order to account for effects due to participant fatigue and boredom. At the group level, the resultant regression coefficient beta values were then regressed against participants' gambling-related psychometric scores and their group status (frequent gamblers or infrequent gamblers), controlling for potentially confounding variables of age and IQ. In order to seek for common constructs underlying participants' behaviours on both games, the regression coefficient beta values obtained from slot-machine data analyses were also regressed against participants' betting ratios in the card game (see below).

Card-game data analyses Participants' bet sizes in the self- and computer-choose conditions were analysed using a repeated-measures ANOVA with condition (self-choose vs. computer-choose) and bonus (2 levels) as the within-subjects variables and group (frequent gamblers vs. infrequent gamblers) as the

[4] Please refer to the Methods section of Chapter 4 for a discussion on why only the associations involving the interactive influence of winning and near-miss frequencies were examined in this part of analyses.

between-subjects variable. We also compared participants' bet sizes in the 2 game conditions using one-sample t-tests on the betting ratios, calculated as the player's averaged bet size in the self-choose condition divided by the averaged bet size in the computer-choose condition. Betting ratios that were significantly greater than 1 suggested overall larger bet sizes in the self-choose compared to the computer-choose condition. Moreover, regression analyses were performed between the betting ratios and participants' gambling-related psychometric scores, and between the betting ratios and the regression coefficient beta values obtained from the slot-machine data analyses (see above). Significance level was set as $p<.05$ for all statistical tests.

Results

Slot-machine analyses

Six participants (1 frequent gambler) were excluded from the slot machine data analyses due to zero optional-play buying on every round, leaving 45 participants (24 frequent gamblers). As in Experiment 3, the mean number of optional plays bought showed considerable inter-subject variability, ranging between 0.07±0.05 and 6.98±0.41. Analyses of effects on *mean* buying revealed that the number of optional plays bought increased with the frequency of winning outcomes ($F (2, 86) = 47.759$, $p<.05$), but not with the frequency of near-miss outcomes ($F (2, 86) = 0.321$, $p>.1$). The 2-way interaction effect

between the frequency of winning and near-miss outcomes was not significant ($F(4, 172) = 0.522$, $p>.1$).

Analyses of the trend effects showed that the effect of win frequency was both linear ($F(1, 43) = 55.262$, $p<.05$) and quadratic ($F(1, 43) = 10.044$, $p<.05$), suggesting that overall, the increase of buying was not the same as the number of winning outcomes increased from 0 to 2 and from 2 to 4 in a 12-play round. Also, the joint influence of winning and near-miss outcome frequencies, as characterised by a quadratic trend effect of near-miss frequency overlaid with a quadratic trend effect of win frequency, was different among frequent and infrequent gamblers ($F(1, 43) = 5.006$, $p<.05$).

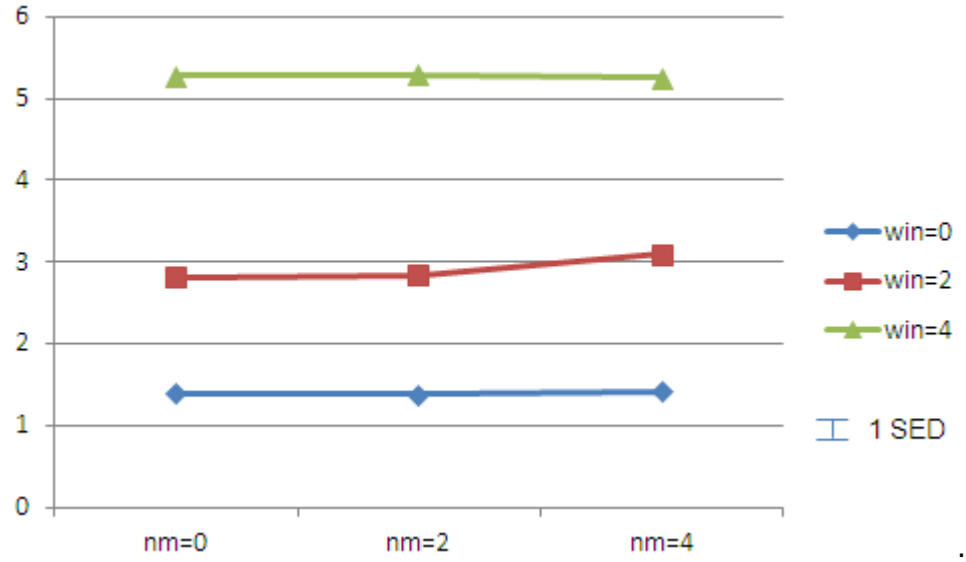
Frequent gamblers Among the frequent gamblers, the *mean* numbers of optional plays bought increased with the frequency of winning outcomes ($F(2, 46) = 22.491$, $p<.05$), but not with the frequency of near-miss outcomes ($F(2, 46) = 0.493$, $p>.1$). The 2-way interaction effect between the frequency of winning and near-miss outcomes was not significant, either ($F(4, 92) = 0.301$, $p>.1$). Analyses of the trends revealed that the effect of winning outcome frequency was linear ($F(1, 23) = 24.913$, $p<.05$). No significant trends were observed for the influence of near-miss frequency or the win × near-miss interaction (ps>.1) (Figure 2a).

Infrequent gamblers We observed a different pattern of results for the infrequent gamblers. These participants bought significantly more optional plays as the frequency of winning outcomes increased ($F (2, 40) = 26.61$, $p<.05$). However, trend analyses showed that this effect was characterised by both linear ($F (1, 20) = 33.232$, $p<.05$) and quadratic ($F (1, 20) = 6.521$, $p<.05$) trends. Moreover, among infrequent gamblers, the quadratic trend effect of near-miss frequency was modulated by the quadratic trend effect of win frequency ($F (1, 20) = 6.934$, $p<.05$)[5] (Figure 2b).

Inspection of Figure 2b indicates that, in rounds containing 2 winning outcomes, infrequent gamblers bought more optional plays when 2 near-miss outcomes were also delivered, compared to when 4 near-miss outcomes were delivered. By contrast, in rounds containing 4 winning outcomes, participants decided to buy more optional plays when the round contained 0 or 4 near-miss outcomes compared to when the round contained 2 near-miss outcomes (Figure 2b). The latter observation was confirmed by simple-effects analyses, which generated an almost-significant quadratic trend effect of near-miss outcome frequency when 4 winning outcomes were delivered ($F (1, 20) = 3.622$, $p=.072$).

[5] Similar result was obtained if using the original error term for this trend analysis at the level of total participant sample, $F (1, 43) = 6.211$, $p<.05$.

a



b

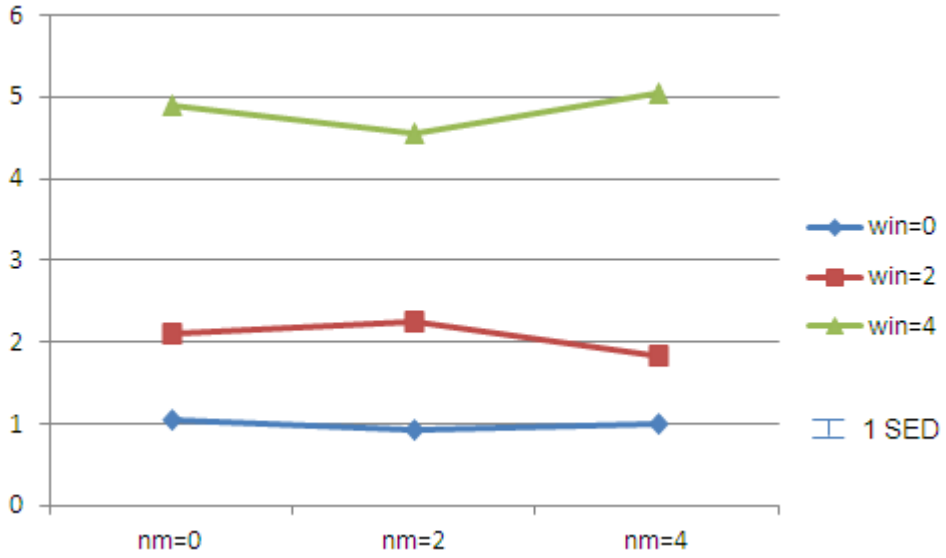


Figure 2. The numbers of optional plays frequent gamblers (a) and infrequent gamblers (b) chose to buy immediately following rounds containing different numbers of winning (0, 2 or 4) and near-miss (0, 2 or 4) outcomes. nm: near-miss outcome. 1 SED represents one standard error of the difference on the means for the win × near-miss interaction effect, calculated according to the formula √MSE/n, where MSE = mean square of the error term and n equals the sample size (i.e. 24 for frequent gamblers and 21 for infrequent gamblers) (Cochran and Cox, 1957).

ANOVA analyses on enjoyment ratings Participants reported greater enjoyment from playing rounds containing more winning outcomes ($F(2, 86) = 72.642$, $p<.05$). *Mean* enjoyment ratings also increased with the number of near-miss outcomes ($F(2, 86) = 3.815$, $p<.05$). Furthermore, the interactive effect of winning and near-miss outcome frequencies on *mean* enjoyment ratings differed significantly among frequent and infrequent gamblers ($F(4, 172) = 2.706$, $p<.05$). The trend analyses revealed that the effect of winning outcome frequency was both linear ($F(1, 43) = 79.792$, $p<.05$) and quadratic ($F(1, 43) = 8.274$, $p<.05$), while the effect of near-miss frequency was mainly linear ($F(1, 43) = 5.653$, $p<.05$). Paired-sample t-tests showed that participants experienced more enjoyment from playing rounds containing 2 ($t(44) = 2.612$, $p<.05$) or 4 ($t(44) = 2.448$, $p<.05$) near-miss outcomes compared to rounds delivering no near-miss outcome.

Analyses of the trends also showed that the joint influence of winning and near-miss outcome frequencies on participants' enjoyment ratings, as characterised by a linear trend effect of near-miss frequency overlaid with a quadratic trend effect of win frequency, differed marginally between the frequent and infrequent gambler groups ($F(1, 43) = 3.969$, $p=.053$) (Figure 3). Among the frequent gamblers, the joint influence of winning and near-miss outcome frequencies was characterised by a linear trend effect of near-miss frequency overlaid with another linear trend effect of win frequency ($F(1, 23) = 6.537$, $p<.05$)[6] (Figure 3a). Specifically, near-miss frequency had positive linear trend effects on

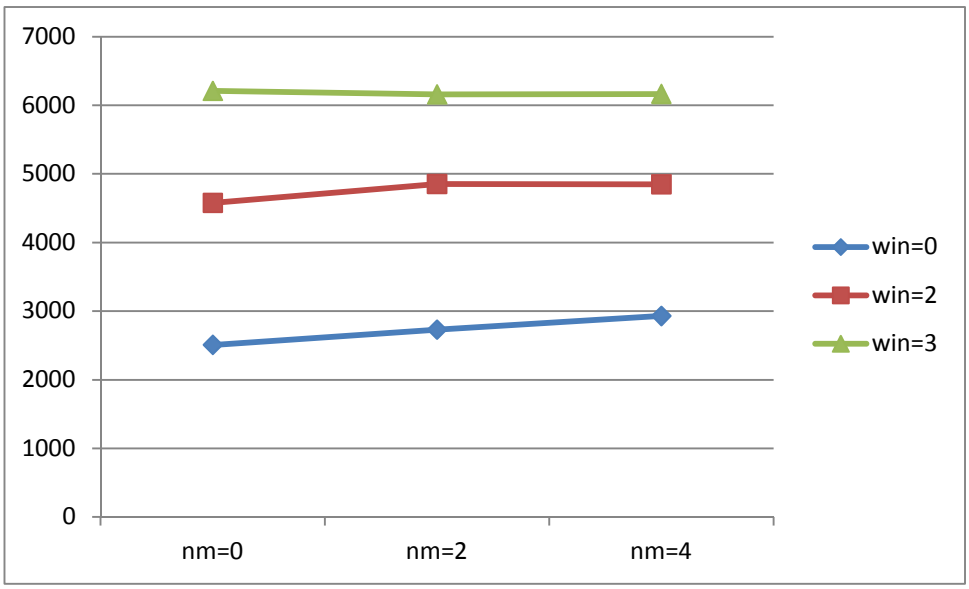
[6] Similar result was obtained if using the original error term for this trend analysis at the level of total participant sample, $F(1, 43) = 5.58$, $p<.05$.

participants' enjoyment ratings when the preceding round delivered either 0 ($F(1, 23) = 6.93$, $p<.05$) or 2 winning outcomes ($F(1, 23) = 4.831$, $p<.05$), but not when 4 winning outcomes were delivered ($p>.1$).

Among the infrequent gamblers, the effects upon enjoyment ratings were characterised by a linear trend of near-miss frequency overlaid with a quadratic trend of win frequency ($F(1, 20) = 6.378$, $p<.05$)[7] (Figure 3b). Specifically, the frequency of near-miss outcomes had quadratic trend effect on participants' enjoyment ratings when the preceding round delivered no winning outcome ($F(1, 20) = 5.947$, $p<.05$), with 2 near-miss outcomes associated with the greatest enjoyment and 0 near-miss outcome associated with the least. The frequency of near-miss outcomes had a near-significant negative linear trend effect on enjoyment ratings when there were 2 winning outcomes ($F(1, 20) = 3.871$, $p=.063$), and no discernible effect when there were 4 winning outcomes ($p>.1$).

[7] Similar result was obtained if using the original error term for this trend analysis at the level of total participant sample, $F(1, 43) = 4.923$, $p<.05$.

a



b

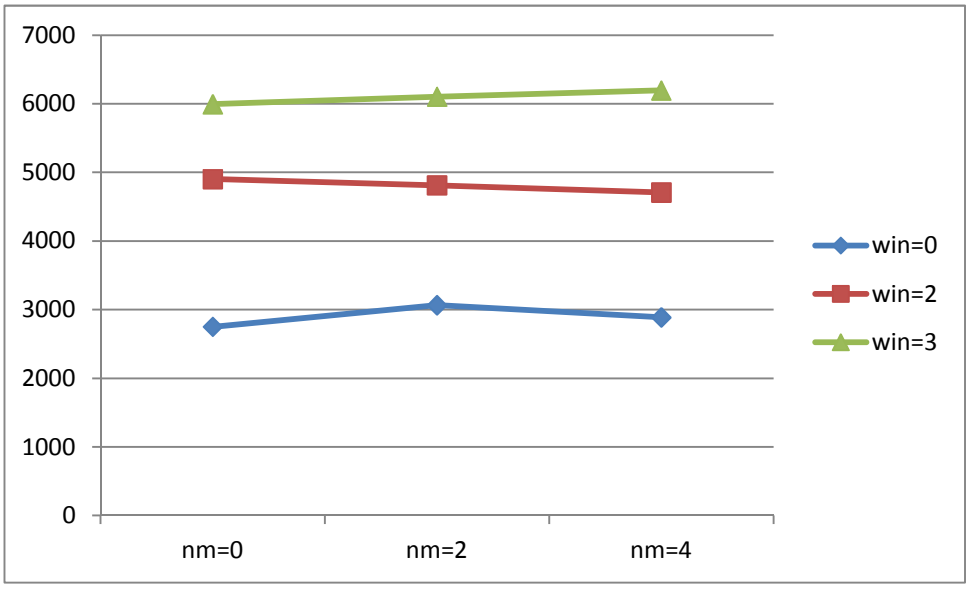


Figure 3. The feelings of enjoyment reported by frequent gamblers (a) and infrequent gamblers (b) immediately following rounds containing different numbers of winning (0, 2 or 4) and near-miss (0, 2 or 4) outcomes. nm: near-miss outcome. The SED (for the win × near-miss interaction effect) for the frequent gambler group is 85.5 and that for the infrequent gambler group is 97.8. These values are too small (compared to the main effect of winning outcomes) and thus are not marked on the figures.

ANOVA analyses on luckiness ratings Participants' *mean* ratings of luckiness also increased following rounds containing more frequent winning outcomes (F (2, 86) = 88.269, p<.05), but did not markedly change with the frequency of near-miss outcomes (F (2, 86) = 0.463, p>.1). The 2-way interaction effect between the frequencies of winning and near-miss outcomes was also not significant (F (4, 172) = 0.688, p>.1). Tests of between-subjects effects showed that, overall, infrequent gamblers tended to feel luckier than frequent gamblers (F (1, 43) = 3.926, p=.054). Analyses of the trends revealed that the effect of winning outcome frequency upon luckiness ratings was linear (F (1, 43) = 107.46, p<.05). No significant trend effects were identified for the frequency of near-miss outcomes or the interaction between winning and near-miss frequencies (ps>.1).

Linear regression analyses on buying behaviour Unstandardized coefficient beta values were obtained by regressing the number of optional plays bought against the numbers of winning, near-miss outcomes and their interaction. The beta values representing the interactive effects of winning and near-miss frequencies were then regressed against participants' gambling-related psychometric scores, their group status (frequent vs. infrequent gamblers, with the latter as the reference category), and the psychometric score × group interaction term, which were entered simultaneously into the model as predictor variables, while controlling for additional factors of age and IQ. These analyses revealed no significant results for the infrequent gambler group (p>.05). However, several associations were differentially observed in the frequent compared to the infrequent gamblers. These included associations between the

interactive influence of winning and near-miss frequencies and participants' scores on the GRCS gambling expectancy subscale (β=-.015, t (39) = -3.08, p<.05), scores on the GRCS predictive control subscale (β=-.01, t (39) = -2.818, p<.05) and their beliefs of good fortune in gambling as indicated by scores on the luck/perseverance subscale of GBQ (β=-.005, t (39) = -2.401, p<.05).

Among the frequent gamblers, those for whom the influence of near-miss outcome frequency depended more positively on the frequency of co-occurring winning outcomes reported less positive gambling expectancies (β=-.011, t (20) = -3.611, p<.05) (Figure 4), weaker beliefs in predictive control in gambling (β=-.006, t (20) = -2.203, p<.05) (Figure 5), and weaker beliefs of good luck and persistence in gambling as measured by GBQ (β=-.003, t (20) = -2.167, p<.05). Equivalent associations were not found in the infrequent gamblers (ps>.1).

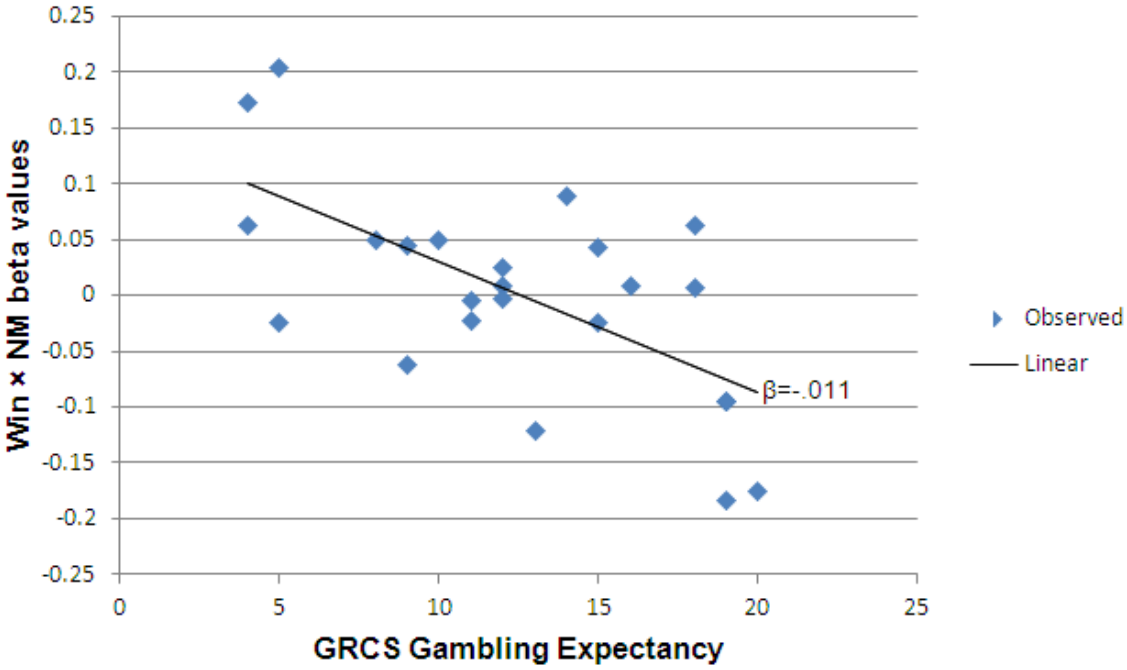


Figure 4. The association between the interactive influence of winning and near-miss frequencies on the number of optional plays bought, expressed as unstandardized regression coefficient beta values, and participants' scores on the gambling expectancy subscale of GRCS, among the group of frequent gamblers. NM: near-miss outcomes.

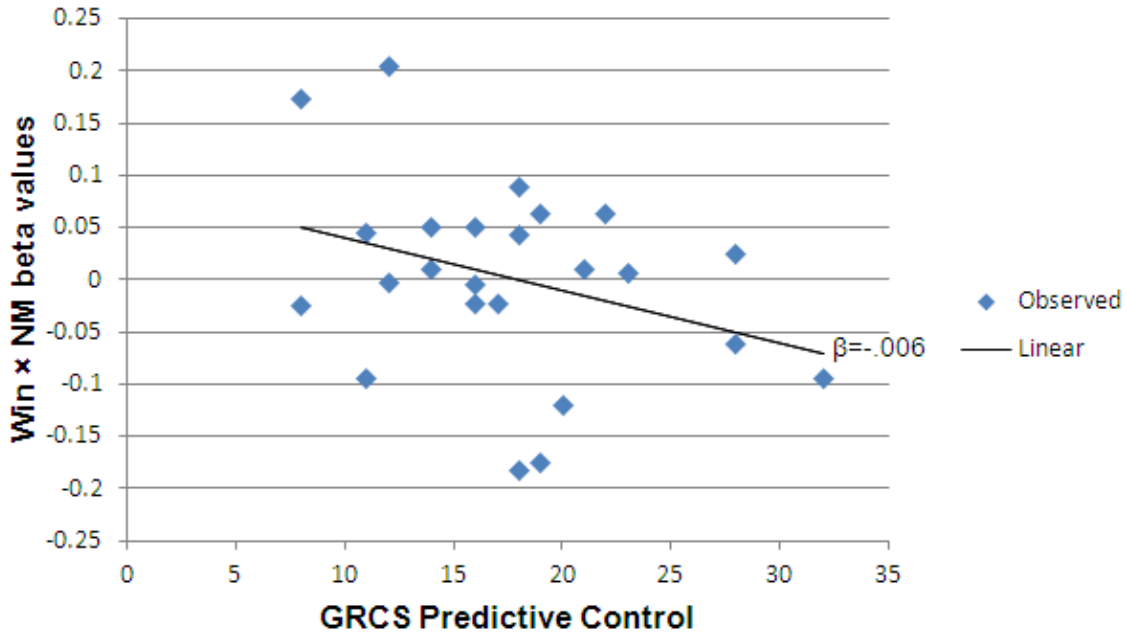


Figure 5. The association between the interactive influence of winning and near-miss frequencies on the number of optional plays bought, expressed as unstandardized regression coefficient beta values, and participants' scores on the predictive control subscale of GRCS, among the group of frequent gamblers. NM: near-miss outcomes.

Card-game betting behaviour

ANOVA Participants' average bet sizes in the self- and computer-choose conditions of the card game are shown in Table 2. Bet sizes are shown separately for bonus and non-bonus plays. Participants placed significantly larger bets when they were allowed to choose the cards compared to when the computer chose the cards for them ($F (1, 49) = 16.842$, $p<.05$). They also betted higher on bonus plays compared to non-bonus plays ($F (1, 49) = 48.764$, $p<.05$). Frequent gamblers showed a tendency to place larger bets overall than the infrequent gamblers ($F (1, 49) = 3.81$, $p=.057$), but the differences in their bet sizes between the two control conditions were not markedly different from the infrequent gamblers, as indicated by the non-significant condition × group interaction ($p>.1$).

	All plays		Bonus plays		Non-bonus plays	
	Self-choose	Computer-choose	Self-choose	Computer-choose	Self-choose	Computer-choose
Frequent gamblers	18.13±2.66	15.41±2.51	29.94±3.96	27.27±3.80	16.31±2.58	13.59±2.41
Infrequent gamblers	12.05±1.70	10.00±1.42	22.10±3.30	17.68±2.98	10.51±1.57	8.81±1.34
Total	15.03±1.61	12.65±1.46	25.94±2.60	22.38±2.48	13.35±1.54	11.15±1.40

Table 2. Participants' bet sizes in different types of plays (bonus vs. non-bonus) and in different control conditions (self-choose vs. computer-choose). Both the means and the SEs are shown.

Further analyses demonstrated that participants placed larger-sized bets when they were allowed to choose the cards themselves compared to when the computer made the card choices, both for bonus plays ($F (1, 49) = 10.832$,

$p<.05$) and for non-bonus plays ($F (1, 49) = 18.932$, $p<.05$). The average bet sizes in the bonus plays where the prize amounts were doubled were also significantly greater than those in the non-bonus plays in both the self-choose ($F (1, 49) = 49.975$, $p<.05$) and the computer-choose (($F (1, 49) = 40.985$, $p<.05$) conditions.

Similar results were obtained using one-sample t-tests on the betting ratios, calculated by dividing participants' bet sizes in the self-choose condition by their bet sizes in the computer-choose condition. Overall, the betting ratio was significantly greater than 1 for both the bonus ($t (50) = 2.919$, $p<.05$) and the non-bonus ($t (50) = 3.525$, $p<.05$) plays. Analyses of bets placed by the frequent gamblers and infrequent gamblers separately confirmed that both the bonus and non-bonus ratios were greater than 1 in the frequent gamblers ($t (24) = 2.319$, $p<.05$ and $t (24) = 2.729$, $p<.05$, respectively) and infrequent gamblers ($t (25) = 2.491$, $p<.05$ and $t (25) = 2.328$, $p<.05$, respectively) (Figure 6).

The above results on participants' betting behaviours in the card game were consistent with the findings of Experiment 3 and provided strong evidence that both frequent and infrequent gamblers betted higher stakes when they had control over which cards to choose.

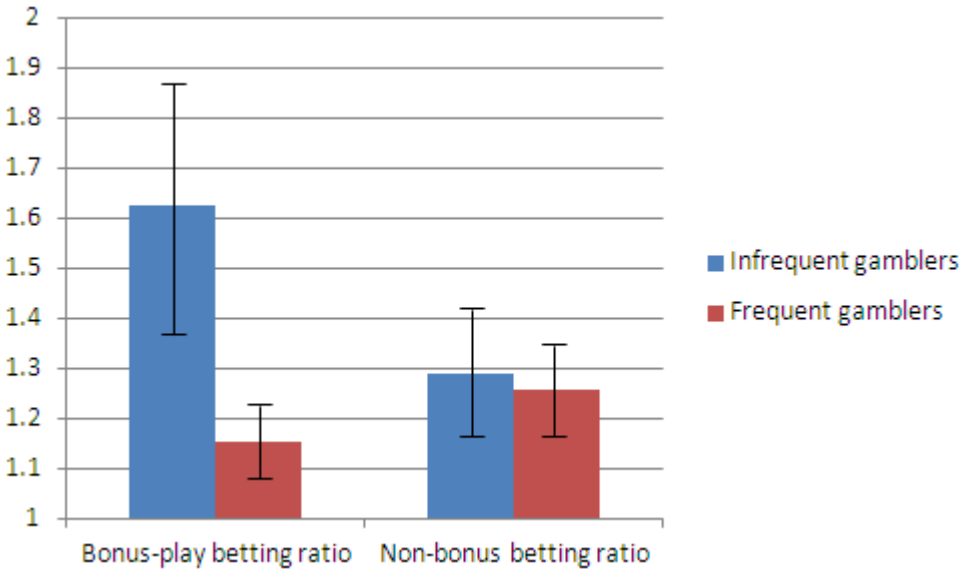


Figure 6. Frequent and infrequent gamblers' betting ratios, calculated as their mean bet sizes in the self-choose condition divided by their mean bet sizes in the computer-choose condition, over the bonus and non-bonus plays of the card game. Error bars indicate standard errors of the mean.

Regression analyses We performed similar regression analyses between participants' betting ratios in the card game and their gambling-related psychometric scores, group/gambling status and the psychometric score × group interaction, controlling for variables of age and IQ. No significant associations were found between betting ratios calculated over all plays and any of the psychometric measures (ps>.05).

However, betting ratios calculated over bonus plays showed positive associations with psychometric scores of infrequent gamblers, including illusions of control as measured by GBQ (β=.048, t (45) = 2.335, p<.05) (Figure 7) and GRCS illusion of control subscale (β=.203, t (45) = 3.88, p<.05), beliefs of predictive control in gambling (β=.072, t (45) = 2.991, p<.05) and biased interpretation of gambling outcomes (β=.071, t (45) = 2.158, p<.05) as

measured by GRCS. Among infrequent gamblers, bonus-play betting ratios were also positively associated with participants' beliefs of good luck and persistence in gambling as measured by GBQ (β=.053, t (45) = 4.203, p<.05). None of the above associations were observed in the frequent gamblers (ps>.1).

Finally, we carried out regression analyses with the betting ratios from the card game as the dependent variable, and the regression coefficient beta values from the slot-machine game, participants' group status and their interaction as independent variables, controlling for age and IQ. These analyses revealed no significant associations (p>.05).

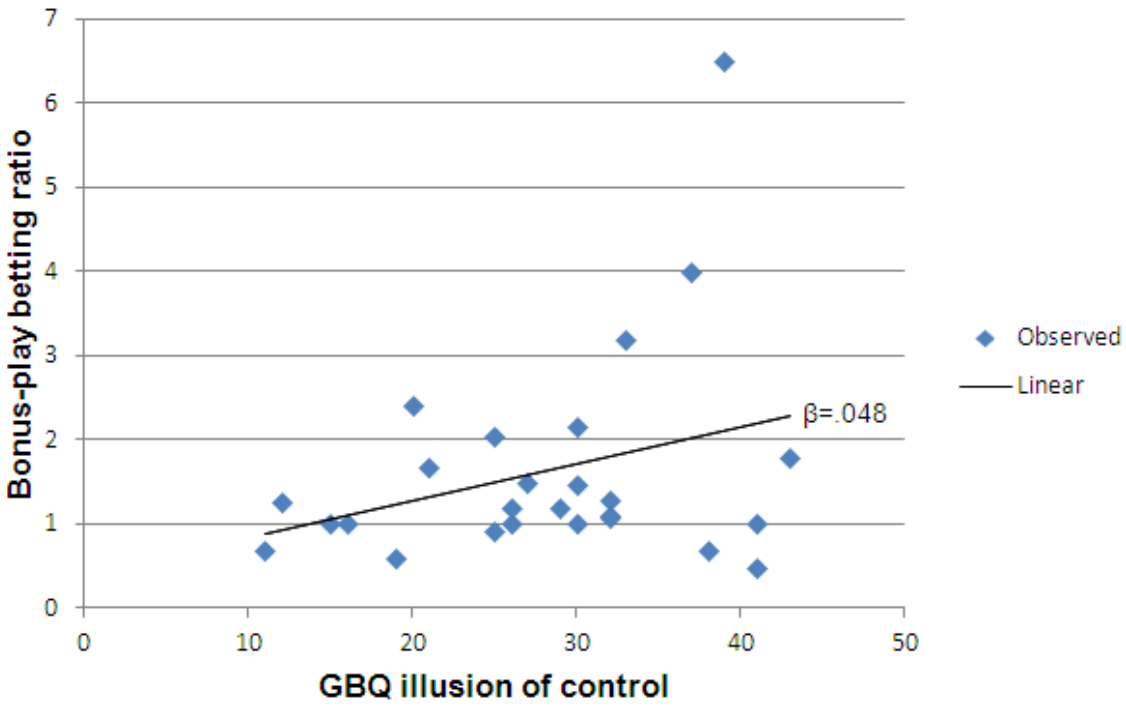


Figure 7. The association between infrequent gamblers' betting ratios over the bonus plays of the card game and their scores on the illusion of control subscale of the Gamblers' Beliefs Questionnaire.

Discussion

An overview of results The design of Experiment 4 was similar to that of Experiment 3, with several modifications to the slot-machine game and participant samples. Each round of the slot-machine game contained twice the number of plays (i.e. 12) as the game in Experiment 3, which allowed participants to valuate the game over more prolonged play experiences. Participants also did not need to complete the optional plays they decided to buy. Moreover, participants were asked to rate the feelings of enjoyment and perceived luckiness following each round, which was to help us understand the cognitive and emotional mechanisms of the near-miss effects on gambling behaviour. Finally, we recruited both infrequent gamblers and frequent gamblers in Experiment 4. Inspection of the differences between these 2 groups could tell us more about the influences of near-miss and winning outcomes on participants' game valuations, and their associations with cognitive biases, among people with varying amounts of gambling participation.

Experiment 4 found that the frequency of winning outcomes in a simple 3-reel slot-machine game had positive influence over participants' *mean* game valuations, as indicated by the number of optional plays bought, their *mean* feelings of enjoyment and perceived luckiness. As in Experiment 3, the frequency of near-miss outcomes had no effect on the number of plays purchased. However, near-miss frequency had positive effect on participants' *mean* enjoyment ratings. Moreover, similar to Experiment 3, we found some statistical evidence that among participants with very limited gambling

involvement, the intermediate frequency of near-miss outcomes (i.e. 1 in 6) tended to increase the number of optional plays bought if co-occurring with an intermediate frequency of winning outcomes (1 in 6). However, no positive influence of near-miss frequency was observed following either 0 or the highest frequency of winning outcomes (1 in 3) (Figure 2b). These joint influences of near-miss and winning frequencies on purchasing behaviour were, perhaps surprisingly, not observed among participants who reported frequent gambling participation (Figure 2a). We also found that, as in Experiment 3, both frequent and infrequent gamblers betted higher stakes when choosing their own cards in the card game compared to when the computer chose the cards.

Among the frequent gamblers, those who were less positively influenced by the interaction of winning and near-miss frequencies in terms of the number of optional plays bought showed more positive gambling expectancies, stronger beliefs in good luck and persistence in gambling, and stronger beliefs in predictive control. Finally, among the infrequent gamblers, those who placed much larger bets in the bonus plays when they chose the cards compared to when computer chose the cards showed higher levels of illusions of control as measured by the illusion of control, predictive control and interpretative bias subscales of GRCS and the illusion of control subscale of GBQ.

Slot-machine outcomes influence game valuations Experiment 4 found that participants chose to buy larger numbers of optional plays following the delivery of more frequent winning outcomes in rounds of the slot-machine game. These

participants also reported greater levels of enjoyment from playing rounds containing more winning outcomes. These findings offer some reassurance that our model of purchasing behaviour can be developed to measure the way that people valuate EGMs such as slot-machines which is sensitive to individual differences in gambling behaviour and its underlying cognitive and emotional processes. Although being entirely expected, these findings are also consistent with the idea that it is the winning outcomes of a slot-machine game that act as the most powerful positive reinforcement stimuli (Kassinove and Schare, 2001), encouraging people to engage in further gambling behaviour. Experiment 4 also demonstrated that high frequencies of winning outcomes enhanced participants' perceived luckiness, which may again facilitate further play (Wohl and Enzle, 2003). Our findings also indicate an absence of the influence of 'gambler's fallacy' (Rogers, 1998; Griffiths, 1994), which would have been manifested as the belief that the chances of further winning outcomes would be lower in the optional plays following rounds containing high frequencies of winning outcomes, prompting participants to buy fewer rather than more optional plays.

By contrast, as in Experiment 3, we found little evidence that near-miss outcomes had positive effect on the number of optional plays bought, suggesting that overall, the effect of near-miss outcomes on positive valuations of slot-machine games is either absent or much weaker than the effect of winning outcomes. However, as in Experiment 3, we found that the influence of the frequency of near-miss outcomes on participants' buying behaviours depended on the frequency of the co-occurring winning outcomes, as revealed by the analyses of trends, which effects depended upon gambling involvement.

Specifically, among participants with limited gambling involvement only, an intermediate frequency of near-miss outcomes (i.e. 1 in 6) in a slot-machine round was associated with more optional plays purchased when the round also delivered an intermediate frequency of winning outcomes (1 in 6). However, no clear positive influence of near-miss frequency was observed when either 0 or the highest frequency of winning outcomes (1 in 3) was delivered (Figure 2b). These joint influences of near-miss and winning frequencies on purchasing behaviour was characterised by a quadratic trend effect of near-miss frequency modulated by a quadratic trend of win frequency.

On the other hand, there was little evidence for the interactive influence of near-miss and winning frequencies on purchasing behaviour among participants who gambled frequently. No previous study has investigated the joint influence of winning and near-miss slot-machine outcomes on the play behaviours of regular compared to occasional gamblers. Other evidence suggests that compared to other losses, near-miss outcomes produce large BOLD amplitudes within reinforcement circuitries among gamblers with high SOGS scores (Chase and Clark, 2010) and among a sample of pathological gamblers (Habib and Dixon, 2010). In addition, young frequent slot-machine players report positive feelings associated with the experience of near-miss outcomes, which may have contributed to their persistence in play (Griffiths, 1994). However, in Experiment 4 we found that the interactive influence of winning and near-miss frequencies on purchasing behaviour was most clearly expressed in the infrequent compared to the frequent gamblers. At the current time, it is unclear why this should be so but, as suggested in Chapter 4, it might be that individuals use

both winning and near-miss frequencies when attempting to model the likely outcome structure of EGMs during play. Infrequent gamblers, who were relatively unfamiliar with the structure of the game, may be more inclined to consider the frequencies of both winning and near-miss outcomes when forming game valuations.

Slot-machine outcomes influence ratings of enjoyment Experiment 4 also showed that participants reported higher levels of enjoyment following rounds containing larger numbers of near-miss outcomes. Detailed examination of the trend of effects upon enjoyment ratings among the 2 groups of participants separately revealed that in the frequent gamblers, near-miss outcomes had positive linear influence on enjoyment when either 0 or an intermediate frequency of winning outcomes (1 in 6) was delivered (Figure 3a). By contrast, amongst the infrequent gamblers, intermediate frequency of near-miss outcomes (1 in 6) tended to increase enjoyment when no winning outcome was delivered, but the frequency of near-miss outcomes had marginal negative linear influence upon enjoyment when the intermediate frequency of winning outcomes (1 in 6) was delivered (Figure 3b). Thus, the data suggest that near-miss outcomes may enhance the enjoyment of playing slot-machine games among frequent gamblers, consistent with previous findings (Griffiths, 1994). However, under some conditions at least, near-miss outcomes may reduce enjoyment in occasional gamblers. This finding is consistent with both the broader proposal that near-miss outcomes encourage gambling by acting as appetitive conditioned stimuli (Reid, 1986), and aspects of the negative affect

theory that near-miss outcomes motivate further gambling behaviours through eliciting negative emotions and frustration (Loftus and Loftus, 1983).

The interactive influence of winning and near-miss frequencies and cognitive bias Among frequent gamblers, those individuals who showed less positive interactive effects of winning and near-miss frequencies upon purchasing behaviour tended to endorse stronger beliefs that persistence in gambling would eventually lead to success and positive outcomes, as measured by the luck/perseverance subscale of the GBQ and the gambling expectancy subscale of the GRCS (Figure 4). Similar negative association was found between the interactive effect of winning and near-miss frequencies and participants' beliefs in predictive control in gambling as measured by the GRCS (Figure 5). One implication of these findings is that regular gamblers endorsing high levels of cognitive biases in gambling ascribe positive reinforcement value to near-miss outcomes even when no winning outcomes were delivered. As such, these individuals may constantly consider themselves as 'nearly-winning', not losing, when experiencing consecutive near-miss outcomes in gambling (Griffiths, 1991); they may also be particularly likely to engage in persistent gambling on EGMs which deliver disproportionately high frequencies of near-miss outcomes compared to winning outcomes (Harrigan, 2007, 2009). Another implication of these findings is that regular gamblers with heightened positive gambling expectancy and stronger beliefs in predictive control have difficulties in integrating the frequencies of both winning and near-miss outcomes when making play decisions. This might make it more difficult for these individuals to build a comprehensive mental model of the game's outcome structures.

Participants' betting behaviours in the card-guessing game In Experiment 4, we also replicated the findings of Experiment 3 that participants exhibited betting patterns in our card game that have previously been taken to indicate illusions of control (Langer, 1975; Martinez et al., 2011). Both frequent and infrequent gamblers betted significantly higher stakes when they were allowed to choose the cards compared to when computer chose the cards, and they did so in both the ordinary plays and the bonus plays which offer 'double' prize.

Previous studies showed that regular slot-machine gamblers considered the game as more skill-oriented and themselves as possessing more skills than irregular gamblers did (Griffiths, 1994). Also, frequent gamblers made more statements suggesting illusions of control than infrequent gamblers, who tended to consider luck and chance as more important than skills (Strickland et al., 2006). In Experiment 4, we managed to demonstrate that game-play behaviours indicative of illusions of control are apparent in both frequent and infrequent gamblers, with no clear difference between them.

However, similar to Experiment 3, we again found no clear association between participants' betting ratios in the card game and their scores on psychometric measures of illusions of control in gambling among either the frequent gamblers or the infrequent gamblers, raising the possibility that the behaviours seen in our card game do not reflect illusions of control as measured by the GBQ or the GRCS. On the other hand, participants' betting ratios in the bonus plays which

offer ‘double’ prizes were positively associated with scores on the illusion of control subscale of GBQ and GRCS, as well as scores on the predictive control and interpretative bias subscales of GRCS, among the group of infrequent gamblers. It might be that betting behaviours in gambling contexts involving high potential returns are more reflective of illusions of control as assessed by psychometric measures, compared to betting patterns when only moderate returns are available.

A summary of results and directions for Experiment 5 In Experiment 4, we found evidence that the frequency of winning outcomes, but not that of the near-miss outcomes, influenced the mean number of optional plays purchased by the frequent and infrequent gamblers. We also found, as in Experiment 4, that the frequency of near-miss slot-machine outcomes on purchasing behaviour was dependent on the frequency of co-occurring winning outcomes. The intermediate frequency of near-miss outcomes (1 in 6) led participants to buy larger numbers of optional plays if co-occurring with the intermediate frequency of winning outcomes (1 in 6). No positive influence of near-miss outcomes was observed when either no or the highest frequency of winning outcomes (1 in 3) was delivered. We also replicated the results of Experiment 3 that both frequent and infrequent gamblers placed higher bets in the card-guessing game when they chose the cards compared to when computer chose the cards. Furthermore, frequent gamblers who reported more optimistic expectancies and stronger beliefs in predictive control in gambling were less positively influenced by the interactive influence of winning and near-miss frequencies when deciding the number of optional plays to buy. Finally, infrequent gamblers who showed

larger betting ratios in the bonus plays of the card game reported higher levels of illusions of control on the psychometric scales.

Thus, Experiment 4 provided further evidence that participants' valuations of the slot-machine game, expressed both as purchase of optional plays and affect ratings, were jointly influenced by the frequencies of winning and near-miss outcomes. However, we now sought to test whether further optimisations of the paradigm might tell us more about the interactive influence of winning and near-miss outcome frequencies on slot-machine play, among a more homogenous group of individuals with very limited gambling involvement. Improvements made to the slot-machine game included shortening the rounds from 12 to 9 plays, and reverting to the design that required participants to actually complete the purchased plays. Also importantly, the discontinuous numbers of 0, 2 or 4 winning and near-miss outcomes in each round were replaced by continuous numbers of 0, 1, 2 or 3.

Chapter VI–Experiment 5

Introduction

In Experiment 4, we used a slot machine game modified from the one used in Experiment 3 to test further the association between the frequencies of near-miss and winning outcomes and participants' valuations of the slot-machine game. We obtained results which partially overlapped with the findings of Experiment 3. In both these studies, we found no positive influence of near-miss outcomes in rounds containing either 0 or the highest frequency of winning outcomes. However, the intermediate frequency of near-miss outcomes led to relatively high numbers of optional plays bought if the round also contained the intermediate frequency of winning outcomes.

On the other hand, the results of Experiment 3 and Experiment 4 were also slightly different. For example, when winning outcomes occurred at an intermediate frequency of 1 in 6, near-miss outcomes delivered at the highest frequency (1 in 3) led to relatively more optional-play buying in Experiment 3 but less buying in Experiment 4, among participants with very limited gambling involvements.

We speculated that these differences might arise from several aspects of game and experimental design. First, each round of the slot-machine game used in

Experiment 4 contained twice as many winning, near-miss and loss outcomes as the rounds of the game used in Experiment 3, while each reel spin of Experiment 4's game was shorter in duration than the spins in Experiment 3's game. These changes were motivated by the goals to test the near-miss effect on participants' learning over more extended game-play experiences, and to make the play experience more like the casual plays that might be encountered in a commercial gambling setting. However, this also meant that both the outcome frequency (the number of a certain type of outcome relative to other types) and outcome rate (the number of a certain outcome over a length of time) were different in the games used by the two experiments. In Experiment 5, we changed the game structure once again by shortening each round to 9 plays, so that the number of plays in each round was closer to that in Experiment 3, but still large enough to provide prolonged play experiences. Each spin in the game used in Experiment 5 lasted for duration of about 2s, similar to the spin durations of the game used in Experiment 4. This was to shorten the overall game time and increase the pace of the game.

Another difference between the games used in Experiment 3 and Experiment 4 was that although the frequencies of winning and near-miss outcomes in the rounds of the two games were the same (0, 1, 2 in 6 plays and 0, 2, 4 in 12 plays), the *absolute* numbers of outcomes in the game used by the latter experiment were not continuous i.e. there were no game rounds containing 1 or 3 winning or near-miss outcomes. This discontinuity in the absolute numbers of outcomes delivered in individual game rounds might mean that the round structure was not optimal, such that participants might have doubts about the

game if they never won 1 or 3 times in a round. In Experiment 5, we solved this problem by having rounds delivering 0, 1, 2 or 3 wins and 0, 1, 2 or 3 near-misses, forming a total of 16 different types. This arrangement of structures eliminated discontinuity in the absolute numbers of outcomes, yet still conformed to the overall variable ratio of 1 in 6 for both winning and near-miss outcomes.

A third notable difference between the 2 experiments was that, while in Experiment 3 participants actually completed the optional plays they decided to buy following each round, in Experiment 4 participants were asked the hypothetical question how many optional plays to buy if given the opportunity, but did not complete those plays. It might be argued that the questions about optional-play buying in the two games indeed measured different aspects of game valuations, as one led to actual play behaviours whereas the other did not. To remedy this, we reverted using the same procedure in Experiment 5 as what we used in Experiment 3 i.e. participants needed to complete the optional plays. Since this meant that the total game durations were also increased, we divided the game into 2 sessions with a short break (6-7 mins).

Lastly, the slot-machine game used in Experiment 3 and in Experiment 4 were programmed using different softwares and consisted of different visual displays and auditory stimuli. The interfaces of the post-round question windows were also quite different. The slot machine game used in Experiment 5 was

programmed using the same software (i.e. Presentation) as the one used in Experiment 3 and was thus comprised of similar visual and auditory features.

Therefore, Experiment 5 employed a new version of the slot-machine game which was designed to be more similar to the one used in Experiment 3, with only a few differences in round structure, spin duration and post-round questions (see Methods). In order to reconcile the findings from the 2 previous experiments on the influences of the frequencies of near-miss and winning outcomes on participants' purchasing behaviours, in Experiment 5 we used a sample of participants who reported very limited involvements in gambling and were thus similar to the sample used by Experiment 3 and the infrequent-gambler sample used by Experiment 4. As in the two previous experiments, we included the illusions-of-control card-guessing game in Experiment 5.

Methods

This study was approved by the Central University Research Ethics Committee. All participants provided fully-informed written consents.

Subjects Fifty-one adults (24 females) recruited from the local area of Oxford participated. Participants' mean age was 24.37 ± 0.85 years (range 18-51 years). The screening included assessment with a semi-structured SCID-I interview to ensure that none of the following exclusion criteria were met: i) major physical illnesses; ii) current or previous DSM-IV major mood or psychotic

disorders; iii) current or previous DSM-IV substance abuse disorders. Participants were also assessed with the National Opinion Research Centre DSM-IV Screening for Gambling Problems (NODS) and the South Oaks Gambling Screening Questionnaire (SOGS) to establish that none had any history of DSM-IV pathological or problem gambling episodes.

All participants were paid £30 plus travelling expenses, which amount comprised of base payments plus winnings from the task games (see below).

Psychometric assessments Participants completed the South Oaks Gambling Screening Questionnaire (SOGS) (Lesieur and Blume, 1987) (range: 0-3, mean=0.33±0.08). Verbal IQ was assessed with the National Adult Reading Test (Nelson, 1982) (range: 102-124, mean=114.69±0.73). The present sample of participants reported no or very limited past or present involvement in gambling activities. Participants' scores on SOGS were mostly 0 and 1, with no one scoring higher than 3. Impulsivity was measured using the I-7 Impulsiveness Scale (Eysenck and Eysenck, 1978, 1985) (range: 0-19, mean=7.84± 0.57).

Participants were also assessed with the Gambling-Related Cognitions Scale (GRCS) (Raylu and Oei, 2004), the Chasing Questionnaire (CHQ) (O'Connor and Dickerson, 2003) and the Gamblers' Beliefs Questionnaire (GBQ)

(Steenbergh et al., 2002) (Table 1). Detailed descriptions of these questionnaires were included in chapter 3 earlier.

	Age	SOGS	GBQ[8]	
			Luck/perseverance	Illusion of control
Males	23.89 ± 0.89	0.37 ± 0.13	29.41 ± 2.12	25.00 ± 1.64
Females	24.92 ± 1.52	0.29 ± 0.09	30.71 ± 2.78	27.42 ± 1.80
Total	24.37 ± 0.85	0.33 ± 0.08	30.02 ± 1.71	26.14 ± 1.21

	I-7	CHQ		
		Win-chasing	Loss-chasing	Near-miss-chasing
Males	9.15 ± 0.81	11.11 ± 1.14	7.59 ± 0.54	3.37 ± 0.27
Females	6.38 ± 0.70	10.21 ± 1.01	8.04 ± 0.71	3.67 ± 0.37
Total	7.84 ± 0.57	10.69 ± 0.76	7.80 ± 0.44	3.51 ± 0.23

	GRCS				
	Gambling Expectancy	Illusion of Control	Predictive Control	Inability to Stop	Interpretative Bias
Males	8.52 ± 0.71	5.56 ± 0.57	13.44 ± 1.07	5.59 ± 0.26	10.15 ± 0.85
Females	6.92 ± 0.81	6.25 ± 0.72	12.63 ± 1.36	6.38 ± 0.76	9.13 ± 1.17
Total	7.76 ± 0.54	5.88 ± 0.45	13.06 ± 0.85	5.96 ± 0.38	9.67 ± 0.71

Table 1. Demographic and psychometric scores (mean and standard error) of male and female participants. SOGS: South Oaks Gambling Screening (Lesieur and Blume, 1987). GBQ: the Gamblers' Beliefs Questionnaire (Steenbergh et al., 2002). I-7: The Eysenck Impulsiveness Questionnaire (Eysenck and Eysenck, 1985). CHQ: the Chasing Questionnaire (O'Connor and Dickerson, 2003). GRCS: the Gambling Related Cognitions Scale (Raylu and Oei, 2004).

Design All participants completed 2 games. The first game was a simple slot machine similar to the one used in Experiment 3 with 1 pay-line and 3 fruit reels (see Methods, Chapter 4). The slot machine game consisted of a total of 64 rounds divided into 2 sessions. Each round had 2 parts: i) 9 compulsory plays with a variable-ratio (VR) of 6 for both winning and near-miss outcomes and ii) optional plays in which the VRs for winning and near-miss outcomes were also set as 6. Participants paid 90 credits per play, or a total of 51,840 credits for all

[8] Scores on the GBQ were inversely coded. See Methods section of Chapter 3.

the compulsory plays, and won back 48,000 credits in total from those plays (a return-to-player of 92.6%). The second game was an illusion-of-control card game consisted of 60 plays in total, out of which 16 ended with winning outcomes (VR = 3.75).

Computer-simulated slot-machine game The slot-machine game was designed and implemented using Presentation v. 14.5 software (Neurobehavioral Systems, San Pablo, USA). As in conventional slot-machine games, the display consisted of 3 horizontal reels showing fruit symbols (Figure 1). Total available credits within each round were displayed at the bottom to the left, and the accumulated prize amount within each round was shown at the bottom to the right. In this game, participants started each round with 2000 credits. The prizes associated with different reel combinations were shown at the top of the display. As in Experiment 3 and 4, all winning outcomes gave a standard prize of 500 credits. Participants completed 64 rounds of 9 plays. Each round was of one of the 4 (rounds containing 0, 1, 2 or 3 plays ending with winning outcomes) × 4 (rounds containing 0, 1, 2 or 3 plays ending with near-miss outcomes) types. Each type of round was repeated 4 times.

Participants pressed the left mouse button with their right hand to start each reel spin, following which the three fruit ‘wheels’ started to rotate at a constant speed of 0.4s per 360º cycle. The reels stopped sequentially from left to right with latencies of 0.6-0.7 seconds between each stop and revealed the outcome, immediately after which participants could press the button again to initiate the

next spin. If the reels displayed 3 identical fruits in a row, participants won a standard reward of 500 credits (all 6 fruit symbols were shown with an equal probability). Near-miss outcomes were defined as those in which the first two reels showed the same fruit while the third reel showed a different fruit. All other outcomes were counted as losses (fruit combinations in the forms of ABB or ABA never occurred, so losing outcomes always involved 3 different symbols). Winning outcomes were signalled by a 'cashing' sound effect and an incremental increase of prize amount by 500. Near-miss and loss outcomes were not accompanied by special visual or sound effects.

In each round, the 9 compulsory plays were followed by the display of a page containing 4 questions (Figure 1). The first question asked how many optional plays participants would like to buy with the remaining credits from the round they just finished, with a range of 0 to 10. Participants could choose one of those numbers with the mouse cursor. They were told that if they chose to buy no optional play, all the remaining credits would be transferred to the bank and added to their total score in the end. If they decided to buy some numbers of optional plays, then the cost of those plays at 90 credits per play would be subtracted from the remaining credits before the latter was transferred to the bank, and the player gained the chance of completing the optional plays before going into the next round. Participants were informed that the whole game would finish after a fixed (unknown) number of individual rounds. They were also told that the total score at the end of game, comprised of the credits in the 'bank' and the total prize sum, would be converted to real money based on comparison with other players and paid to them as part of their experimental fee.

During the course of the game, this accumulated credit score was not visible to the player.

There were also 3 other questions asking participants to rate the chance of winning in the preceding round (question 2, from ‘very poor’ to ‘very great’), the level of enjoyment they experienced (question 3, from ‘not at all’ to ‘very much’), and their perceived luckiness at that moment (question 4, from ‘not at all’ to ‘very lucky’). The ratings were made using the mouse cursor and clicking on different positions of continuous scales (Figure 1).

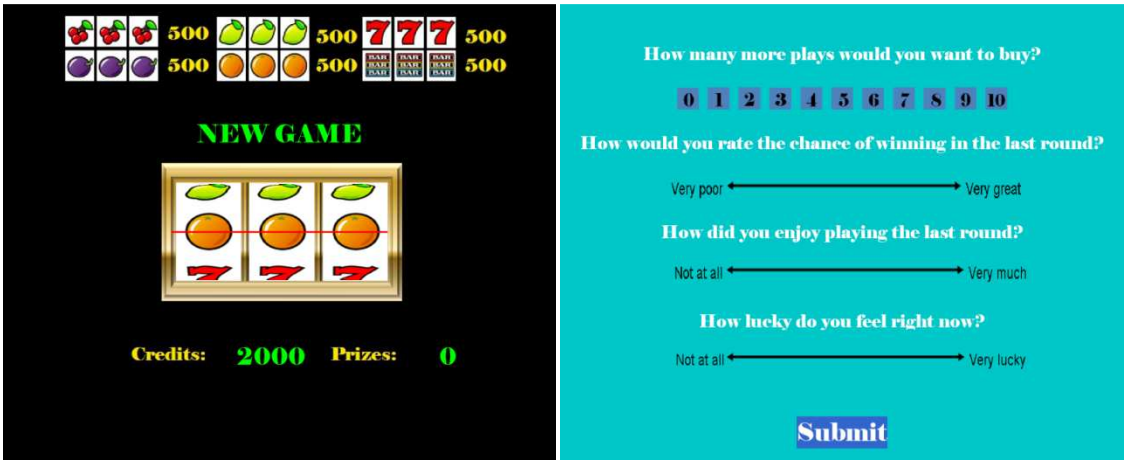


Figure 1. **The computer-simulated slot-machine game**. Left: The game display showed the available credits and accumulated prize amount for the current round, the winning combinations of fruits symbols and the three fruit reels. After a clicking response was made on the left mouse button, the reels started to rotate at a speed of 0.4s per 360º cycle. The reels stopped sequentially from left to right with latencies of 0.6-0.7 seconds between each stop and revealed the outcome, immediately following which participants could press the button again to initiate the next spin. Right: In each round after completion of the 9 compulsory plays, participants were provided with the opportunity to decide how many optional plays to buy (ranging from 0 to 10), indicated by moving the mouse cursor to one of the numbers and clicking on it. After a number was chosen, it was marked by red borders. Participants also needed to answer the 3 rating questions below by clicking on the continuous scales before submitting the responses and going into the next round. See text for more details.

Computer-simulated card-guessing game The card game measuring illusions of control in terms of betting strategies following card selections made by participants versus computer was exactly the same as that used in Experiment 3 and Experiment 4. Detailed descriptions of the game displays and structures were presented in the Methods section of Chapter 4.

Procedure On study day, participants arrived at the University Department of Psychiatry and completed the screening as described above. Following the completion of the psychometric tests, participants were taken into the computer room and played the two games. All participants played the shorter card game first (about 20 mins) before the longer slot-machine game (about 50 mins in total, divided into 2 sessions with a 6-7 mins break in between). After both games were completed, participants were debriefed and filled out a payment form before leaving.

Statistical analyses As in the previous 2 experiments, the main focus of the analyses was to test how the frequencies of winning and near-miss outcomes in slot machine game rounds influenced participants' valuations of the game, as indicated by their buying of optional plays, and how the interactive influence of winning and near-miss frequencies was associated with psychometric measures of gambling-related cognitive biases and behavioural patterns.

Slot-machine data analyses As in Experiment 3 and 4, the analyses of slot-machine data consisted of 2 parts. In the first part, we examined how the frequencies of winning, near-miss outcomes and their interaction influenced participants' decisions on the numbers of optional plays to buy and their win chance, enjoyment and luckiness ratings. This was done with a repeated-measures ANOVA on the numbers of optional plays bought with the numbers of winning (0, 1, 2 or 3) and near-miss (0, 1, 2 or 3) outcomes as within-subjects factors and gender as a between-subjects factor. Simple-effects ANOVAs were carried out to test individual contrasts where applicable. As before, we focused on both the analyses of the effects upon the means and the trend effects. The same analyses were run on the win chance, enjoyment and luckiness ratings.

In the second part of the analyses, we looked at how the influence of the interaction between winning and near-miss frequencies on participants' optional-play buying was associated with participants' scores on gambling-related psychometric measures. At the single-participant level, the number of optional plays bought was regressed against the numbers of winning and near-miss outcomes, plus their interaction (win × near-miss). At the group level, participants' resultant regression coefficient beta values were then regressed against their gambling-related psychometric scores, controlling for other variables such as age and IQ. Moreover, in order to seek for common constructs underlying participants' play behaviours on both games, the regression coefficient beta values obtained from slot-machine data analyses were also regressed against participants' betting ratios in the card game (see below).

Card-game data analyses Participants' bet sizes in the self- and computer-choose conditions were analysed using a repeated-measures ANOVA with condition (self-choose vs. computer-choose) and bonus (2 levels) as the within-subjects variables and gender as the between-subjects variable. We also compared participants' bet sizes in the 2 game conditions using one-sample t-tests on the betting ratios, calculated as the player's averaged bet size in the self-choose condition divided by the averaged bet size in the computer-choose condition. Betting ratios which were significantly greater than 1 suggested overall larger bet size in the self-choose compared to the computer-choose condition. Moreover, regression analyses were performed between the betting ratios and participants' gambling-related psychometric scores, and between the betting ratios and the regression coefficient beta values obtained from the slot-machine data analyses (see above). Significance level was set as $p<.05$ for all statistical tests.

Results

Psychometrics Details of participants' scores on the gambling-related questionnaires are included in Table 1. In general, participants reported infrequent and limited involvement in gambling activities, confined to poker/card games, sports-betting, horse-betting, slot machines, lottery/scratch card, and occasional visits to the casino.

Slot-machine analyses

ANOVA analyses on buying behaviours Ten participants (1 female) were excluded from the slot machine data analyses due to zero optional play buying following every game round or being identified as outliers in the numbers of optional plays bought, leaving 41 participants (23 females). Figure 2 shows the numbers of optional plays bought, expressed as integers from 0 to 10 and averaged across all participants, following the 16 different combinations of winning and near-miss outcomes (0, 1, 2 or 3 wins × 0, 1, 2 or 3 near-misses). As in the 2 previous experiments, the mean number of optional plays bought showed considerable inter-subject variability, ranging between 0.02 ± 0.02 and 4.77 ± 0.52. Overall, the *mean* number of optional plays bought increased significantly with the number of winning outcomes ($F(3, 117) = 6.063$, $p<.05$), but not with the number of near-misses ($F(3, 117) = 1.984$, $p>.1$). The 2-way interaction effect between the numbers of winning and near-miss outcomes was not significant ($F(9, 351) = 1.238$, $p>.1$). Analyses of the trends showed that the effect of win frequency was both linear ($F(1, 39) = 5.782$, $p<.05$) and quadratic ($F(1, 39) = 8.387$, $p<.05$), suggesting that the increase of optional plays bought was not the same as the number of winning outcomes increased from 0 to 1, from 1 to 2 and from 2 to 3. Analyses of the trends also showed a significant interactive effect of winning and near-miss frequencies, characterised by a linear trend effect for near-miss frequency overlaid with a quadratic trend effect for win frequency ($F(1, 39) = 12.017$, $p<.05$).

Inspection of Figure 2 and simple-effects ANOVA analyses revealed that when the preceding round delivered 0 or 1 winning outcomes, participants tended to buy more optional plays following 1 near-miss outcome compared to 3 or 0 near-miss outcomes, respectively. Near-miss outcomes did not have much influence over the number of optional plays bought when there were 2 winning outcomes. However, when co-occurring with the highest frequency of winning outcomes (1 in 3), the frequency of near-miss outcomes exerted a negative linear influence on the number of optional plays bought ($F(1, 39) = 6.139$, $p<.05$) (Figure 2).

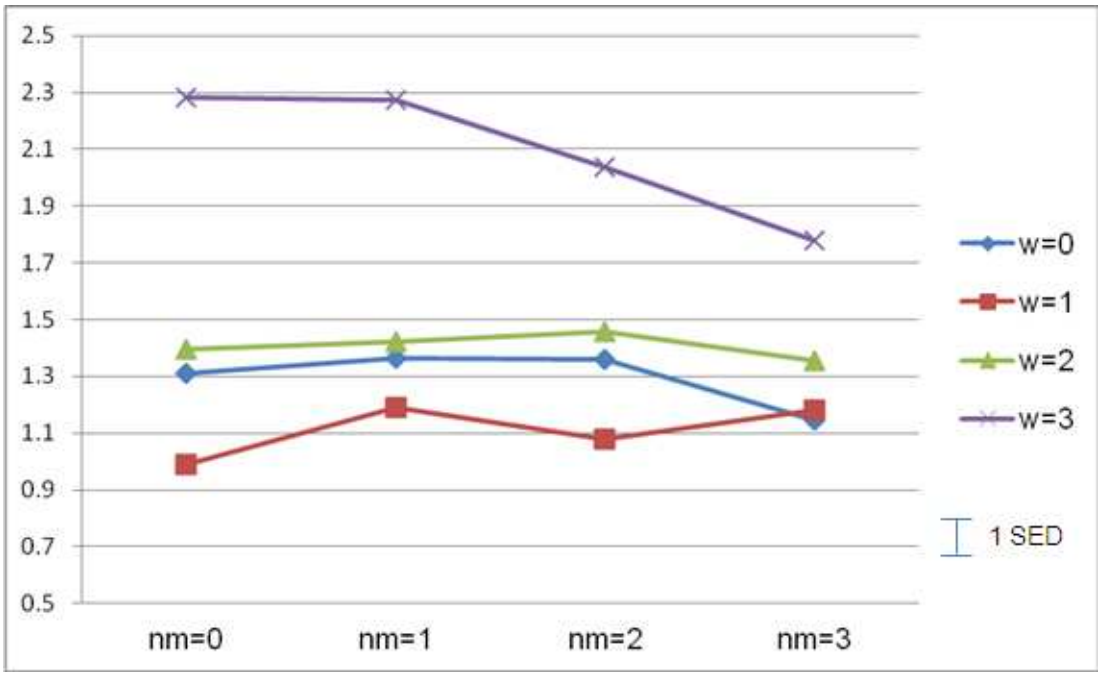


Figure 2. The number of optional plays participants chose to buy immediately following rounds containing different numbers of winning (0, 1, 2 or 3) and near-miss (0, 1, 2 or 3) outcomes. nm: near-miss outcome. 1 SED represents one standard error of the difference on the means for the win × near-miss interaction effect, calculated according to the formula $\sqrt{MSE/n}$, where MSE = mean square of the error term and n equals the sample size (i.e. 41) (Cochran and Cox, 1957).

ANOVA analyses on win-chance ratings Similar repeated-measures ANOVAs were carried out on participants' ratings of the chances of winning, enjoyment and perceived luckiness. Participants reported higher *mean* chances of winning following rounds containing larger numbers of winning outcomes ($F(3, 117) = 70.292$, $p<.05$) (Figure 3). However, participants' *mean* ratings of their chances of winning were not significantly influenced by the number of near-miss outcomes ($F(3, 117) = 0.14$, $p>.1$). The 2-way interaction effect between the numbers of winning and near-miss outcomes was not significant ($F(9, 351) = 0.873$, $p>.1$). Analyses of trends revealed that the effect of winning outcome frequency upon rated chances of winning followed both linear ($F(1, 39) = 79.878$, $p<.05$) and quadratic ($F(1, 39) = 6.046$, $p<.05$) trends.

Examination of the trends also revealed a marginally significant interaction between winning and near-miss frequencies on participants' ratings of their chances of winning ($F(1, 39) = 3.83$, $p=.058$). This interaction was characterised by a quadratic trend effect of near-miss outcome frequency overlaid with a cubic effect of win frequency (Figure 3). Inspection of Figure 3 and simple-effects ANOVA tests revealed that the frequency of near-miss outcomes had little influence in rounds delivering 0 or 1 winning outcome. Following rounds delivering 2 winning outcomes, 0 or 3 near-miss outcomes increased ratings of chances of winning relative to 1 near-miss outcome. This pattern of influence was reversed in rounds that delivered 3 winning outcomes, where near-miss frequency exerted a marginally significant quadratic trend effect ($F(1, 39) = 4.002$, $p=.052$), with 1 near-miss leading to higher ratings of chances of winning than 0 or 3 near-miss outcomes.

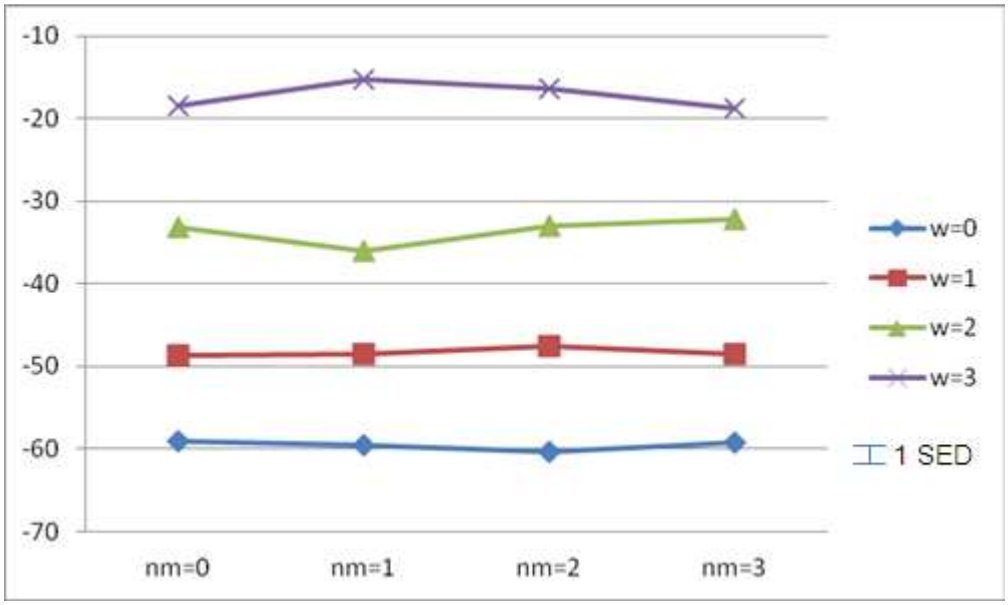


Figure 3. Participants' ratings of chances of winning immediately following rounds containing different numbers of winning (0, 1, 2 or 3) and near-miss (0, 1, 2 or 3) outcomes. w: winning outcome. nm: near-miss outcome. 1 SED represents one standard error of the difference on the means for the win × near-miss interaction effect.

ANOVA analyses on enjoyment ratings Participants reported significantly greater enjoyment following rounds delivering larger numbers of winning outcomes ($F(3, 117) = 56.863$, $p<.05$). By contrast, participants' *mean* ratings of enjoyment did not change with the number of near-miss outcomes ($F(3, 117) = 1.566$, $p>.1$). The 2-way interaction effect between the numbers of winning and near-miss outcomes was not significant ($F(9, 351) = 0.979$, $p>.1$). Analyses of the trends showed that the positive effect of win frequency on rated enjoyment was linear ($F(1, 39) = 65.298$, $p<.05$). There was a near-significant linear trend for near-miss frequency to increase enjoyment ($F(1, 39) = 3.308$, $p=.077$), with 1, 2 or 3 near-miss outcomes producing higher ratings of enjoyment than 0 near-miss outcome (Figure 4).

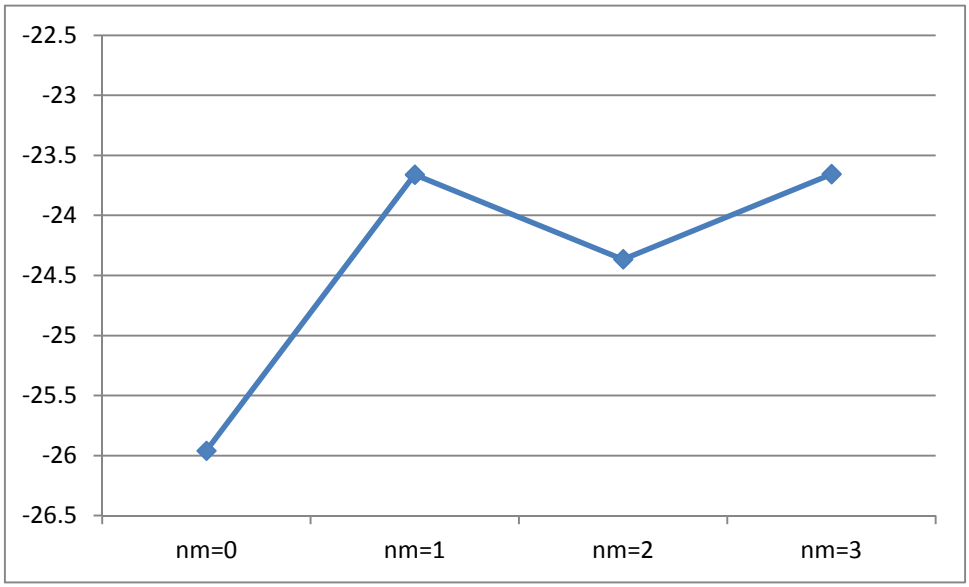


Figure 4. Participants' ratings of enjoyment immediately following rounds containing different numbers of near-miss (0, 1, 2 or 3) outcomes. nm: near-miss outcome.

ANOVA analyses on luckiness ratings Participants' *mean* perceived luckiness increased with the number of winning outcomes ($F(3, 117) = 38.523$, $p<.05$), but did not change significantly with the number of near-miss outcomes ($F(3, 117) = 0.251$, $p>.1$) or with the win × near-miss interaction ($F(9, 351) = 0.587$, $p>.1$).Trend analyses showed that the effect of winning outcome frequency was both linear ($F(1, 39) = 41.47$, $p<.05$) and quadratic ($F(1, 39) = 4.258$, $p<.05$). No significant trend effects were observed for the near-miss frequency or the win × near-miss interaction (ps>.1).

Linear regression analyses on buying behaviour Unstandardized coefficient beta values were obtained by regressing the number of optional plays bought against the frequencies of winning outcomes, near-miss outcomes and their interaction. The beta values representing the interactive influence of winning

and near-miss frequencies on the number of optional plays bought were then regressed against participants' scores on gambling-related psychometric measures, controlling for factors of age and IQ. Participants for whom the influence of near-miss frequency on purchasing behaviours depended more positively on the frequency of winning outcomes reported less positive gambling expectancies as measured by the GRCS (β=-.021, t (37) = -2.885, p<.05) (Figure 5).

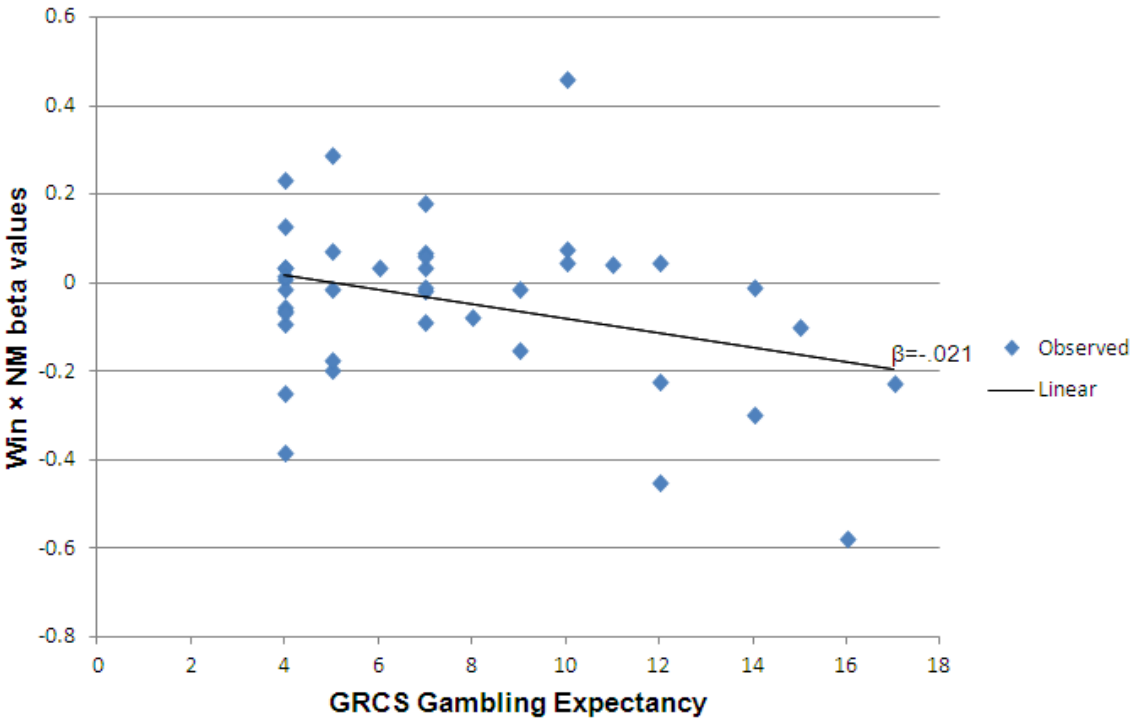


Figure 5. The association between the interactive influence of winning and near-miss frequencies on the number of optional plays bought, expressed as unstandardized regression coefficient beta values, and participants' scores on the gambling expectancy subscale of GRCS. NM: near-miss outcomes.

Card-game betting behaviour

ANOVA Participants' mean bet values in the self- and computer-choose conditions of the card game are shown in Table 2. Bet values are shown separately for bonus and non-bonus plays. Participants placed significantly larger bets when they were allowed to choose the cards in the game compared to when the computer chose the cards for them ($F(1, 49) = 6.32$, $p<.05$). Participants also placed larger bets in bonus plays compared to non-bonus plays ($F(1, 49) = 32.177$, $p<.05$).

Further analyses confirmed that participants placed larger-sized bets when they were allowed to choose the cards themselves compared to when the computer made the card choices, both for bonus plays ($F(1, 49) = 5.298$, $p<.05$) and for non-bonus plays ($F(1, 49) = 5.796$, $p<.05$) separately. The average bet value in the bonus plays where the prize amounts were doubled were also significantly greater than those in the non-bonus plays in both the self-choose ($F(1, 49) = 32.799$, $p<.05$) and the computer-choose ($F(1, 49) = 22.021$, $p<.05$) conditions.

Similar results were obtained for the betting ratios, calculated by dividing participants' bet sizes in the self-choose condition by their bet sizes in the computer-choose condition. Specifically, the betting ratio was significantly greater than 1 in both bonus (mean = 1.83, SE=0.30, $t(50) = 2.764$, $p<.05$) and non-bonus (mean = 1.79, SE=0.32, $t(50) = 2.437$, $p<.05$) plays.

The above results are entirely consistent with findings from both Experiment 3 and Experiment 4 and lend further support to the hypothesis that players bet higher stakes when they have control over which cards to choose.

	All plays	Bonus plays	Non-bonus plays
Self-choose	16.19 ± 1.65	23.53 ± 2.04	15.06 ± 1.67
Computer-choose	12.84 ± 1.52	19.41 ± 2.06	11.83 ± 1.53

Table 2. Players' bet sizes in different types of plays (bonus vs. non-bonus) and different control conditions (self-choose vs. computer-choose). Both the means and the SEs are shown.

Regression analyses We performed similar regression analyses between participants' betting ratios in the card game and their gambling-related psychometric scores, controlling for factors of age and IQ. These analyses revealed no significant associations.

Finally, we carried out regression analyses between the regression coefficient beta values from the slot-machine data and the betting ratios from the card game data, again controlling for age and IQ. These analyses again showed no clear associations.

Discussion

Overview In Experiment 5, we carried out a final investigation of the effects of winning and near-miss frequencies upon the valuation of slot-machine games. Neither Experiment 3 or 4 provided evidence that, overall, near-misses influenced the purchase of optional plays. However, they did provide some statistical evidence for the interactive influence of winning and near-miss frequencies upon purchasing behaviour. Since this evidence was stronger among infrequent gamblers, in Experiment 5 we selected a participant sample with very limited gambling involvement. Experiment 5 also involved several other adaptations to the slot-machine paradigm as suggested by the previous 2 experiments. First, we shortened each game round from 12 plays to 9 plays, which we believed might facilitate the completion of the protocol while still providing sufficient play experience for participants to form adequate game valuations. Second, each round of the game used in Experiment 5 contained continuous numbers of winning and near-miss outcomes (i.e. 0, 1, 2 or 3), which gave rise to the same variable ratio (VR) of 6 for both these outcomes. Third, as in Experiment 3, we asked participants to actually complete the optional plays they bought. Finally, the slot- machine game in Experiment 5 was programmed using the same software as the game in Experiment 3, so that they contained similar visual presentation, interface and auditory stimuli.

The results of Experiment 5 suggest that, similar to the findings of Experiment 4, more frequent winning outcomes increased participants' positive valuations of the slot-machine game, as indicated by the number of optional plays bought, as well as participants' estimates of their chances of winning and perceived

luckiness. Replicating Experiment 4, participants also reported greater enjoyment from playing rounds containing more winning outcomes. In addition, similar to the findings of both Experiment 3 and Experiment 4, the frequency of near-miss outcomes did not change the *mean* number of optional plays purchased. However, there were also some indications that the influence of near-miss frequency on participants' purchasing behaviours depended on the frequency of co-occurring winning outcomes, expressed as a linear trend effect of near-miss frequency overlaid with a quadratic effect of win frequency. Following rounds delivering either 0 or the intermediate frequency of winning outcomes (1 in 9), an intermediate frequency of near-miss outcomes tended to increase the number of optional plays purchased. However, following rounds delivering the highest frequency of winning outcomes (1 in 3), near-miss outcome frequency showed a negative linear influence, with 0 or 1 near-misses leading to more optional plays bought than 2 or 3 near-misses (Figure 2).

We also found that, among participants who reported more positive gambling expectancies as measured by the subscale of the GRCS, the influence of near-miss frequency upon purchasing behaviours was less positively dependent on the frequency of winning outcomes. Finally, no clear associations were found between participants' betting patterns in our card-guessing game and their scores on any of the gambling-related psychometric measures.

Slot-machine outcomes influence game valuations Replicating Experiment 4, we found that participants decided to buy larger numbers of optional plays

following rounds that delivered higher frequencies of winning outcomes. Their estimates of chances of winning and feelings of enjoyment also increased with the number of winning outcomes in the preceding round. Thus, we have convincing evidence that winning outcomes are the principle determinant of participants' game valuations, at least in laboratory conditions, as well as providing the primary motivation for engaging in further gambling behaviours (Kassinove and Schare, 2001). In addition, participants tended to feel luckier following episodes of slot-machine play containing larger numbers of winning outcomes, which may again facilitate gambling (Wohl and Enzle, 2003). By contrast, the frequency of near-miss outcomes did not reliably influence the mean number of optional plays purchased, further highlighting the view that the experience of almost-winning may have only limited or subtle impacts upon perceived game value.

However, as in Experiment 3 and 4, we did find some statistical evidence that the frequencies of winning and near-miss outcomes interacted to influence valuations of the slot-machine game as expressed in the purchasing behaviours, among participants with limited gambling involvement. Specifically, following rounds delivering an intermediate frequency of winning outcomes (1 in 9), the same intermediate frequency of near-miss outcomes led to small increase in the number of optional plays bought. By contrast, following rounds containing the highest frequency of winning outcomes (1 in 3), near-miss frequency exerted a negative linear influence on the number of optional plays bought (Figure 2). These results are similar to the findings of the 2 previous experiments, which also showed that the co-occurrence of an intermediate frequency of both

winning and near-miss outcomes tended to have facilitatory influence on purchasing behaviour, while no positive influence of near-miss frequency was observed when either 0 or the highest frequency of winning outcomes were delivered.

As discussed in Chapter 4, these findings are compatible with at least 2 theories of the near-miss effect in gambling. First, among individuals with limited gambling involvement, slot-machine play is likely to involve a process of building a mental model of the game's outcome structure on the basis of a history of play outcomes. In this context, near-misses could be erroneously interpreted as positive predictive cues for imminent success through fostering illusions of control (Reid, 1986), which can impact on players' game valuations. According to this view, near-miss frequency had little positive influence on game valuations when no winning outcomes were delivered, because players needed to experience some success to maintain the perception of the value of near-miss outcomes in signalling forthcoming wins (Dickerson, 1993). On the other hand, the positive predictive value of near-misses may also decrease when co-occurring with high frequencies of winning outcomes, under which condition there would be little need for players to use near-misses as cues for predicting future outcomes—that is, the predictive value of near-misses was blocked by the more salient winning outcomes which may have even stronger predictive values for future success.

Second, we speculated in Chapter 4 that, based on the negative affect theory of the near-miss effects (Loftus and Loftus, 1983), participants experienced moderate negative emotions and frustration following the delivery of intermediate frequency of near-miss and winning outcomes, which motivated further play (Loftus and Loftus, 1983; Reid, 1986; Clark et al., 2009). However, near-miss outcomes, when delivered in rounds containing no winning outcomes, may produce excessive negative emotions in participants who gamble only occasionally, which may suppress further purchasing behaviours (Dickerson et al., 1991; Dickerson, 1993). On the other hand, when the highest frequency of winning outcomes were delivered, the co-occurring near-miss outcomes may not have elicited sufficient negative emotions, again blocking the facilitatory effect on further gambling.

Slot-machine outcomes influence win-chance ratings Our findings on the influence of the interaction between winning and near-miss frequencies upon participants' ratings of their chances of winning provide further insights on the predictive value of near-misses when co-occurring with different frequencies of wins. Specifically, following rounds delivering a moderately high frequency of winning outcomes (2 in 9), it was the lowest (0 in 9) and the highest (1 in 3) frequencies of near-miss outcomes that led to higher ratings of chances of winning (Figure 3). We speculate that, under the conditions of moderately high frequencies of winning outcomes, a high frequency of near-misses act as positive predictive stimuli and increased participants' estimated chances of winning. On the other hand, zero near-miss outcomes may increase the salience of winning outcomes, again increasing participants' estimated chances

of winning. However, this pattern of influence of near-miss frequency was reversed when the round delivered the highest frequency of winning outcomes. Under this condition, 1 near-miss was associated with higher ratings of chances of winning than 0 or 3 near-misses (Figure 3), as characterised by a marginal quadratic influence of near-miss frequency. Thus, it might be that as the frequency of co-occurring wins increased to the highest, the positive predictive value of high frequencies of near-misses decreased, consistent with the earlier discussions. However, the delivery of 1 near-miss, when co-occurring with the highest frequency of wins, still led to higher ratings of chances of winning than 0 near-misses, possibly because its singular appearance in a slot-machine round increased its salience and hence its predictive value.

The interactive influence of winning and near-miss frequencies and gambling expectancy In addition, as in Experiment 4, Experiment 5 showed that the interactive influence of winning and near-miss frequencies upon purchasing behaviour was less positive among participants who hold stronger beliefs that gambling will bring about positive outcomes. The gambling expectancy subscale of the GRCS predicts severity of gambling problems as measured by SOGS (Oei et al., 2008) and mediates the influence of fate control belief on problem gambling among recreational gamblers (Tang and Wu, 2010). Individuals who score high on this subscale tend to believe that gambling serves good purposes and brings about good outcomes in the future (Raylu and Oei, 2004). These results suggest that prior cognitive biases in relate to gambling expectancies interfere with the construction of a mental model of the game's outcome structures based on the integration of both winning and near-

miss frequencies. The results are also consistent with our further speculation that among participants with more positive expectancies in gambling, near-miss outcomes are perceived as rewarding even when no winning outcomes were delivered. Consequently, these individuals might consider themselves to be 'constantly almost winning' (Griffiths, 1991) or feel that a win is 'just around the corner' during episodes of consecutive losses containing high frequencies of near-miss outcomes. Their vulnerability is exacerbated by the structural characteristics of modern slot-machine devices, which are often constructed to deliver disproportionately high frequencies of near-miss outcomes relative to winning outcomes (Harrigan, 2007, 2009).

Participants' betting behaviours and illusions of control Consistent with what we found in both Experiment 3 and 4, participants of Experiment 5 exhibited betting behaviours in our card-guessing game in ways that have previously been taken as indicative of illusions of control (Langer, 1975; Martinez et al., 2011). This was the case in both ordinary plays and bonus plays which offer 'double' prize. Thus, the card game, which was designed to measure illusions of control using well-controlled task conditions and valid behavioural measures, has proven to be able to elicit manifestations of this cognitive bias in all the 3 experiments and among both frequent and infrequent gamblers

However, as in both Experiment 3 and 4, we found little evidence that participants' betting ratios in the card game were associated with their scores

on any of the psychometric scales assessing illusions of control. As discussed in Chapter 4, the reason for the lack of association is unclear. It might be that the betting patterns shown in our card-guessing game do not reflect illusions of control as expressed in self-report psychometric questionnaires. For example, the illusion of control subscale of the GRCS emphasises charms and luck (Raylu and Oei, 2004), which may be of less importance in a relatively young European sample with limited gambling involvement. Second, the illusions of control measured using the card game might be 'local' and specific to the game, whereas those measured by questionnaires are more general to gambling as a whole. This latter possibility might also explain the lack of association between participants' betting patterns in the card game and their purchasing behaviours following different frequencies of winning and near-miss outcomes in the slot-machine game. Alternatively, it might be that the card game assesses, among others, illusions of 'active' control, such as the attempt to influence the play outcome by controlling the durations of card-shuffle in the self-choose condition, which element is absent in the slot-machine game.

A summary of major results Consistent with the findings of both Experiment 3 and Experiment 4, the frequency of winning slot-machine outcomes exerted principle influence on participants' valuations of the slot-machine game, expressed both in purchasing behaviours and in affect and cognition ratings, while near-miss frequency had no overall positive influence on game valuations. However, again similar to the 2 previous experiments, we found some evidence that participants bought more optional plays following the intermediate frequency of near-miss slot-machine outcomes (1 in 9) if the same intermediate

frequency of winning outcomes (1 in 9) were also delivered. No positive influence of near-miss frequency on purchasing behaviour was observed at either 0 or the highest frequency of winning outcomes. Similar to the results of Experiment 4, participants who reported more positive gambling expectancies showed buying behaviours which were more positively dependent on near-miss outcomes if a lower frequency of winning outcomes were delivered. As in both Experiment 3 and Experiment 4, participants exhibited betting behaviours in the card game that were indicative of illusions of control, which were unrelated to participants' scores on questionnaires assessing this cognitive bias in gambling.

Chapter VII–A general discussion of the thesis

Overview

In this thesis I described 5 experiments. The first 2 experiments investigated the neural mechanisms of slot-machine play, and the other 3 experiments looked at the 'near-miss' effect on people's play behaviours in Electronic Gaming Machines (EGMs) such as slot-machines and in particular, how the frequency of near-miss outcomes interacts with the frequency of co-occurring winning outcomes and jointly determine people's valuations of the game. We obtained valuable findings from each of these experiments, which have important theoretical, clinical and practical implications for future gambling research, treatment of gambling problems and the regulation of gambling industries (e.g. Griffiths, 2008a). In the following sections of this chapter, I will review the findings of each of the 5 experiments and their implications, followed by a discussion of the limitations of the experiments, including suggestions on improvements and future directions. This chapter will be finished with a paragraph of conclusion and final remarks.

Experiment 1: The effects of prior game experience on neural signals during slot-machine play

Outline of experiment and results There has been abundant previous research on the mechanisms of problem or pathological gambling. For example, the integrated pathway model (Blaszczynski and Nower, 2002) proposes that people may be drawn into heavy gambling as a result of cognitive-behavioural conditioning, pre-existing depression and anxiety, or pre-existing impulsivity characteristics. One of the aspects that are lacking in this model and other similar models (e.g. Jacobs, 1988) is the neural mechanism of regular and/or problem gambling. In specific, what changes in neural systems involved in reinforcement processing accompany the transition from someone who has never gambled before to someone who gambles occasionally, and then to someone who gambles regularly and have gambling problems? Studying the neural mechanisms of gambling adds important information to our current understanding of problem gambling and was the goal of my first 2 experiments. We focused on EGM and in particular, slot-machine play because EGMs represent one of the most popular (Turner and Horbay, 2004) and compulsive (Griffiths, 1995a) forms of gambling activity.

In the first fMRI image experiment, we investigated the changes in neural signals during slot-machine play following previous experience with the same game. Existing models of reinforcement learning (e.g. Schultz, 1997a; Hollerman and Schultz, 1998) form the theoretical background for studying the impact of prior experience on neural responses during game play. Based on these models, we predicted that the dopaminergic reinforcement circuitries, in particular the ventral striatum, would show signal increase to the reel spins of the game and signal decrease to the delivery of winning outcomes following

previous game experience, reflecting the changing evaluation of the anticipatory and consummatory aspects of the game. We manipulated game experience by randomly allocating half of our participants to a practiced group, who played the game once in a prolonged session before playing the same game again in the scanner.

The results of experiment 1 confirmed our hypothesis that prior game experience shifts the neural responses within the dopaminergic reinforcement circuitries from the rewarding outcomes to predictive stimuli that signal the possible occurrence of rewards (i.e. reel spins). Ventral striatum, a brain region implicated in reward processing (Elliott et al., 2000) and the coding of reward prediction errors (D'Ardenne et al., 2008), showed both increase in anticipatory signals and decrease in responses to actual winning outcomes. These results are particularly compelling for the following reasons. First, the changes in neural signals were observed following only 1 episode of previous play, which happened 1-3 days before the scan. The results of Experiment 1 thus illustrates the sensitivity of dopaminergic reinforcement circuitries to learning experience within gambling contexts, consistent with findings of previous research (e.g. O'Doherty et al., 2003). The results also suggest that the learning effect was maintained for intervals of days, consistent with research from animal models that the consolidation of reward-related information is supported by activity in the ventral striatum (Lansink et al., 2008). The intervals of 1-3 days between the first and the second episodes of play in the practiced participants also make our findings more ecologically valid, as it is common in real-life commercial settings where people might learn and play a game for 30-60 mins, leave and return

some days later. Finally, the shift of dopaminergic neural activities was observed during playing a slot-machine game which has an overall negative reinforcement schedule i.e. participants always lost credits during the whole course of the game. This suggests that the increase in anticipatory activity within the ventral striatum and the amygdala was not limited to stimuli that have positive predictive values, consistent with evidence that activity of these brain regions codes incentive salience of environmental stimuli (Jensen et al., 2003; Seymour et al., 2004; Yacubian et al., 2006). In the context of slot-machine gambling, this means that the reel spins of game machines, and the configuration of visual and auditory stimuli that accompany them, become more salient and attention-capturing to players with previous experience of play, encouraging further gambling behaviours (Griffiths, 1993a).

Further implications of results The findings of Experiment 1 have 3 further implications. First, the changes in neural responses during slot-machine play following previous game experience were observed among participants with very limited gambling involvement. This illustrates how slot-machine play experience influences neural responses to later play of the same game among non-clinical populations who are not particularly vulnerable to develop problem gambling or other types of impulse-control disorders (APA, 1994). Second, the shift of neural signals from the outcome to the anticipatory phase of the game suggests that a significant proportion of the arousal and enjoyment experienced during slot-machine play might arise from watching the reels spin and waiting for the outcome. In most modern commercial slot-machines, reel-spins are accompanied by distinctive visual effects and auditory features associated with

different prize amounts (Dixon et al., 2010), which makes them more exciting, attention-capturing and arousing. Our findings of Experiment 1 add to the evidence that a large part of the 'addictive potential' of EGMs such as slot-machines is due to the effects of anticipating for prize. Third, our findings suggest that the brain dopaminergic reinforcement pathways play important roles in the acquisition of gambling behaviours, consistent with previous evidence that the dopaminergic neural system functions differently among pathological gamblers compared to controls (e.g. Reuter et al., 2005; Zack and Poulos, 2004, 2007). This in turn has important clinical implications for both the prevention and treatment of gambling problems (Gschwandtner et al., 2001).

Experiment 2: Impulsivity and illusions of control modulate neural responses to slot-machine outcomes

Outline of experiment As described above, individuals who are particularly impulsive might be at higher risk of developing problematic gambling behaviours (Blaszczynski and Nower, 2002). This view is supported by a number of studies which showed that problem (e.g. Clarke, 2004) and pathological gambling (e.g. Nower et al., 2004) are predicted by high impulsivity as measured by the Eysenck's Impulsiveness Scale (EIS) (Eysenck et al., 1985). High impulsivity has also been shown to compromise the treatment outcome of pathological gamblers (Leblond et al., 2003). In addition, there is evidence that high impulsivity is mediated by altered dopaminergic transmissions within the mesolimbic dopamine circuitries (Besson et al., 2010; Dalley et al., 2007; Buckholtz et al., 2010; Bjork et al., 2008). Furthermore,

previous studies found that high-impulsive individuals showed greater activations to reward-predictive cues in a Monetary Incentive Delay (MID) task within the mesolimbic dopaminergic circuitries (Hahn et al., 2009), but high-impulsive alcoholics showed reduced ventral striatum activation during reward anticipation of the same task (Beck et al., 2009). Similarly, illusions of control are associated with the severity of gambling problems (e.g. Carol and Huxley, 1994; Griffiths, 1990) and the level of gambling participation (Griffiths, 1994), and recent evidence suggests that near-miss slot-machine outcomes may encourage gambling through potentiating illusions of control (Clark et al., 2009; Billieux et al., 2011).

Nevertheless, research directly examining the influence of impulsivity and illusions of control on neural responses during slot-machine play among non-clinical population is still lacking. This research could help us understand the neural mechanisms of the association between high impulsivity or high levels of illusions of control and problem gambling, which was the goal of Experiment 2. Since all of our participants in Experiment 2 reported very limited gambling involvement, with levels of impulsivity and illusions of control distributed evenly across the practiced and unpracticed groups, any differences observed in neural activities in relate to these 2 variables of interest could not be attributed to significant pre-existing differences in knowledge or experience with gambling.

Impulsivity modulates BOLD signals to wins and near-misses We found in Experiment 2 some evidence that high impulsivity as measured by the EIS

enhanced the reinforcing effects of winning slot-machine outcomes, as indicated by the influence of EIS scores on both the reaction times during game play and the neural signals to winning outcomes. The more curious results were that individuals who scored higher on impulsivity showed less positive signals to near-miss outcomes in both the ventral striatal regions and the amygdala. Near-miss outcomes are a special type of loss that is close to a win (Reid, 1986). In our 3-reel slot-machine game, near-miss outcomes were those comprised of 2 identical symbols and a third different symbol. A number of previous studies found that near-miss outcomes have potentiating effects on gambling behaviours and encourage further play (e.g. Kassinove and Schare, 2001; Cote et al., 2003). Findings of Experiment 2 revealed that difference in impulsivity levels was associated with different neural processing of near-miss outcomes, which might contribute to the heightened risks of developing gambling problems among high-impulsive individuals.

The above findings have several theoretical, clinical and practical implications. First, the results are incompatible with the theory that near-miss outcomes encourage gambling through acting as ‘mini-wins’, because if they did, high impulsivity would have enhanced the positive neural signals to them, just as it did to winning outcomes. Instead, our findings are more compatible with the view that the BOLD amplitudes elicited by near-miss outcomes within mesolimbic dopaminergic circuitries, as observed in several previous studies (Clark et al., 2009; Chase and Clark, 2010) and in the low-impulsive participants in Experiment 2, signal the negative affects or prediction errors upon

experiencing near-misses (see below). Certainly, more research is needed to examine this question more closely.

Second, the diminished responses in the ventral striatum and amygdala to near-miss outcomes among high-impulsive individuals might reflect the cognitively-mediated attenuation of aversive states following near-miss outcomes, consistent with previous evidence that aversive states are associated with activations within the ventral striatum and amygdala (Coricelli et al., 2005; Nitschke et al., 2006; Goldin et al., 2008), and that aversive signals within the amygdala can be diminished by cognitive re-appraisal (Goldin et al., 2008). This explanation of our results is at odds with the negative affect theory of near-miss effects, which proposes that the negative emotions elicited by near-miss outcomes *potentiate* rather than *suppress* gambling (Loftus and Loftus, 1983), but is consistent with previous finding that high levels of negative emotions suppress gambling behaviours among low-frequency gamblers (Dickerson, 1993). Thus, the diminished negative emotions in response to near-miss outcomes (O'Connor and Dickerson, 2003) might be one reason that high-impulsive individuals are more vulnerable to become heavily involved in gambling, and this could be a potential target for treatment of gambling problems among these individuals.

Third, based on previous findings that salient aversive events elicit positive signals within the ventral striatum which may encode the prediction errors that mediate aversive learning (Seymour et al., 2004), and that monetary losses and

their associated prediction errors may be encoded within the amygdala (Yacubian et al., 2006), it might be that high-impulsive participants in Experiment 2 showed attenuation of positively-signed prediction error signals to near-miss outcomes within the ventral striatum and amygdala. As a result, these individuals were not as good at understanding the underlying reinforcement contingencies of our slot-machine game, which involves learning from previous history of outcomes including near-misses. Interestingly, high impulsivity was not associated with reduced (or increased) neural signals to loss outcomes, suggesting that individuals who are more impulsive might have specific difficulties in learning from near-miss outcomes. This again has clinical implications. For example, a cognitive-behavioural therapy might target to teach high-impulsive problem gamblers the appropriate ways to evaluate near-miss outcomes in gambling. It also has practical implications on the regulation of commercial EGMs. For example, many virtual slot-machines are programmed to deliver disproportionately high frequencies of near-miss outcomes (compared to both winning and losing outcomes) (Harrigan, 2007, 2009), which might be particularly effective in potentiating gambling behaviours among high-impulsive individuals.

Illusions of control modulate near-miss signals after practice We also found that participants' illusions of control scores were positively associated with BOLD amplitudes in the ACC and the insular cortex in response to near-miss outcomes among practiced participants compared to the unpracticed participants. We speculated that a previous prolonged episode of play provided the basis on which beliefs in skill improvement on the game were formed

among practiced participants endorsing high levels of illusions of control, through which near-miss outcomes acquired positive predictive values for imminent success, as expressed in BOLD signals in the ACC and insular regions during playing the game again in the scanner. These results are compelling because the slot-machine game involved little element of control; they also provide evidence supporting the illusions of control theory of the near-miss effect in gambling (Reid, 1986).

Limitations of Experiment 1 and 2

I consider 3 major limitations of the 2 fMRI image experiments. First, our Experiment 1 is only the first step of the investigation of the neural basis for problem gambling. The current findings could be expanded by studying the neural responses during slot-machine play after more prolonged or multi-session previous play experience on the game. Alternatively, neural responses during game play can be compared between regular or problem gamblers and occasional or non-gamblers. Future experiments of the kinds described above should be promising in helping us delineate the neural mechanisms of problem gambling.

Second, the slot-machine game we used in Experiment 1 and 2 was of the very basic form which, while being suitable to test our hypotheses, does not allow participants to make decisions during play. Consequently, one might argue that our findings do not generalize to the more sophisticated games with additional

features, many of which provide the player with opportunities to decide what to do at different points during the course of play (Parke and Griffiths, 2006). Nevertheless, I am inclined to believe that although the modern slot-machine games have undergone significant changes from the older generation, in which the player simply pulls the arm and hopes to get 3 identical symbols in a row, the basic underlying structure of the games stays the same. The slot-machine games we see in commercial settings nowadays still involve 2 key components: the reel-spin and the outcome. I also believe that it is still the case for the modern slot-machine games that a significant proportion of the arousal and excitement players experience arises from watching the reels spin. Thus, my opinion is that the core findings of our experiments may still generalise to the more sophisticated modern EGMs.

Third, our slot-machine game does not provide behavioural measures (except reaction times) based on which participants' learning about the game could be independently estimated. This is again because we used a very basic form of slot-machine game in which participants made unitary motor responses in each play without alternatives. It is possible that we could get a measure of learning by asking participants following each play their estimated chances of winning in the game. However, this would break the flow of the game and make it more likely that participants guessed (or tried to guess) the aim of our experiment. Moreover, given the simplicity of the slot-machine game, we were confident that our practiced participants acquired significant learning about the game in the practice session, which involved as many as 120 plays. This was further supported by the finding that practiced participants overall showed smaller

reaction times than the unpracticed participants, and by the shift of neural signals among practiced participants which was exactly what was found in previous studies after learning had taken place (e.g. Hollerman and Schultz, 1998).

Experiment 3-5: The influence of winning and near-miss frequencies on people's slot-machine game valuations

Outline of experiment After the first 2 fMRI experiments, we carried out 3 behavioural experiments with the aim to investigate in more details the effects of near-miss slot-machine outcome frequency on participants' valuations of the game. Near-miss outcomes have been found previously to encourage gambling on slot-machine games when occurring at a frequency of 25% (Cote et al., 2003), and their potentiating effects are greater when occurring at an intermediate frequency of 30% compared to 15% and 45% (Kassinove and Schare, 2001). Different theories have been advocated to explain the near-miss effects. Near-miss outcomes may act as 'mini-wins' through conditioning, stimulus generalization or verbal associative processes (Reid, 1986; Dixon and Schreiber, 2004). Alternatively, near-miss outcomes may motivate further play through producing negative affects and frustration (Loftus and Loftus, 1983). Furthermore, near-miss outcomes may signal imminent successes through cognitive illusions of control (Reid, 1986; Langer, 1975).

Most of the previous studies that have investigated the near-miss effects in gambling used one of 3 different design approaches. The first involves providing participants the opportunity to freely choose which of several slot-machine games to play, each delivering a different frequency of near-miss outcomes (e.g. MacLin et al., 2007; Kurucz and Kormendi, 2011). The second involves allocating participants randomly to games delivering different frequencies of near-miss outcomes, and assessing their persistence of play in extinction phase in which no winning outcomes are delivered (e.g. Cote et al., 2003; Kassinove and Schare, 2001). The third involves asking participants questions about enjoyment and desirability to play following the delivery of near-miss outcomes (e.g. Clark et al., 2009; Billieux et al., 2011). One shortcoming of all these design approaches is that it is not easy to test the effects of near-miss outcomes in different reinforcement environments i.e. at different frequencies of winning outcomes. For example, a 3 (nm) × 3 (win) design of factors will generate 9 different combinations or conditions. It doesn't seem very practical to ask participants to choose among 9 different machines, or allocating 9 different groups of participants to these 9 conditions. Also, previous studies that adopted the third design approach as described above did not include the frequency of co-occurring winning outcomes as an additional factor that might influence people's appraisal of near-miss outcomes.

Consequently, to the author's knowledge, there has been no study to date that has systematically varied the frequencies of both near-miss and winning outcomes and tested the effect of near-miss outcomes when co-occurring with different frequencies of winning outcomes. We decided to fill in this gap using a

different design approach, which involves asking participants to play a number of rounds of a slot-machine game, each round delivering one of the 9 (Experiment 3 and 4) or 16 (Experiment 5) different combinations of the frequencies of winning and near-miss outcomes. Following each round, we assessed participants' valuations of the game by asking them the numbers of optional plays to buy (Experiment 3, 4 and 5), their estimated chances of winning in the preceding round (Experiment 5), their feelings of enjoyment (Experiment 4 and 5) and perceived luckiness (Experiment 4 and 5). The underlying assumption of this design approach is that participants' responses to the questions were under direct influence of the frequencies of both near-miss and winning outcomes in the preceding round. Our behavioural studies involved mainly people with limited gambling involvement, with Experiment 4 as the only exception involving both occasional and frequent gamblers, as we wanted to test the effect of near-miss frequency on game valuations that was not confounded by previous knowledge or experience with gambling.

The influence of slot-machine outcomes on game valuations Our findings of the 3 behavioural experiments were very consistent. In both Experiment 4 and Experiment 5, the frequency of winning outcomes was the principle determinant of participants' game valuations. By contrast, none of the experiments found any main effect of near-miss frequency on buying behaviours, suggesting that the experience of almost winning may have only subtle or weak influence on game valuations. However, in all these experiments among participants with limited gambling involvement, we found some evidence that the intermediate frequency of near-miss outcomes (1 in 6 in Experiment 3

and 4, 1in 9 in Experiment 5) led participants to form more positive valuations of the game, as expressed in purchasing behaviours, compared to either 0 (Experiment 3 and 5) or the highest frequency (1 in 3, Experiment 4) of near-miss outcomes, provided that the same intermediate frequency of winning outcomes (1 in 6 in Experiment 3 and 4, 1 in 9 in Experiment 5) were also delivered in that round. When the round contained either 0 or the highest frequency of winning outcomes (1 in 3), no positive influence of near-miss frequency on game valuations was observed in any of the experiment. Thus, our findings suggested that there may not exist a 'unitary' near-miss effect that is equally present in all gambling situations. Rather, the effects of near-miss outcomes seemed to depend on both the reinforcement environment and their specific frequency of occurrence.

Implications of the findings The above findings have several theoretical, clinical and practical implications. First, the findings may be compatible with at least 2 theories of the near-miss effect in gambling. Specifically, it is natural to suppose that when participants with limited gambling involvement are introduced to a new slot-machine game, they would try to 'grip' the outcome contingencies of the game by monitoring all types of outcomes, including wins and near-misses, during initial play. In this context, near-miss outcomes might be erroneously interpreted as predictive cues for forthcoming success, through processes such as eliciting illusions of control (Reid, 1986), consistent with the positive association found in Experiment 3 between the interactive influence of winning and near-miss frequencies on purchasing behaviours and participants' beliefs in predictive control in gambling. However, following an episode of play

containing no winning outcomes, the positive predictive value of near-misses may decrease, as does their positive influence on game valuations, consistent with previous observation that the experience of wins has large influence on gamblers' illusions of control (Dickerson, 1993). On the other hand, if the frequency of winning outcomes in the preceding round was very high, it is likely that participants would turn to those outcomes as predictors for future success, and use them as basis for making game valuations, while ignoring the frequency of near-misses. According to this view, players only need limited amount of information when making prediction for future outcomes and forming game valuations. When too much information from different sources is available, players are inclined to pick the source that is the most salient, reliable and informative (i.e. wins) and discard the source that is less so (i.e. near-misses). This speculation is supported by our findings in both Experiment 4 and 5 that winning outcomes are the principle determinant of participants' game valuations expressed in behaviours, affects and cognitions (see above). However, as discussed before, the theory that near-misses acquire positive values through signalling forthcoming success may be difficult to reconcile with our findings from Experiment 2 that impulsivity has opposite influence on neural responses to near-misses and wins.

Alternatively, based on the negative affect theory of the near-miss effect (Loftus and Loftus, 1983), participants experience moderate negative emotion and frustration following the delivery of an intermediate frequency of both winning and near-miss outcomes, which motivates further play. However, near-miss outcomes, if delivered in the absence of winning outcomes, may produce

excessive negative emotion that has been shown previously to suppress gambling behaviours at least among some individuals (Dickerson et al., 1991; Dickerson, 1993), corresponding to our earlier discussion that the diminished BOLD signals observed among high-impulsive individuals in response to near-miss outcomes may reflect cognitively-mediated attenuation of this negative affect. On the other hand, if the preceding round delivered a high frequency of winning outcomes, the co-occurring near-miss outcomes may not elicit sufficient negative emotions to motivate gambling, thus a positive influence of near-miss frequency was again not observed. One shortcoming of this theory is that we did not find clear evidence in Experiment 4 or 5 that participants' enjoyment ratings were under negative influence of near-miss frequency in the absence of winning outcomes. However, it might also be argued that participants' feelings of enjoyment were mostly very low following rounds delivering no wins regardless of the frequency of near-misses in those rounds, thus a facilitatory effect of near-miss outcomes on purchasing behaviours was not observed under those conditions.

Second, our findings have implications for the treatment of gambling problems. According to Blaszczynski and Nower (2002), there exists one group of gamblers who develop gambling problems as a result of behavioural conditioning and cognitive biases, including the potentiating effects of near-miss outcomes. Treating the problems of these individuals involves altering the cognitive biases and conditioning effects associated with near-miss outcomes, using techniques such as CBT. In the only experiment that included people who gamble regularly (Experiment 5), we found no evidence that the influence of

near-miss frequency on game valuations depended on the frequency of winning outcomes among the frequent gamblers, which was in contrast to what we found in people with very limited gambling involvement (see above). If this finding was replicated, it means that frequent gamblers who are more likely to develop gambling problems may be under different influence of the frequency of near-miss outcomes compared to occasional or non-gamblers. For example, these individuals might have difficulties in integrating the frequencies of both near-miss and winning outcomes when forming game valuations. This highlights the importance of targeting at gamblers' evaluation of near-miss outcomes in treatment.

Third, our findings have implications on the regulation of EGMs in commercial settings. For example, if near-miss outcomes encourage gambling through producing negative affect and frustration, then it might help to reduce gambling by introducing mandatory 'breaks' into continuous games which allows the player to have a 'cooling-off' period (Griffiths, 2008a). Similarly, one previous study found that the removal of note receptors on slot-machines reduced gambling among young people, possibly because the need to leave the gambling setting temporally to exchange notes into coins results in a switch from 'hot' to 'cool' state of mind (Hansen and Rossow, 2010). Alternatively, if near-miss outcomes act as positive predictive stimuli through eliciting illusions of control, then the display of accurate information about the game such as the lack of control over outcomes or the negative return to player might reduce gambling, with some supporting evidence (Weatherly and Meier, 2008).

The interactive influence of winning and near-miss frequencies on game valuation and gambling expectancy In all 3 behavioural studies, we also assessed the relationships between the interactive influence of winning and near-miss frequencies on participants' game valuations and their scores on gambling-related cognitive measures. The most consistent finding was that among participants who reported more positive expectancies in gambling, as measured by the GRCS subscale (Raylu and Oei, 2004), the influence of near-miss frequency on purchasing behaviour was less positively dependent on the frequency of co-occurring winning outcomes. This pattern of results was observed in both the frequent gamblers (Experiment 4) and in participants with limited gambling involvement (Experiment 5), and provide important pioneer evidence that people's play behaviours on EGMs such as slot-machines, as influenced by the frequencies of both winning and almost-winning events, are based on their pre-existing cognitive bias in gambling, in particular the belief that gambling will bring about positive outcomes (Raylu and Oei, 2004).

As discussed in Chapter 5 and 6, these results have at least 2 implications. First, it might be that individuals who hold over-optimistic expectancies in gambling have difficulties in effectively integrating the frequencies of both wins and near-misses when building a mental model of the game's outcome contingencies, or at least they do not combine the frequencies of these 2 types of outcomes in the same way as those who are not biased on this aspect of gambling cognition. Other evidence from previous research suggests that the gambling expectancy

subscale of the GRCS predicts severity of gambling problems as measured by SOGS (Oei et al., 2008) and mediates the influence of fate control belief on problem gambling among recreational gamblers (Tang and Wu, 2010). Thus, it is reasonable to suppose that there exists a link between the interactive influence of winning and near-miss frequencies on game valuations as expressed in purchasing behaviour, and vulnerability to gambling problems. This again highlights a potential target for treatment and a need for further research studying this particular cognitive bias of gambling expectancy.

Second, the results can also be interpreted to mean that people with more positive gambling expectancies perceive near-miss outcomes as positively-reinforcing even in the absence of actual success. This probably illustrates the 'purest' form of the near-miss effect which is not conditional on the presence of winning outcomes. It is not difficult to imagine that these individuals would be particularly vulnerable to persistent gambling, particularly on modern EGM devices that are constructed to deliver disproportionately high frequency of near-miss outcomes compared to wins (Harrigan, 2007, 2009), as a result of considering themselves to be 'constantly nearly winning' (Griffiths, 1991) or feeling that a win is 'just around the corner' during consecutive losses containing large numbers of near-misses. This again indicates that individuals who hold positive gambling expectancies are particularly vulnerable to develop problematic gambling behaviours, hence should be an important target for treatment.

Illusions of control and the card-guessing game We also designed a novel card-guessing game which assesses illusions of control using well-balanced experimental conditions involving no element of real control or skill. We used participants' bet size difference between the self-choose and computer-choose conditions as the index for illusions of control for 3 reasons. First, illusions of control are closely related to players' confidence of winning the game and hence the amount of money they would wager (Langer, 1975). Second, bet size is an important index for the amount of total expenditure and chasing behaviour in gambling (O'Connor and Dickerson, 2003), and risk-taking in general is associated with a greater affinity for gambling and more gambling-related problems (Lejuez et al., 2002). Third, bet size has been previously used to assess illusions of control (Langer, 1975; Martinez et al., 2011).

In all 3 behavioural studies, we found that our card game was successful in eliciting behavioural manifestations of illusions of control among both frequent (Experiment 4) and infrequent gamblers (Experiment 3, 4, 5). This pattern of result was also found in both the ordinary plays and the 'bonus' plays which offer double prizes. Thus, the card game has proven to be a valid and sensitive instrument for measuring illusions of control, which can be adapted for use in future studies investigating this cognitive bias among participant samples with different levels of gambling participation.

However, to our surprise, we found little association between participants' betting patterns in the card game and their scores on self-report questionnaires

assessing illusions of control in any of the 3 behavioural experiments. This highlights a potential issue for researchers in this area, such that illusions of control as manifested in game-play behaviours might not be the same as those expressed in self-reports. Previous studies that investigated illusions of control have mostly used either behavioural or self-report measures, but not both (e.g. Carol and Huxley, 1994; Toneatto et al., 1997; Dixon et al., 2007). In one of the few studies that included both types of measures, Martinez et al. (2011) assessed illusions of control using subjective rating scales and the time taken to place a bet, and found that these measures were highly correlated. Our experiments measured illusions of control using both questionnaires such as the GBQ (Steenbergh et al., 2002) and the GRCS (Raylu and Oei, 2004) and the card game, and found little association between them, suggesting that the self-report and behavioural measures of illusions of control may not always converge. One reason for this might be that the illusions of control measured using the card game are 'local' and specific to the game, whereas those measured by questionnaires are more general to gambling as a whole. Clearly, future research is needed to clarify this issue.

Limitations of Experiment 3-5

We also consider 3 major limitations of the behavioural studies. First, Experiment 3-5 represent an initial step towards the understanding of the interactive influence of winning and near-miss frequencies on EGM play. As such, the slot-machine games used in our experiments were relatively basic, with no additional features such as the opportunity to bet on multiple lines (e.g.

Dixon et al. 2010) or bonus (Parke and Griffiths, 2006). It might be argued that the use of more sophisticated machines with added features would offer better player involvement and improve the ecological validity of the findings (Parke and Griffiths, 2006). However, this would complicate our design and data analyses, and might mean that the influence of winning and near-miss frequencies is confounded by previous experience with the game acquired by some individuals but not others.

Second, and relatedly, a 'near-miss' may be a concept representing a continuum, with no identical symbols on the pay line at one end and a 'jackpot' delivering large prize at the other end (Sharpe, 2002). Our experiments only examined one particular type of near-miss which would sit very closely to straight losses on the continuum i.e. 2 identical symbols followed by a third symbol on a 3-reel pay line. Future experiments employing slot-machine games with more reels and features should be able to study other types of near-misses sitting more closely to the other end of the continuum (e.g. Dixon et al., 2010).

Third, only 1 of our studies (Experiment 4) involved individuals who report frequent gambling participations, which limits our confidence on the findings from this sample of participants. Further research is much needed to investigate the interactive influence of winning and near-miss frequencies on EGM play among regular and/or problem gamblers. Also, the type of gambling activities people engage in may be an important factor that was previously associated with the level of cognitive biases in gambling (Myrseth et al., 2010) and the

severity of gambling problems (Petry, 2003), which factor was not examined in our experiments.

Conclusion and final remarks

EGM gambling, while providing highly profitable revenue streams for commercial gambling outlets, is possibly one of the most addictive forms of gambling that has aroused significant concerns from the government and the public. There was a proliferation of research during the last 10-20 years on cognitive biases and personality traits that are closely associated with problematic EGM play, in particular the near-miss effect, illusions of control and impulsivity. Our experiments as presented in this thesis add important new information to our current understanding of how the frequency of near-miss outcomes influence people's valuations of slot-machine games, what changes in neural systems are implicated in the acquisition of slot-machine play experience, and the relationship between impulsivity, illusions of control and the neural processing of winning and near-miss slot-machine outcomes. It is our best hope that our findings provide inspirations for future research on EGM play, which will mean a lot to the development of better gambling industry regulations and treatment of gambling problems.

Reference

Alessi, S., Petry NM (2003). Pathological gambling severity is associated with impulsivity in a delay discounting procedure. Behav Process *64*, 345-354.

Alexander, G., DeLong MR, Strick PL (1986). Parallel organization of functionally segregated circuits linking basal ganglia and cortex. Ann Rev Neurosci *9*, 357-381.

Allcock, C.C., and Grace, D.M. (1988). Pathological gamblers are neither impulsive nor sensation-seekers. Aust N Z J Psychiatry *22*, 307-311.

Ambroggi, F., Ishikawa, A., Fields, H.L., and Nicola, S.M. (2008). Basolateral amygdala neurons facilitate reward-seeking behavior by exciting nucleus accumbens neurons. Neuron *59*, 648-661.

Amiez, C., Joseph, J.P., and Procyk, E. (2006). Reward encoding in the monkey anterior cingulate cortex. Cereb. Cortex *16,* 1040–1055.

APA (1994). *Diagnostic and Statistical Manual of Mental Disorders, 4th edition* (Washington D.C., American Psychiatric Association).

Australia PC (2009). Gambling Inquiry. Available at http://www.pc.gov.au/projects/inquiry/gambling-2009.

Australian Productivity Commission (APC) (1999). Australias Gambling Industries. Report No. 10. Canberra: Ausinfo.

Avanzi, M., Uber, E., and Bonfa, F. (2004). Pathological gambling in two patients on dopamine replacement therapy for Parkinson's disease. Neurol Sci *25*, 98-101.

Balleine, B.W., Delgado, M.R., and Hikosaka, O. (2007). The role of the dorsal striatum in reward and decision-making. J Neurosci *27*, 8161-8165.

Bandini, F., Primavera, A., Pizzorno, M., and Cocito, L. (2007). Using STN DBS and medication reduction as a strategy to treat pathological gambling in Parkinson's disease. Parkinsonism Relat Disord *13*, 369-371.

Barratt, E.S. (1985). Impulsiveness subtraits: Arousal and information processing. In J.T. Spence and C.E. Izard (Eds.), *Motivation, Emotion and Personality* (pp. 137-146) (Elsevier, North-Holland).

Beck, A.T., Steer, R.A., and Brown, G.K. (1996). *Manual for the Beck Depression Inventory-II* (Psychological Corporation, San Antonio, TX).

Beck, A., Schlagenhauf, F., Wustenberg, T., Hein, J., Kienast, T., Kahnt, T., Schmack, K., Hagele, C., Knutson, B., Heinz, A*., et al.* (2009). Ventral striatal activation during reward anticipation correlates with impulsivity in alcoholics. Biol Psychiatry *66*, 734-742.

Beckmann, C.F., and Smith, S.M. (2004). Probabilistic independent component analysis for functional magnetic resonance imaging. IEEE Trans Med Imaging *23*, 137-152.

Behrens, T.E., Woolrich, M.W., Walton, M.E., and Rushworth, M.F. (2007). Learning the value of information in an uncertain world. Nat Neurosci *10*, 1214-1221.

Bergh, C., Eklund, T., Sodersten, P., and Nordin, C. (1997). Altered dopamine function in pathological gambling. Psychol Med *27*, 473-475.

Berridge, K.C. (2007). The debate over dopamine's role in reward: the case for incentive salience. Psychopharmacology (Berl) *191*, 391-431.

Besson, M., Belin, D., McNamara, R., Theobald, D.E., Castel, A., Beckett, V.L., Crittenden, B.M., Newman, A.H., Everitt, B.J., Robbins, T.W.*, et al.* (2010). Dissociable control of impulsivity in rats by dopamine d2/3 receptors in the core and shell subregions of the nucleus accumbens. Neuropsychopharmacology *35*, 560-569.

Billieux, J., Van der Linden, M., Khazaal, Y., Zullino, D., and Clark, L. (2011). Trait gambling cognitions predict near-miss experiences and persistence in laboratory slot machine gambling. British Journal of Psychology Published on-line. DOI: 10.1111/j.2044-8295.2011.02083.x.

Bjork, J.M., Smith, A.R., and Hommer, D.W. (2008). Striatal sensitivity to reward deliveries and omissions in substance dependent patients. NeuroImage *42*, 1609-1621.

Blaszczynski, A. (2000). Pathways to pathological gambling: Identifying typologies. Journal of Gambling Issues *1*. Retrieved from http://jgi.camh.net/doi/full/ 10.4309/ jgi.2000.1.1

Blaszczynski, A., and Nower, L. (2002). A pathways model of problem and pathological gambling. Addiction *97*, 487-499.

Bornhovd, K., Quante, M., Glauche, V., Bromm, B., Weiller, C., and Buchel, C. (2002). Painful stimuli evoke different stimulus-response functions in the amygdala, prefrontal, insula and somatosensory cortex: A single-trial fMRI study. Brain *125,* 1326-1336.

Breen, R. B., and Zimmerman, M. (2005). Rapid onset of pathological gambling in machine gamblers. Journal of Gambling Studies *18*, 31–43.

Breiter, H.C., Aharon, I., Kahneman, D., Dale, A., and Shizgal, P. (2001). Functional imaging of neural responses to expectancy and experience of monetary gains and losses. Neuron *30*, 619-639.

Bromberg-Martin, E.S., Matsumoto, M., and Hikosaka, O. (2010). Distinct tonic and phasic anticipatory activity in lateral habenula and dopamine neurons. Neuron *67*, 144-155.

Buckholtz, J.W., Treadway, M.T., Cowan, R.L., Woodward, N.D., Li, R., Ansari, M.S., Baldwin, R.M., Schwartzman, A.N., Shelby, E.S., Smith, C.E.*, et al.* (2010). Dopaminergic network differences in human impulsivity. Science *329*, 532.

Bush, G., Vogt, B.A., Holmes, J., Dale, A.M., Greve, D., Jenike, M.A., and Rosen, B.R. (2002). Dorsal anterior cingulate cortex: a role in reward-based decision making. Proc Natl Acad Sci U S A *99*, 523-528.

Cardinal, R.N., Pennicott, D.R., Sugathapala, C.L., Robbins, T.W., and Everitt, B.J. (2001). Impulsive choice induced in rats by lesions of the nucleus accumbens core. Science *292*, 2499-2501.

Carlezon, W., Devine, D., and Wise, R. (1995). Habit-forming actions of nomifensine in nucleus accumbens. Psychopharmacology, *122*, 194-197.

Carol, D., and Huxley, J.A. (1994). Cognitive, dispositional, and psychophysiological correlates of dependent slot machine gambling in young people.

Chase, H.W., and Clark, L. (2010). Gambling severity predicts midbrain response to near-miss outcomes. J Neurosci *30*, 6180-6187.

Cho´liz, M. (2009). Experimental analysis of the game in pathological gamblers: effect of the immediacy of the reward in slot machines. J Gambling Stud *26*, 249-256.

Clark, L., Lawrence, A.J., Astley-Jones, F., and Gray, N. (2009). Gambling near-misses enhance motivation to gamble and recruit win-related brain circuitry. Neuron *61*, 481-490.

Clark, L., Crooks, B., Clarke, R., Aitken, M.R., and Dunn, B.D. (2011). Physiological responses to near-miss outcomes and personal control during simulated gambling. J Gambl Stud Published on-line. DOI: 10.1007/s10899-011-9247-z.

Clarke, D. (2004). Impulsiveness, locus of control, motivation and problem gambling. J Gambl Stud 20(4), 319-345.

Clarke, D. (2006). Impulsivity as a mediator in the relationship between depression and problem gambling. Personality and Individual Differences *40*, 5-15.

Cochran, W.G., and Cox, G.M. (1957). *Experimental designs* (Wiley, New York).

Comings, D.E., Rosenthal, R.J., Lesieur, H.R., Rugle, L.J., Muhleman, D., Chiu, C., Dietz, G., and Gade, R. (1996). A study of the dopamine D2 receptor gene in pathological gambling. Pharmacogenetics *6*, 223-234.

Contreras, M., Ceric, F., and Torrealba, F. (2007). Inactivation of the Interoceptive Insula Disrupts Drug Craving and Malaise Induced by Lithium. Science *318*, 655-658.

Coricelli, G., Critchley, H.D., Joffily, M., O'Doherty, J.P., Sirigu, A., and Dolan, R.J. (2005). Regret and its avoidance: a neuroimaging study of choice behavior. Nat Neurosci *8*, 1255-1262.

Cote, D., Caron, A., Aubert, J., Desrochers, V., and Ladouceur, R. (2003). Near wins prolong gambling on a video lottery terminal. J Gambl Stud *19*, 433-438.

Craig, A.D. (2002). How do you feel? Interoception: the sense of the physiological condition of the body. Nat Rev Neurosci *3*, 655-666.

Croxson, P.L., Johansen-Berg, H., Behrens, T.E., Robson, M.D., Pinsk, M.A., et al., (2005). Quantitative investigation of connections of the prefrontal cortex in the human and macaque using probabilistic diffusion tractography. J. Neurosci. *25*, 8854–8866.

D'Ardenne, K., McClure, S.M., Nystrom, L.E., and Cohen, J.D. (2008). BOLD responses reflecting dopaminergic signals in the human ventral tegmental area. Science *319*, 1264-1267.

Dalley, J.W., Fryer, T.D., Brichard, L., Robinson, E.S., Theobald, D.E., Laane, K., Pena, Y., Murphy, E.R., Shah, Y., Probst, K.*, et al.* (2007). Nucleus accumbens D2/3 receptors predict trait impulsivity and cocaine reinforcement. Science *315*, 1267-1270.

Daugherty, D., and MacLin, O.H. (2007). Perception of luck: Near wins and near loss experiences. Analysis of Gambling Behavior 1(2), 123-132.

de Ruiter, M.B., Veltman, D.J., Goudriaan, A.E., Oosterlaan, J., Sjoerds, Z., and van den Brink, W. (2009). Response perseveration and ventral prefrontal sensitivity to reward and punishment in male problem gamblers and smokers. Neuropsychopharmacology *34*, 1027-1038.

Deichmann, R., Gottfried, J.A., Hutton, C., and Turner, R. (2003). Optimized EPI for fMRI studies of the orbitofrontal cortex. Neuroimage *19*, 430-441.

Delfabbro, P.H., and Winefield, A.H. (1999). Poker machine gambling: An analysis of within session characteristics. British Journal of Psychology *90*, 425-439.

Delfabbro, P.H., and Winefield, A.H. (2000). Predictors of irrational thinking in regular slot machine gamblers. J Psychol *134*, 117-128.

Delgado, M., Nystrom LE, Fissell C, Noll C, Fiez JA (2000). Tracking the hemodynamic responses to reward and punishment in the striatum. J Neurophysiol *84*, 3072-3077.

Delgado, M.R., Miller, M.M., Inati, S., and Phelps, E.A. (2005). An fMRI study of reward-related probability learning. Neuroimage *24*, 862-873.

Di Ciano, P., Underwood, R.J., Hagan, J.J., and Everitt, B.J. (2003). Attenuation of cue-controlled cocaine-seeking by a selective D3 dopamine receptor antagonist SB-277011-A. Neuropsychopharmacology *28*, 329-338.

Di Ciano, P., and Everitt, B.J. (2004). Direct interactions between the basolateral amygdala and nucleus accumbens core underlie cocaine-seeking behavior by rats. J Neurosci *24*, 7167-7173.

Dickerson, M., Cunningham, R., England, S.L., and Hinchy, J. (1991). On the determinants of persistent gambling. III. Personality, prior mood, and poker machine play. Int J Addict *26*, 531-548.

Dickerson, M. (1993). Internal and external determinants of persistent gambling: problems in generalising from one form of gambling to another. J Gambl Stud 9(3), 225-245.

Dickerson, M. (2004). *Analysis of clients presenting to problem gambling counselling services, July 2001 to June 2002, client and services analysis report No. 8.* Melbourne: Victorian Government, Department of Human Services.

Diergaarde, L., Pattij, T., Poortvliet, I., Hogenboom, F., de Vries, W., Schoffelmeer, A.N., et al. (2008). Impulsive choice and impulsive action predict vulnerability to distinct stages of nicotine seeking in rats. Biol Psychiatry *63*, 301–308.

Distin, K.M., and Hodgins, D.C. (2001). Narrowed focus and dissociative experiences in a community sample of experienced video lottery gamblers. Canadian Journal of Behavioral Sciences *33(1)*, 58-64.

Dixon, M.R., Hayes, L.J., and Ebbs, R.E. (1998). Engaging in "illusory control" during repeated risk-taking. Psychol Rep *83*, 959-962.

Dixon, M.R., and Schreiber, J.E. (2004). Near-miss effects on response latencies and win estimations of slot machine players. The Psychological Record *54*, 335-348.

Dixon, M.R., Jackson, J.W., Delaney, J., Holton, B., and Crothers, M.C. (2007). Assessing and manipulating the illusion of control of video poker players. Analysis of Gambling behavior *1(2)*, 90-108.

Dixon, M.R., Nastally, B.L., Jackson, J.E., and Habib, R. (2009). Altering the near-miss effect in slot machine gamblers. J Appl Behav Anal *42*, 913-918.

Dixon, M.J., Harrigan, K.A., Sandhu, R., Collins, K., and Fugelsang, J.A. (2010). Losses disguised as wins in modern multi-line video slot machines. Addiction *105*, 1819-1824.

Dodd, M.L., Klos, K.J., Bower, J.H., Geda, Y.E., Josephs, K.A., and Ahlskog, J.E. (2005). Pathological gambling caused by drugs used to treat Parkinson disease. Arch Neurol *62*, 1377-1381.

Dowling, N., Smith, D., and Thomas, T. (2005). Electronic gaming machines: Are they the 'crack-cocaine' of gambling? Addiction *100*, 33-45.

Dreher, J.C., Kohn, P., and Berman, K.F. (2006). Neural coding of distinct statistical properties of reward information in humans. Cereb Cortex *16*, 561-573.

Eadington, W.R. (2007). Gambling policy in the European Union: monopolies, market access, economic rents, and competitive pressures among gaming sectors in the member states. In *Economic aspects of gambling regulation: EU and US perspectives*, T. Coryn, C. Fijnaut, and A. Littler, eds. (Leiden, Martinus Niijhoff).

Elliott, R., Friston, K.J., and Dolan, R.J. (2000). Dissociable neural responses in human reward systems. J Neurosci *20*, 6159-6165.

Everitt, B.J., Cador, M., and Robbins, T.W. (1989). Interactions between the amygdala and ventral striatum in stimulus-reward associations: Studies using a second-order schedule of sexual reinforcement. Neuroscience *30(1),* 63-75.

Everitt, B.J., Morris, K.A., O'Brien, A., and Robbins, T.W. (1991). The basolateral amygdala-ventral striatal system and conditined place preference: further evidence of limbic-striatal interactions underlying reward-related processes. Neuroscience *42(1),* 1-18.

Everitt, B.J., Parkinson, J.A., Olmstead, M.C., Arroyo, M., Robledo, P., and Robbins, T.W. (1999). Associative processes in addiction and reward. The role of amygdala-ventral striatal subsystems. Ann N Y Acad Sci *877*, 412-438.

Everitt, B., and Robbins, T. (2005). Neural systems of reinforcement for drug addiction: from actions to habits to compulsion. Nat Neurosci *8*, 1481-1489.

Eysenck, S.B., and Eysenck, H.J. (1978). Impulsiveness and venturesomeness: their position in a dimensional system of personality description. Psychol Rep *43*, 1247-1255.

Eysenck, S.B.G., Pearson, P.R., Easting, G., and Allsop, j.F. (1985). Age norms for impulsiveness, venturesomeness and empathy in adults. Personality and Individual Differences *6*, 613-619.

Fiorillo, C., Tobler PN, Schultz W (2003). Discrete coding of reward probability and uncertainty by dopamine neurons. Science *299*, 1898-1902.

Forbes, E.E., Brown, S.M., Kimak, M., Ferrell, R.E., Manuck, S.B., and Hariri, A.R. (2009). Genetic variation in components of dopamine neurotransmission impacts ventral striatal reactivity associated with impulsivity. Mol Psychiatry *14*, 60-70.

Frank, M.J., and O'Reilly, R.C. (2006). A mechanistic account of striatal dopamine function in human cognition: psychopharmacological studies with cabergoline and haloperidol. Behav Neurosci *120*, 497-517.

Friston, K.J., Fletcher, P., Josephs, O., Holmes, A., Rugg, M.D., and Turner, R. (1998). Event-related fMRI: characterizing differential responses. Neuroimage *7*, 30-40.

Frith, C.D., Friston, K., Liddle, P.F., and Frackowiak, R.S. (1991). Willed action and the prefrontal cortex in man: A study with PET. Proc. R. Soc. Lond., B Biol. Sci. *244*, 241-246.

Fudge, J.L., Kunishio, K., Walsh, P., Richard, C., and Haber, S.N. (2002). Amygdaloid projections to ventromedial striatal subterritories in the primate. Neuroscience *110*, 257-275.

Gaboury, A., and Ladouceur, R. (1988). *Erroneous perceptions and gambling.* Unpublished Manuscript.

Gaffan, D., and Harrison, S. (1987). Amygdalectomy and disconnection in visual learning for auditory secondary reinforcement by monkeys. J. Neurosci. *7,* 2285-2292.

Galvan, A., Hare, T.A., Davidson, M., Spicer, J., Glover, G., and Casey, B.J. (2005). The role of ventral frontostriatal circuitry in reward-based learning in humans. J Neurosci *25*, 8650-8656.

Gerstein, D., Murphy, S., Toce, M., Volberg, R.A., Harwood, H., and Tucker, A. (1999). Gambling impact and behavioral study. Report to the National Gambling Impact Study Commission, April 1, 1999 (p. 104) (National Opinion Research Center, Chicago, IL).

Ghezzi, P.M., Lyons, C.A., and Dixon, M.R. (2000). Gambling in socialeconomic perspective. In W.K. Bickel and R.E. Vuchinich (eds.) *Reframing health behavior change with behavioral economics* (pp. 313-338) (Lawrence Erlbaum, New Jersey).

Gilovich, T., and Douglas,C. (1986). Biased evaluations of randomly determined gambling outcomes. Journal of Experimental Social Psychology 22, 228-241.

Gjedde, A., Kumakura, Y., Cumming, P., Linnet, J., and Moller, A. (2010). PNAS 23, 107(8), 3870-3875.

Glascher, J., Hampton, A.N., and O'Doherty, J.P. (2009). Determining a role for ventromedial prefrontal cortex in encoding action-based value signals during reward-related decision making. Cereb Cortex *19*, 483-495.

Goldin, P.R., McRae, K., Ramel, W., and Gross, J.J. (2008). The neural bases of emotion regulation: reappraisal and suppression of negative emotion. Biol Psychiatry *63*, 577-586.

Goudriaan, A.E., Oosterlaan, J., De Beurs, E., and Van Den Brink, W. (2008). The role of self-reported impulsivity and reward sensitivity versus neurocognitive measures of disinhibition and decision-making in the prediction of relapse in pathological gamblers. Psychol Med *38*, 41-50.

Griffiths, M.D. (1990). The cognitive psychology of gambling. J Gambl Stud *6(1)*, 31-42.

Griffiths, M.D. (1991). Psychobiology of the near-miss in fruit machine gambling. The Journal of Psychology, *125(3)*, 347-357.

Griffiths, M.D. (1993a). Fruit machine gambling: The importance of structural characteristics. Journal of Gambling Studies *9*, 101-120.

Griffiths, M.D. (1993b). Tolerance in gambling: An objective measure using the psychophysiological analysis of male fruit machine players. Addictive Behaviors *18*, 365-372.

Griffiths, M.D. (1994). The role of cognitive bias and skill in fruit machine gambling. British Journal of Psychology *85* 351-369.

Griffiths, M.D. (1995a). *Adolescent gambling* (Routledge, London).

Griffiths, M.D. (1995b). The role of subjective mood states in the maintenance of fruit machine gambling behaviour. J Gambl Stud *11(2)*, 123-135.

Griffiths, M.D. (2008a). Strategies for detecting and controlling electronic gaming vulerabilities. Casino & Gaming International *4(4)*, 103-108.

Griffiths, M.D. (2008b). Impact of high-stake, high-prize gaming machines on problem gambling: Overview of research findings. (Report to the Gambling Commission).

Gschwandtner, U., Aston, J., Renaud, S., and Fuhr, P. (2001). Pathologic gambling in patients with Parkinson's disease. Clin Neuropharmacol. *24(3)*, 170-2.

Habib, R., and Dixon, M.R. (2010). Neurobehavioral Evidence for the "near-Miss" Effect in Pathological Gamblers. Journal of the Experimental Analysis of Behavior *93*, 313-328.

Hadland, K.A., Rushworth, M.F.S., Gaffan, D., and Passingham, R.E. (2003). The anterior cingulate and reward-guided selection of actions. *J Neurophysiol 89*, 1161–1164.

Hahn, T., Dresler, T., Ehlis, A.C., Plichta, M.M., Heinzel, S., Polak, T., Lesch, K.P., Breuer, F., Jakob, P.M., and Fallgatter, A.J. (2009). Neural response to reward anticipation is modulated by Gray's impulsivity. NeuroImage *46*, 1148-1153.

Hampton, A.N., Bossaerts, P., and O'Doherty, J.P. (2006). The role of the ventromedial prefrontal cortex in abstract state-based inference during decision making in humans. J Neurosci *26*, 8360-8367.

Hampton, A.N., Adolphs, R., Tyszka, M.J., and O'Doherty, J.P. (2007). Contributions of the amygdala to reward expectancy and choice signals in human prefrontal cortex. Neuron *55*, 545-555.

Hansen, M., and Rossow, I. (2010). Limited cash flow on slot machines: Effects of prohibition of note acceptors on adolescent gambling behaviour. Int J Ment Health Addiction 8, 70-81.

Hariri, A.R., Brown, S.M., Williamson, D.E., Flory, J.D., de Wit, H., and Manuck, S.B. (2006). Preference for immediate over delayed rewards is associated with magnitude of ventral striatal activity. J Neurosci *26*, 13213-13217.

Harrigan, K. A. (2007). Slot machine structural characteristics: Distorted player views of payback percentages. Journal of Gambling Issues *20* 215-234.

Harrigan, K. A. (2009). Slot machines: pursuing responsible gaming practices for virtual reels and near misses. Int J Ment Health Addiction *7* 68-83.

Haruno, M., Kuroda, T., Doya, K., Toyama, K., Kimura, M., Samejima, K., Imamizu, H., and Kawato, M. (2004). A neural correlate of reward-based behavioral learning in caudate nucleus: a functional magnetic resonance imaging study of a stochastic decision task. J Neurosci *24*, 1660-1665.

Haruno, M., and Kawato, M. (2006). Different neural correlates of reward expectation and reward expectation error in the putamen and caudate nucleus during stimulus-action-reward association learning. J Neurophysiol *95*, 948-959.

Henslin, J.M. (1967). Craps and magic. American Journal of Sociology 73, 316-330.

Hoebel, B., Monaco, A., Hermandez, L., Aulisi, E., Stanley, B., and Lenard, L. (1983). Self-injection of amphetamine directly into the brain. *Psychopharmacology*, *81*, 158-163.

Holden, C. (2010). Behavioral Addictions Debut in Proposed DSM-V. Science *327*, 935.

Hollerman, J.R., and Schultz, W. (1998). Dopamine neurons report an error in the temporal prediction of reward during learning. Nat Neurosci *1*, 304-309.

Holroyd, C.B., and Coles, M.G. (2002). The neural basis of human error processing: reinforcement learning, dopamine, and the error-related negativity. Psychol Rev *109*, 679–709

Hsu, M., Bhatt, M., Adolphs, R., Tranel, D., and Camerer, C. (2005). Neural systems responding to degrees of uncertainty in human decision-making. Science *310*, 1680-1683.

Hsu, M., Krajbich, I., Zhao, C., and Camerer, C.F. (2009). Neural response to reward anticipation under risk is nonlinear in probabilities. J Neurosci *29*, 2231-2237.

Ito, R., Dalley, J.W., Robbins, T.W., and Everitt, B.J. (2002). Dopamine release in the dorsal striatum during cocaine-seeking behavior under the control of a drug-associated cue. J. Neurosci. *22,* 6247– 6253.

Izuma, K., Saito, D.N., and Sadato, N. (2008). Processing of social and monetary rewards in the human striatum. Neuron *58*, 284–94.

Jackson, A. C., Thomas, S. A., Thomason, N., Holt, T. A., and McCormack, J. (2000). *Analysis of clients presenting to break even problem gambling services, July 1 1998 to June 20 1999. Client and Service Analysis Report no 5.* Melbourne, Victoria: Victorian Department of Human Services.

Jacobs, D.F. (1988). Evidence for a common dissociative-like reaction among addicts. Journal of Gambling Behavior *4*, 27-37.

Jenkinson, M., Bannister, P., Brady, M., and Smith, S. (2002). Improved Optimization for the Robust and Accurate Linear Registration and Motion Correction of Brain Images. NeuroImage *17*, 825-841.

Jenkinson, M. (2003). Fast, automated, N-dimensional phase-unwrapping algorithm. Magnetic Resonance in Medicine *49*, 193-197.

Jensen, J., McIntosh, A., Crawley, A., Mikulis, D., Remington, G., and Kapur, S. (2003). Direct activation of the ventral striatum in anticipation of aversive stimuli. Neuron *40*, 1251-1257.

Jensen, J., Smith, A.J., Willeit, M., Crawley, A.P., Mikulis, D.J., Vitcu, I., and Kapur, S. (2007). Separate brain regions code for salience vs. valence during reward prediction in humans. Hum Brain Mapp *28*, 294-302.

Joukhador, J., Maccallum, F., and Blaszczynski, A. (2003). Differences in cognitive distortions between problem and social gamblers. Psychol Rep *92*, 1203-1214.

Kable, J.W., and Glimcher, P.W. (2007). The neural correlates of subjective value during intertemporal choice. Nat Neurosci *10*, 1625-1633.

Kassinove, J.I., and Schare, M.L. (2001). Effects of the "near miss" and the "big win" on persistence at slot machine gambling. Psychol Addict Behav *15*, 155-158.

Kennerley, S.W., Walton, M.E., Behrens, T.E., Buckley, M.J., and Rushworth, M.F. (2006). Optimal decision making and the anterior cingulate cortex. Nat Neurosci *9*, 940-947.

Knutson, B., Adams CM, Fong GW, Hommer D (2001a). Anticipation of increasing monetary reward selectively recruits nucleus accumbens. J Neurosci *21*, RC159 (151-155).

Knutson, B., Fong, G., Adams, C., Varner, J., and Hommer, D. (2001b). Dissociation of reward anticipation and outcome with event-related fMRI. NeuroReport *12*, 3683-3687.

Knutson, B., Taylor, J., Kaufman, M., Peterson, R., and Glover, G. (2005). Distributed neural representation of expected value. J Neurosci *25*, 4806-4812.

Koepp, M., Gunn, RN, Lawrence, AD, Cunningham, VJ, Dagher, A, Jones, T, Brooks, DJ, Bench, CJ, and Grasby, PM (1998). Evidence for striatal dopamine release during a video game. Nature *393*, 266-268.

Kriegeskorte, N., Simmons, W.K., Bellgowan, P.S., and Baker, C.I. (2009). Circular analysis in systems neuroscience: the dangers of double dipping. Nat Neurosci *12*, 535-540.

Kurucz, G., and Kormendi, A. (2011). Can we perceive near miss? An empirical study. J Gambl Stud Published on-line. DOI 10.1007/s10899-011-9240-6.

LaPlante DA, Nelson SE, LaBrie RA, Shaffer HJ (2011). Disordered gambling, type of gambling and gambling involvement in the British Gambling Prevalence Survey 2007. Eur J Public Health *21***,** 532-537.

Ladouceur, R., Gaboury, A., Dumont, M., and Rochette, P. (1988). Gambling: Relationship between the frequency of wins and irrational thinking. Journal of Psychology *122*, 409-414.

Ladouceur, R. (2004). Perceptions among pathological and nonpathological gamblers. Addict Behav *29*, 555-565.

Ladouceur, R., and Sevigny, S. (2005). Structural characteristics of video lotteries: effects of a stopping device on illusion of control and gambling persistence. J Gambl Stud *21*, 117-131.

Langer, E.J. (1975). The illusion of control. J Personality Soc Psychol *32*, 311-328.

Langer, E.J., and Roth, J. (1975). Heads I win, tail it's chance: The illusions of control as a function of the sequence of outcomes in a purely chance task. Journal of Personality and Social Psychology 32(6), 951-955.

Lansink, C.S., Goltstein, P.M., Lankelma, J.V., Joosten, R.N., McNaughton, B.L., and Pennartz, C.M. (2008). Preferential reactivation of motivationally relevant information in the ventral striatum. J Neurosci *28*, 6372-6382.

Lawrence, A., Luty, J., Bogdan, N., Sahakian, B., and Clark, L. (2009). Problem gamblers share deficits in impulsive decision-making with alcohol-dependent individuals. Addiction *104*, 1006-1015.

Leblond, J., Ladouceur, R., and Blaszczynski, A. (2003). Which pathological gamblers will complete treatment? Br J Clin Psychol *42*, 205-209.

Lehericy, S., Ducros, M., Van de Moortele, P.F., Francois, C., Thivard, L., Poupon, C., Swindale, N., Ugurbil, K., and Kim, D.S. (2004). Diffusion tensor fiber tracking shows distinct corticostriatal circuits in humans. Ann Neurol *55*, 522-529.

Lesieur, H.R., and Blume, S.B. (1987). The South Oaks Gambling Screen (SOGS): A new instrument for the identification of pathological gamblers. Am J Psychiatry *144(9),* 1184-1188.

Linnet, J., Moller, A., Peterson, E., Gjedde, A., and Doudet, D. (2011). Inverse association between dopaminergic neurotransmission and Iowa gambling task performance in pathological gamblers and healthy controls. Scandinavian Journal of Psychology *52,* 28-34.

Loba, P., Stewarrt, S., Klein, R., and Blackburn, J. (2001). Manipulations of the features of standard video lottery terminal (VLT) games: Effects in pathological and non-pathological gamblers. J Gambling Stud *17*, 297-320.

Ledgerwood, D.M., Alessi, S.M., Phoenix, N., and Petry, N.M. (2009). Behavioral assessment of impulsivity in pathological gamblers with and without substance use disorder histories versus healthy controls. Drug Alcohol Depend *105*, 89-96.

Lejuez, C.W., Read, J.P., Kahler, C.W., Richards, J.B., Ramsey, S.E., Stuart, G.L., Strong, D.R., and Brown, R.A. (2002). Evaluation of a behavioral measure of risk taking: the Balloon Analogue Risk Task (BART). J Exp Psychol Appl *8*, 75-84.

Loftus, G.R., and Loftus, E.K. (1983). *Mind at play* (New York, Basic Books).

MacKillop, J., Anderson, E.J., Castelda, B.A., Mattson, R.E., and Donovick, P.J. (2006). Divergent validity of measures of cognitive distortions, impulsivity, and time perspective in pathological gambling. J Gambl Stud *22*, 339-354.

MacLin, O.H., Dixon, M.R., Daugherty, D., and Small, S.L. (2007). Using a computer simulation of three slot machines to investigate a gambler's

preference among varying densities of near-miss alternatives. Behav Res Methods *39*, 237-241.

Martinez, F., Le Floch, V., Gaffie, B., and Villejoubert, G. (2011). Reports of wins and risk taking: An investigation of the mediating effect of the illusion of control. J Gambl Stud *27(2)*, 271-285.

McClure, S., Berns GS, Montague PR (2003). Temporal prediction errors in a passive learning task activate human striatum. Neuron *38*, 339-346.

McCoy, A.N., Crowley, J.C., Haghighian, G., Dean, H.L., and Platt, M.L. (2003). Saccade reward signals in posterior cingulate cortex. Neuron *40*, 1031-1040.

Milosevic, A., and Ledgerwood, D.M. (2010). The subtyping of pathological gambling: a comprehensive review. Clin Psychol Rev *30*, 988-998.

Monaghan, S. (2008). Review of pop-up messages on Electronic Gaming Machines as a proposed responsible gambling strategy. Int J Ment Health Addiction *6*, 214-222.

Montague, P.R., Hyman, S.E., and Cohen, J.D. (2004). Computational roles for dopamine in behavioural control. Nature *431*, 760-767.

Moore, S. M., and Ohtsuka, K. (1997). Gambling activities of young Australians: Developing a model of behaviour. Journal of Gambling Studies, *13*, 207-236.

Myrseth, H., Brunborg, G.S., and Eidem, M. (2010). Differences in cognitive distortions between pathological and non-pathological gamblers with preferences for chance or skill games. J Gambl Stud *26*, 561-569.

Naqvi, N. H., Rudrauf, D., Damasio, H., and Bechara, A. (2007). Damage to the Insula Disrupts Addiction to Cigarette Smoking. Science *315*, 531-534.

Nelson, H. (1982). *National Adult Reading Test (NART) Test Manual* (Windsor (UK), NFER-Nelson).

Nitschke, J.B., Sarinopoulos, I., Mackiewicz, K.L., Schaefer, H.S., and Davidson, R.J. (2006). Functional neuroanatomy of aversion and its anticipation. NeuroImage *29*, 106-116.

Norwegian Gambling Authority (2006). *Annual Report*. Førde, Norway. Retrieved Dec. 19 2008 from: http://www.lottstift.no/eway/default.aspx?pid = 236&trg = visliste_5998&MainPaige_5482 = 5609:0:8,1573&visliste_5998 = 6122:0:8,1575.

Nower, L., Derevensky JL, Gupta R (2004). The relationship of impulsivity, sensation seeking, coping, and substance use in youth gamblers. Psychology Addict Behav *18*, 49-55.

O'Connor, J., and Dickerson, M. (2003). Definition and measurement of chasing in off-course betting and gaming machine play. J Gambl Stud 19(4), 359-386.

O'Doherty, J., Deichmann R, Critchley HD, Dolan RJ (2002). Neural responses during anticipation of a primary taste reward. Neuron *33*, 815-826.

O'Doherty, J.P., Dayan, P., Friston, K., Critchley, H., and Dolan, R.J. (2003). Temporal difference models and reward-related learning in the human brain. Neuron *38*, 329-337.

O'Doherty, J., Dayan, P., Schultz, J., Deichmann, R., Friston, K., and Dolan, R.J. (2004a). Dissociable Roles of Ventral and Dorsal Striatum in Instrumental Conditioning. Science *304*, 452-454.

O'Doherty, J.P. (2004b). Reward representations and reward-related learning in the human brain: insights from neuroimaging. Curr Opin Neurobiol *14*, 769-776.

O'Doherty, J.P., Buchanan, T.W., Seymour, B., and Dolan, R.J. (2006). Predictive neural coding of reward preference involves dissociable responses in human ventral midbrain and ventral striatum. Neuron *49*, 157-166.

Oei, T.P., and Gordon, L.M. (2008). Psychosocial factors related to gambling abstinence and relapse in members of gamblers anonymous. J Gambl Stud *24*, 91-105.

Oei, T.P., Lin, J., and Raylu, N. (2008). The relationship between gambling cognitions, psychological states, and gambling: A cross-cultural study of Chinese and Caucasians in Australia. Journal of Cross-Cultural Psychology *39(2),* 147-161.

Oldman, D. (1974). Chance and skill: A study of roulette. Sociology 8, 407-426.

Ongur, D., Price JL (2000). The organization of networks within the orbital and medial prefrontal cortex of rats, monkeys and humans. Cerebral Cortex *10*, 206-219.

Orford, J. (2010). *An unsafe bet? : The dangerous rise of gambling and the debate we should be having* (Oxford, Wiley-Blackwell).

Pagnoni, G., Zink, CF, Montague, PR and Berns, GS (2002). Activity in human ventral striatum locked to errors of reward prediction. Nat Neurosci *5*, 97-98.

Parke, J., and Griffiths, M. (2006). The psychology of the fruit machine: The role of structrual characteristics (Revisited). Int J Ment Health Addict *4*, 151-179.

Parke, J., Griffiths, M.D., and Parke, A. (2007). Positive thinking among slot machine gamblers: A case of maladaptive coping? Int J Ment Health Addiction *5*, 39-52.

Paulus, M.P., and Stein, M.B. (2006). An insular view of anxiety. Biol Psychiatry 60, 383-387.

Pearce, J. M. (1987). A model for stimulus generalization in Pavlovian conditioning. Psychological Review *94(1),* 61-73.

Pessiglione, M., Seymour, B., Flandin, G., Dolan, R.J., and Frith, C.D. (2006). Dopamine-dependent prediction errors underpin reward-seeking behaviour in humans. Nature *442*, 1042-1045.

Peters, H., Hunt, M., and Harper, D. (2010). An animal model of slot machine gambling: the effect of structural characteristics on response latency and persistence. J Gambl Stud *26*, 521-531.

Petry, N.M., Bickel, W.K., and Arnett, M. (1998). Shortened time horizons and insensitivity to future consequences in heroin addicts. Addiction *93*, 729-738.

Petry, N.M. (2001). Pathological gamblers, with and without substance use disorders, discount delayed rewards at high rates. J Abnorm Psychol *110*, 482-487.

Petry, N. (2003). A comparison of treatment-seeking pathological gamblers based on preferred gambling activity. Addiction *98*, 645-655.

Potenza, M.N., Kosten , T.R., and Rounsaville, B.J. (2001). Pathological gambling. JAMA *286*, 141-144.

Potenza, M.N., Leung, H.C., Blumberg, H.P., Peterson, B.S., Fulbright, R.K., Lacadie, C.M., Skudlarski, P., and Gore, J.C. (2003a). An FMRI Stroop task study of ventromedial prefrontal cortical function in pathological gamblers. The American Journal of Psychiatry *160*, 1990-1994.

Potenza, M.N., Steinberg, M.A., Skudlarski, P., Fulbright, R.K., Lacadie, C.M., Wilber, M.K., Rounsaville, B.J., Gore, J.C., and Wexler, B.E. (2003b). Gambling urges in pathological gambling: a functional magnetic resonance imaging study. Arch Gen Psychiatry *60*, 828-836.

Potenza, M.N. (2008). The neurobiology of pathological gambling and drug addiction: an overview and new findings. Philos Trans R Soc Lond B Biol Sci *363*, 3181-3189.

Price, J. (2003). Comparative aspects of amygdala connectivity. Ann NY Acad Sci *985*, 50-58.

Raylu, N., and Oei, T.P. (2004). The Gambling Related Cognitions Scale (GRCS): development, confirmatory factor validation and psychometric properties. Addiction *99*, 757-769.

Reid, R.L. (1986). The psychology of the near miss. Journal of Gambling Behavior *2*, 32-39.

Reuter, J., Raedler, T., Rose, M., Hand, I., Glascher, J., and Buchel, C. (2005). Pathological gambling is linked to reduced activation of the mesolimbic reward system. Nat Neurosci *8*, 147-148.

Reynolds, S.M., and Zahm, D.S. (2005). Specificity in the projections of prefrontal and insular cortex to ventral striatopallidum and the extended amygdala. *J Neurosci 25*,11757–11767.

Riba, J., Kramer, U.M., Heldmann, M., Richter, S., and Munte, T.F. (2008). Dopamine agonist increases risk taking but blunts reward-related brain activity. PLoS One *3*, e2479.

Rogers, P. (1998). The Cognitive Psychology of Lottery Gambling: A Theoretical Review. J Gambl Stud *14*, 111-134.

Rogers, R.D., Ramnani, N., Mackay, C., Wilson, J.L., Jezzard, P., Carter, C.S., and Smith, S.M. (2004). Distinct portions of anterior cingulate cortex and medial prefrontal cortex are activated by reward processing in separable phases of decision-making cognition. Biol Psychiatry *55*, 594-602.

Royce, G.J., and Laine, E. (1984). Efferent connections of the caudate nucleus, including cortical projections of the striatum and other basal ganglia: An autoradiographic and horseradish peroxidase investigation in the cat. The Journal of Comparative Neurology *226*, 28-49.

Rudebeck, P.H., Walton, M.E., Smyth, A.N., Bannerman, D.M., and Rushworth, M.F.S. (2006). Separate neural pathways process different decision costs. Nature Neuroscience *9(9)*, 1161-1168.

Rushworth, M.F., Walton, M.E., Kennerley, S.W., and Bannerman, D.M. (2004). Action sets and decisions in the medial frontal cortex. Trends Cogn Sci *8*, 410-417.

Rushworth, M.F.S., Behrens, T.E.J., Rudebeck, P.H., and Walton, M.E. (2007). Contrasting roles for cingulate and orbitofrontal cortex in decisions and social behaviour. Trends in Cognitive Sciences *11(4),* 168-176.

Russchen, F.T., Bakst, I., Amaral, D.G., and Price, J.L. (1985). The amygdalostriatal projections in the monkey: An anterograde tracing study. Brain Research 329, 241-257.

Salinas, J., and White, N. (1998). Contributions of the hippocampus, amygdala, and dorsal striatum to the response elicited by reward reduction. Behavioral Neuroscience *112(4)*, 812-826.

Schreiber, J., Dixon, M.R. (2001). Temporal characteristics of slot machine play in recreational gamblers. Psychological Reports *89*, 67-72.

Schultz, W. (1997a). Dopamine neurons and their role in reward mechanisms. Current Opinion in Neurobiology *7*, 191-197.

Schultz, W., Dayan P, Montague RR (1997b). A neural substrate of prediction and reward. Science *275*, 1593-1599.

Schultz, W., Tremblay L, Hollerman JR (2000). Reward processing in primate orbitofrontal cortex and basal ganglia. Cerebral Cortex *10*, 272-283.

Schultz, W. (2007). Multiple dopamine functions at different time courses. Annu Rev Neurosci *30*, 259-288.

Schultz, W., Preuschoff, K., Camerer, C., Hsu, M., Fiorillo, C.D., Tobler, P.N., and Bossaerts, P. (2008). Explicit neural signals reflecting reward uncertainty. Philos Trans R Soc Lond B Biol Sci *363*, 3801-3811.

Schultz, W. (2010). Dopamine signals for reward value and risk: basic and recent data. Behav Brain Funct *6*, 24.

Seymour, B., O'Doherty, J.P., Dayan, P., Koltzenburg, M., Jones, A.K., Dolan, R.J., Friston, K.J., and Frackowiak, R.S. (2004). Temporal difference models describe higher-order learning in humans. Nature *429*, 664-667.

Sharpe, L. (2002). A reformulated cognitive-behavioral model of problem gambling. A biopsychosocial perspective. Clin Psychol Rev *22*, 1-25.

Skinner, B. F. (1953). *Science and human behavior* (New York, MacMillan).

Spiegler, B. J., and Mishkin, M. (1981). Evidence for the sequential participation of inferior temporal cortex and amygdala in the acquisition of stimulus-reward associations. Behav. Brain Res. *3*, 303-317***.***

Smith, S.M. (2002). Fast robust automated brain extraction. Hum Brain Mapp *17*, 143-155.

Steel, Z., and Blaszczynski, A. (1996). The factorial structure of pathological gambling. J Gambl Stud 12(1), 3-20.

Steel, Z., and Blaszczynski, A. (1998). Impulsivity, personality disorders and pathological gambling severity. Addiction *93(6)*, 895-905.

Steel, Z., and Blaszczynski, A. (2002). Impulsivity, personality disorders and pathological gambling severity. In J. J. Marotta, J. A. Cornelius, and W. R. Eadington (Eds.), *The downside: Problem and pathological gambling* (pp. 107–123) (Reno, NV, Institute for the Study of Gambling and Commercial Gaming Institute, College of Business Administration, University of Nevada).

Steenbergh, T.A., Meyers, A.W., May, R.K., and Whelan, J.P. (2002). Development and validation of the Gamblers' Beliefs Questionnaire. Psychol Addict Behav *16*, 143-149.

Strickland, L.H., Lewicki, R.J., and Katz, A.M. (1966). Temporal orientation and perceived control as determinants of risk-taking. Journal of Experimental Social Psychology *2*, 143-151.

Strickland, L.H., and Grote, F.W. (1967). Temporal presentation of winning symbols and slot machine playing. Journal of Experimental Psychology *74*, 10-13.

Strickland, C.R., Taylor, A., Hendon, K.J., Provost, S., and Bizo, L.A. (2006). Erroneous beliefs among frequent fruit-machine gamblers. Gambling Research: Journal of the National Association for Gambling Studies *18(2),* 42-54.

Sutton, R., and Barto, A. (1998). Reinforcement Learing: An Introduction (Cambridge, MA, MIT Press).

Tang, C., and Wu. A. (2010). Direct and indirect influences of fate control belief, gambling expectancy bias, and self-efficacy on problem gambling and negative mood among Chinese college students: A multiple mediation analysis. J Gambl Stud *26*, 533-543.

Thomas, A.C., Sullivan, G.B., and Allen, F.C.L. (2009). A thereotical model of EGM problem gambling: More than a cognitive escape. Int J Ment Health Addiction *7*, 97-107.

Tobler, P., Fiorillo, C., and Schultz, W. (2005). Adaptive coding of reward value by dopamine neurons. Science *307*, 1642-1645.

Tobler, P.N., Christopoulos, G.I., O'Doherty, J.P., Dolan, R.J., and Schultz, W. (2008). Neuronal distortions of reward probability without choice. J Neurosci *28*, 11703-11711.

Toneatto, T., Blitz-Miller, T., Calderwood, K., Dragonetti, R., and Tsanos, A. (1997). Cognitive distortions in heavy gambling. J Gambl Stud *13*, 253-266.

Toneatto, T. (1999). Cognitive psychopathology of problem gambling. Subst Use Misuse *34*, 1593-1604.

Tremblay, A.M., Desmond, R.C., Poulos, C.X., and Zack, M. (2011). Haloperidol modifies instrumental aspects of slot machine gambling in pathological gamblers and healthy controls. Addict Biol. *16(3)*, 467-484.

Tricomi, E.M., Delgado, M.R., and Fiez, J.A. (2004). Modulation of caudate activity by action contingency. Neuron *41*, 281-292.

Turner, N., and Horbay, R. (2004). How do slot machines and other electronic gambling machines actually work? Journal of Gambling Issues *11*, 1-41.

Vitaro, F., Arseneault, L., and Tremblay, R.E. (1999). Impulsivity predicts problem gambling in low SES adolescent males. Addiction *94*, 565-575.

Volkow, N., Fowler JS, Wang JG, Goldstein RZ (2002). Role of dopamine, the frontal cortex and memory circuits in drug addiction: insight from imaging studies. Neurobio Learning Memory *78*, 610-624.

Voon, V., Thomsen, T., Miyasaki, J.M., de Souza, M., Shafro, A., Fox, S.H., Duff-Canning, S., Lang, A.E., and Zurowski, M. (2007). Factors associated with dopaminergic drug-related pathological gambling in Parkinson disease. Arch Neurol *64*, 212-216.

Voon, V., Reynolds, B., Brezing, C., Gallea, C., Skaljic, M., Ekanayake, V., Fernandez, H., Potenza, M.N., Dolan, R.J., and Hallett, M. (2010). Impulsive choice and response in dopamine agonist-related impulse control behaviors. Psychopharmacology (Berl) *207*, 645-659.

Walker, M.B. (1992). Irrational thinking among slot machine players. J Gambl Stud *8(3),* 245-261.

Walton, M.E., Devlin, J.T., and Rushworth, M.F. (2004). Interactions between decision making and performance monitoring within prefrontal cortex. Nat Neurosci *7*, 1259-1265.

Walton, M.E., Croxson, P.L., Behrens, T.E.J., Kennerley, S.W., and Rushworth, M.F.S. (2007). Adaptive decision making and value in the anterior cingulate cortex. NeuroImage *36*, T142-T154.

Wang, G.J., Volkow, N.D., Fowler, J.S., Cervany, P., Hitzemann, R.J., Pappas, N.R., Wong, C.T., and Felder, C. (1999). Regional brain metabolic activation during craving elicited by recall of previous drug experiences. Life Sci. *64*, 775–784.

Wardle, H., Moody, A., Spence, S., Orford, J., Volberg, R., Jotangia, D., Griffiths, M., Hussey, D., and Dobbie, F. (2011). *British gambling prevalence survey 2010* (Norwich, TSO).

Watson, D., Clark, L.A., and Tellgen, A. (1988). Development and validation of brief measures of positive and negative affect: the PANAS scales. J Pers Soc Psychol *54(6),* 1063-1070.

Weatherly, J.N., and Meier, E. (2008). Does providing accurate information about slot machines alter how participants play them? Analysis of Gambling Behavior *2(1)*, 25-34.

Williams, R.J., and Wood, R.T. (2004). The proportion of gaming revenue derived from problems gamblers: Examining the issues in a Canadian context. Analyses of Social Issues and Public Policy *4(1)*, 33–45.

Winstanley, C., Theobald DE, Cardinal RN, Robbins TW (2004). Contrasting roles of basolateral amygdala and orbitofrontal cortex in impulsive choice. J Neurosci *24*, 4718-4722.

Winstanley, C.A., Cocker, P.J., and Rogers, R.D. (2011). Dopamine modulates reward expectancy during performance of a slot machine task in rats: Evidence for a 'near-miss' effect. Neuropsychopharmacology 36 913-925.

Wise, R.A. (2002). Brain reward circuitry: Insights from unsensed incentives. Neuron *36*, 229-240.

Wohl, M., and Enzle, M. (2003). The effects of near wins and near losses on self-perceived personal luck and subsequent gambling behaviour. Journal of Experimental Social Psychology *39*, 184-191.

Woolrich, M.W., Ripley, B.D., Brady, M., and Smith, S.M. (2001). Temporal Autocorrelation in Univariate Linear Modeling of FMRI Data. NeuroImage *14*, 1370-1386.

Woolrich, M.W., Behrens, T.E.J., Beckmann, C.F., Jenkinson, M., and Smith, S.M. (2004). Multilevel linear modelling for FMRI group analysis using Bayesian inference. NeuroImage *21*, 1732-1747.

Yacubian, J., Glascher, J., Schroeder, K., Sommer, T., Braus, D.F., and Buchel, C. (2006). Dissociable systems for gain- and loss-related value predictions and errors of prediction in the human brain. J Neurosci *26*, 9530-9537.

Zack, M., and Poulos, C. (2004). Amphetamine primes motivation to gamble and gambling-related semantic networks in problem gamblers. Neuropsyhcopharmacology *29*, 195-207.

Zack, M., and Poulos, C. (2007). A D2 antagonist enhances the rewarding and priming effects of a gambling episode in pathological gamblers. Neuropsychopharmacology *32*, 1678-1686.

Zink, C., Pagnoni G, Martin ME, Dhamala M, Berns GS (2003). Human striatal response to salient nonrewarding stimuli. J Neurosci *23*, 8092-8097.

Zuckerman, M. (2005). The psychological model for impulsive unsocialized sensation seeking: A comparative approach. Neuropsychobiology, 34(3), 125-129.

Zuckerman, M., and Kuhlman, D.M. (2000). Personality and risk-taking: common bio-social factors. J Pers 68, 999-1029.