A Neurocognitive Examination of Impulsivity, Inhibitory Control and Decision Making in Problem Gambling

By

Felicity Lorains

This thesis is submitted in partial fulfilment of the requirements for the degree of

Doctor of Psychology (Clinical Neuropsychology)

School of Psychology and Psychiatry

Faculty of Medicine, Nursing and Health Sciences

Monash University

Australia

October 2013

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Abstract

Problem gambling is increasingly viewed as a behavioural addiction of impaired control. Neurocognitive models of substance-based addictions propose that dysfunction within the fronto-striatal networks underlies the impaired control displayed in addictive disorders. In particular, fronto-striatal dysfunction results in elevated levels of impulsivity and impairments in the key cognitive skills of inhibitory control and decision making. The overall goal of the studies presented in my thesis was to investigate impulsivity, inhibitory control and decision making in problem gambling. Furthermore, recent theoretical models of problem gambling have proposed subtypes of problem gamblers may exist. As such, we examined whether impulsivity, inhibitory control and decision making differed between problem gamblers subtyped according to preferred gambling form. Participants included 39 treatment-seeking problem gamblers and 41 age-, gender- and estimated-IQ-matched healthy controls. In addition, the problem gambling sample was further divided into problem gamblers who prefer either strategic gambling activities (e.g., sports-betting, casino games) or non-strategic gambling activities (e.g., electronic gaming machines). To measure self-reported impulsivity we used the Barratt Impulsiveness Scale and the UPPS-P Impulsivity scale. Inhibitory control was measured using the Stop Signal Task, the Sustained Attention to Response Task, an emotional Stroop task and the Random Number Generation task. Decision making tasks included a Loss Aversion Task and the Iowa Gambling Task (IGT). Additionally, we further analysed IGT performance using the Prospect Valence Learning (PVL) model, which is a cognitive model that quantifies the cognitive, motivational and response style factors involved in decision making. With regard to self-reported impulsivity and inhibitory control, we found that overall problem gamblers reported elevated self-reported impulsivity; however, we did not find strong evidence that problem gamblers differed from controls on any of the inhibitory control measures. Moreover, strategic and

non-strategic problem gamblers did not differ from their respective controls on impulsivity or inhibitory control measures. In contrast, on both decision making tasks, problem gamblers performed more poorly than controls, and according to the PVL model, problem gamblers' IGT performance was associated with a heightened attention to gains and less consistency. Importantly, we found striking differences in decision making between strategic and non-strategic problem gamblers. Strategic problem gamblers did not differ from matched controls on either decision making task; however their IGT choices were associated with greater attention to gain, more sensitivity to losses and less choice consistency (i.e., impulsivity). In contrast, non-strategic problem gamblers performed more poorly on both the IGT and the Loss Aversion task than matched controls, and their IGT choices were associated with less sensitivity to losses. In conclusion, we found no evidence of inhibitory control impairments, despite problem gamblers reporting high impulsivity levels. However, we have highlighted the important underlying cognitive processes involved in problem gamblers' decision making, which differed according to problem gambling subtype. This thesis demonstrates the key role of impaired decision making in problem gambling and the presence of cognitive differences between subtypes of problem gamblers. Our findings provide a unique contribution to the literature by further highlighting the importance of heterogeneity in problem gambling.

General Declaration

In accordance with Monash University Doctorate Regulation 17.2 Doctor of Philosophy and Research Master's regulations the following declarations are made:

I hereby declare that this thesis contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

This thesis includes three original papers published or submitted for publication in peer reviewed journals. The core theme of the thesis is **inhibitory control and decision making in problem gambling**. The ideas, development and writing up of all the papers in the thesis were the principal responsibility of myself, the candidate, working within the School of Psychology and Psychiatry under the supervision of Professor Julie Stout, Dr Peter Enticott, Associate Professor Nicki Dowling and Emeritus Professor John Bradshaw.

The inclusion of co-authors reflects the fact that the work came from active collaboration between researchers and acknowledges input into team-based research.

In the case of Chapters two, four and five my contribution to the work involved the following:

Thesis chapter	Publication title	Publication status*	Nature and extent of candidate's contribution
2	A systematic review of cognitive abilities underlying impaired control in pathological gamblers: The role of the fronto-striatal networks	*Submitted*	Systematic literature search, manuscript synthesis and preparation
4	Self-reported impulsivity and inhibitory control in problem gamblers	*Under review (based on amendments)*	Data collection, data analysis, manuscript synthesis and preparation
5	Strategic and non-strategic problem gamblers differ on decision making under risk and ambiguity	*Under Review*	Data collection, data analysis, manuscript synthesis and preparation

I have renumbered sections of submitted or published papers in order to generate a consistent presentation within the thesis.

Signed: ……

Date: ……

Publications and conference proceedings during candidature

This thesis constitutes manuscripts published, accepted, or submitted to academic journals:

Lorains, F., Enticott, P.G., Dowling, N.A., Bradshaw, J.L., & Stout, J.C. (submitted). A systematic review of cognitive abilities underlying impaired control in pathological gamblers: The role of the fronto-striatal networks. *Psychology of Addictive Behaviors.*

Lorains, F., Dowling, N.A, Enticott, P.G, Bradshaw, J.L, Trueblood, J.S., & Stout, J.C. (under review). Strategic and non-strategic problem gamblers differ on decision making under risk and ambiguity. *Addiction.*

Lorains, F., Stout, J.C, Bradshaw, J.L, Dowling, N.A, & Enticott, P.G. (second submission, under review). Self-reported impulsivity and inhibitory control in problem gamblers. *Journal of Experimental and Clinical Neuropsychology.*

Parts of this thesis were presented at local and international conferences and symposiums:

Lorains, F., Stout, J., Bradshaw, J., Dowling, N., & Enticott, P. (2013). Self-reported impulsivity, but not inhibitory control, is associated with problem gambling. *Poster presented at the College of Clinical Neuropsychologists (CCN) 2013 Conference, Brisbane, Australia.*

Lorains, F., Enticott, P., Bradshaw, J., Dowling, N., & Stout, J. (2013). Problem gamblers' decision making under risk and ambiguity. *Poster presented at the International Neuropsychological Society Mid-Year Meeting, Amsterdam, Netherlands.*

Lorains, F., Enticott, P., Bradshaw, J., Dowling, N., & Stout, J. (2013). Decision making under risk and ambiguity in strategic and non-strategic problem gamblers. *Poster presented at the School of Psychology and Psychiatry 2013 research day, Monash University, Australia*.

Lorains, F., Dowling, N., Enticott, P., Bradshaw, J., & Stout, J. (2012). Decision making impairments in problem gambling. *Paper presented at the National Association for Gambling Studies Conference, Launceston, Tasmania, Australia*.

Lorains, F. (2010). The gambler's brain: Neurocognitive and neuroimaging findings associated with gambling. *Paper presented at the Emerging & New Researchers in Gambling (ENERGI) Conference, Melbourne, Australia*.

Acknowledgements

There are many people I'd like to thank for making this doctorate possible. Most importantly, I would like to thank my supervisors for their expertise and continual guidance and support throughout my doctorate. Firstly, my primary supervisor, Julie, thank you for teaching me to strive to conduct the highest quality research possible. I truly appreciate the valuable contribution you have provided to my thesis. John, you started me on this journey and I'm forever grateful for your support and guidance throughout my doctorate. Pete, thank you for always being so positive and encouraging - your enthusiasm always kept a smile on my face. And Nicki, thank you for sparking my interest in problem gambling five years ago and for your valuable knowledge of problem gambling research. Also, a special thanks to all the participants who gave up their time to participate in this study.

I would also like to express my appreciation to the wonderful teaching staff within the Monash Neuro DPsych program. Having the opportunity to attend the INS conference in 2013 made me truly appreciate what a world-class neuropsychology program we have at Monash and how fortunate I was to be able to train under experts within our field. So a big thank you to the Monash DPsych staff and especially our course coordinator, Jennie Ponsford, for their enthusiasm and commitment to neuropsychology. Additionally, to my neuro cohort, it has been a pleasure to have been in the DPsych program with you and I look forward to working alongside such talented neuropsychologists in the future. I know I will still be calling you to discuss a tricky case or the latest neuropsych test! A special thanks to Vanessa for putting up with my frequent questions and requests for proof-reading.

This thesis wouldn't have been possible without the support of my amazing friends and family. To the 'Stout labbers', thank you for making the Stout lab such an enjoyable place to work. To my friends from home, university and Mannix, thanks for always being there to

have fun and lift my stress levels – we can now officially celebrate! And to my family: Mum, Dad, Heath, Tris (and Jackson and Cooper), and my second family the Hall/Glennie's, thank you for your constant support and words of encouragement, and for reminding me life exists outside the DPsych – it made all the difference.

Lastly, to Brendon. You have been my guinea pig for neuropsychological tests and psychological interviews, you've sat through numerous practice presentations and have read more than you ever would have thought about problem gambling. Thank you for being there to celebrate my achievements and to pick me up when things weren't working out. I couldn't have done this without you!

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Abbreviations

ACC	Anterior cingulate cortex
AD	Alcohol dependence
ADHD	Attention Deficit Hyperactivity Disorder
ANOVA	Analysis of variance
AUDIT	Alcohol Use Disorders Identification Test
BART	Balloon Analogue Risk Task
BD	Bipolar disorder
BIC	Bayesian Information Criterion
BIS-11	Barratt Impulsiveness Scale 11th revision
BN	Bulimia nervosa
CGT	Cambridge Gambling Test
CPT	Combined Performance Test
CTT	Circle Tracing Task
dACC	Dorsal anterior cingulate cortex
DASS	Depression Anxiety Stress Scale
DDT	Delay Discounting Task
DIGS	Diagnostic Interview for Gambling Severity
DLPFC	Dorsolateral prefrontal cortex
DMPFC	Dorsomedial prefrontal cortex
DRLRR	Differential Reinforcement of Low Rate Responding Task
DSM	Diagnostic and Statistical Manual of Mental Disorders
EGM	Electronic Gaming Machine
EEG	Electroencephalography
ERP	Event-related potentials
fMRI	functional Magnetic Resonance Imaging
GDT	Game of Dice Task
GGT	Georgia Gambling Task
GUS	Gambling Urge Scale
HC	Healthy control
ICD-10	International Classification of Disease
IGT	Iowa Gambling Task
IST	Information Sampling Test
KFG	Kurzfragebogen zum Glücksspielverhalten (German gambling screen)
MD	Mood disorder
MEG	Magnetoencephalography
MFFT	Matching Familiar Figures Test
MIDT	Money Incentive Delay Task
MINI	Mini International Neuropsychiatric Interview
NART	National Adult Reading Test
ND	Nicotine dependence
NODS	National Opinion Research Centre DSM Screen for Gambling Problems

OCD	Obsessive compulsive disorder
OFC	Orbitofrontal cortex
PDT	Probabilistic Discounting Task
PET	Positron Emission Tomography
PGSI	Problem Gambling Severity Index
PRLT	Probabilistic Reversal Learning Task
PTSD	Post-traumatic stress disorder
PVL	Prospect Valence Learning Model
RNG	Random Number Generation task
RT	Reaction time
SA	Substance abuse
SD	Substance dependence
SART	Sustained Attention to Response Task
SKIP	Single Key Impulsivity paradigm
SOGS	South Oaks Gambling Screen
SSD	Stop signal delay
SSRT	Stop signal reaction time
SST	Stop Signal Task
SUD	Substance use disorder
SZ	Schizophrenia
TS	Tourette's syndrome
Tx	Treatment
VLPFC	Ventrolateral prefrontal cortex
VMPFC	Ventromedial prefrontal cortex
YBOCS	Yale-Brown Obsessive Compulsive Scale.

Preface

Problem gambling is a serious psychiatric disorder with detrimental effects for the individual and a large societal cost. Although originally proposed to be an impulse control disorder, problem gambling is now considered to be a behavioural addiction, akin to substance and alcohol use disorders. Recent neurocognitive explanations of addiction highlight dysfunction within fronto-striatal circuitry that leads to an impaired control over the addictive behaviour. Impairments in the cognitive skills of *inhibitory control* and *decision making*, which are associated with the fronto-striatal networks, are proposed to be central to the impaired control displayed in addictive disorders.

Most problem gamblers have a preferred type of gambling, and there is evidence of subtypes of problem gamblers associated with preferred gambling activity. Problem gamblers who prefer strategic gambling forms (e.g., sports betting) are more likely to be male and to report gambling for excitement or to heighten arousal levels. In contrast, problem gamblers who prefer non-strategic gambling forms (e.g., electronic gaming machines) are more likely to be female, and to report gambling for coping reasons or as an emotional escape. However, limited research is available on whether cognitive differences exist in subtypes of problem gamblers.

The objective of my thesis was to further our understanding of how cognitive dysfunction in problem gambling may be associated with impaired ability to control gambling behaviour. In my thesis, I have focused on the constructs of impulsivity, inhibitory control and decision making. Using experimental neuropsychological paradigms and a cognitive modelling data analysis technique, this thesis provides an examination of cognitive dysfunction in problem gambling. Furthermore, I provide an insight into heterogeneity in problem gambling by examining whether cognitive

differences are present in subtypes of problem gamblers classified according to preferred gambling form.

My thesis comprises six chapters that outline our studies investigating impulsivity, inhibitory control and decision making in problem gamblers. Chapter 1 provides a general overview to problem gambling and the extent of the problem in an Australian context. This overview leads into Chapter 2, which is our systematic review investigating cognitive dysfunction associated with impaired control in problem gambling. Chapter 3 is an overview to the overall thesis methodology, and it outlines the rationale for the selection of our experimental tasks, as well as the development of the novel experimental tasks. Chapters 4 and 5 comprise of empirical papers investigating inhibitory control and decision making in problem gamblers respectively, and these constitute the main findings of my thesis. Finally, Chapter 6 provides a discussion that integrates the main findings from the empirical papers in my thesis with past research, as well as providing directions for future research and clinical implications. My thesis contains manuscripts that have been submitted for publication (Chapters 2, 4 & 5); consequently, a certain degree of repetition is unavoidable, although I have attempted to keep this to a minimum. I have included explanatory notes preceding the published papers in my thesis to provide further clarification and links between chapters.

CHAPTER 1: GENERAL INTRODUCTION

1.1 An Overview of Problem Gambling

1.1.1 Background

Approximately 80% of the adult population gamble each year (Welte, Barnes, Wieczorek, Tidwell, & Parker, 2002), and for the majority of the population gambling is a form of entertainment. However, for some people, gambling develops into a debilitating disorder with severe negative consequences for the individual, their family and society. Problem gambling is a relatively rare psychiatric disorder with a similar prevalence rate to obsessive-compulsive disorder and bipolar disorder (Kessler et al., 2005). Despite the low prevalence, problem gambling is a significant concern for society, given that the social cost is estimated to be $4.7 billion per year in Australia (Productivity Commission, 2010).

Problem gambling is characterised by difficulty limiting time or money gambling, which results in adverse effects on the individual's personal, financial, familial, and vocational pursuits (see Box 1 for diagnostic criteria; American Psychiatric Association (APA), 2013). Problem gambling was first recognised as a psychiatric disorder in 1979 in the International Classification of Diseases ninth edition (World Health Organisation, 1979), and was shortly after introduced into the Diagnostic and Statistical Manual of Mental Disorders third edition (DSM-III) in 1980 (APA, 1980). Until recently, problem gambling was classified as an Impulse Control Disorder Not Otherwise Classified; however, the latest revision of the DSM (DSM-5) has reclassified problem gambling into the re-named 'Substance-Related and Addictive Disorders' category where it sits alongside Substance and Alcohol Use Disorders and is the first 'behavioural addiction' included in this category. The re-classification of problem gambling is due to an evolving understanding of the similarities between problem gambling and substance-based addictions in the clinical characteristics, genetic origins and neurobiological underpinnings (APA, 2000; Brewer & Potenza, 2008;

Leeman & Potenza, 2012; Lobo & Kennedy, 2009; Potenza, 2008; van Holst, van den Brink, Veltman, & Goudriaan, 2010).

Box 1. DSM-5 Criteria for Gambling Disorder

A. Persistent and recurrent maladaptive problematic gambling behaviour leading to clinically significant impairment or distress, as indicated by the individual exhibiting four (or more) of the following in a 12 month period:
   1. Needs to gamble with increasing amounts of money in order to achieve the desired excitement.
   2. Is restless or irritable when attempting to cut down or stop gambling.
   3. Has made repeated unsuccessful efforts to control, cut back, or stop gambling.
   4. Is often preoccupied with gambling (e.g., having persistent thoughts of reliving past gambling experiences, handicapping or planning the next venture, thinking of ways to get money with which to gamble).
   5. Often gambles when feeling distressed (e.g., helpless, guilty, anxious, depressed).
   6. After losing money gambling, often returns another day to get even ("chasing" one's losses).
   7. Lies to conceal the extent of involvement with gambling.
   8. Has jeopardised or lost a significant relationship, job, or educational or career opportunity because of gambling
   9. Relies on others to provide money to relieve a desperate financial situation caused by gambling

B. The gambling behaviour is not better explained by a manic episode.

Problem gambling has been described by a variety of different terms in the literature including: ‘pathological gambling’, ‘problem gambling’, ‘compulsive gambling’, ‘at-risk gambling’, and the newly defined ‘gambling disorder’ from the DSM-5 (APA, 2013; Odlaug, Chamberlain, Kim, Schreiber, & Grant, 2011; Raylu & Oei, 2002). Gambling problems are proposed to lie on a continuum and many jurisdictions internationally have predominantly used the term ‘pathological gambling’ to refer to the psychiatric disorder listed in previous versions of the DSM (i.e., DSM-III & DSM-IV), and employed the term ‘problem gambling’ to refer to a less severe form of the disorder (Raylu & Oei, 2002). However in Australia, clinicians and researchers generally use the term ‘problem gambling’ and this is in

accordance with the national definition in which "problem gambling is characterised by difficulties in limiting money and/or time spent on gambling which leads to adverse consequences for the gambler, others, or for the community" (Neal, Delfrabbo, & O'Neil, 2005, p. 125). Use of the term 'problem gambling' in Australia has been suggested to reflect the emphasis on psychological and sociological explanations of gambling rather than medical, genetic or traditional addiction models (Delfabbro & King, 2012). In reflection of this, we will use the term problem gambling throughout this thesis to reflect people who experience negative consequences associated with maladaptive gambling behaviour.

In this chapter, I provide an overview of the symptomatology, epidemiology and clinical characteristics of problem gambling. I then discuss gambling and problem gambling in an Australian context, and conclude with a discussion of the current theoretical models of problem gambling highlighting the growing evidence for problem gambling subtypes.

1.1.2. Symptomatology

The diagnostic criteria for problem gambling highlight symptoms of preoccupation, craving and urges, tolerance and withdrawal, repeated attempts to quit or cut down, and negative effects associated with maladaptive gambling (APA, 2013). For example, problem gamblers demonstrate a preoccupation with gambling by frequently thinking about gambling or ways to continue gambling, and constantly reliving gambling experiences (APA, 2000). Furthermore, problem gamblers report craving and urges to gamble, and they may demonstrate stronger craving compared to those with alcohol dependence (Tavares, Zilberman, Hodgins, & el-Guebaly, 2005).

Similar to substance-use disorders, problem gamblers demonstrate a tolerance to gambling and they gamble with increasing amounts of money over time (APA, 2013). In the DSM-5, this is attributed to an increased need for excitement, but it also may relate to cognitive distortions such as a belief that gambling with larger amounts of money will

increase the chance of winning (Blaszczynski, Walker, Sharpe, & Nower, 2008). Approximately two-thirds of problem gamblers report withdrawal symptoms of irritability and restlessness when attempting to quit gambling or reduce gambling frequency (Blaszczynski et al., 2008). Furthermore, although the DSM-5 only lists irritability and restlessness as withdrawal symptoms, problem gamblers also report experiencing depression, anxiety, anger, guilt, general discomfort, racing heart, sweating, sleeping problems and headaches when attempting to quit gambling (Blaszczynski et al., 2008; Cunningham-Williams, Gattis, Dore, Shi, & Spitznagel, 2009). The inclusion of additional withdrawal symptoms in the diagnosis of problem gambling was a topic of debate during the DSM-5 revision (Cunningham-Williams et al., 2009). Another key feature of problem gambling is a loss of control over gambling and an inability to stop gambling, despite negative consequences and desire to quit. Problem gamblers can also develop a pattern of 'chasing losses', whereby they continue to gamble in an attempt to win back previous losses and this can include more frequent gambling, increased persistence, and heightened risk-taking (Breen & Zuckerman, 1999).

Negative consequences of problem gambling include high levels of psychological distress and affective symptoms (Petry, Stinson, & Grant, 2005), and difficulties with interpersonal relationships (Hodgins, Shead, & Makarchuk, 2007). Problem gamblers may lie to family members and friends about the extent of their gambling and require financial assistance from family and/or friends (Kalischuk, Nowatzki, Cardwell, Klein, & Solowoniuk, 2006). Problem gambling has also been associated with increased rates of intimate partner violence (Korman et al., 2008) and child abuse (Shaw, Forbush, Schlinder, Rosenman, & Black, 2007). Moreover, problem gambling has negative influences on employment, with problem gamblers more likely to arrive for work late, have days off and to report reduced productivity (Dickerson, Baron, Hong, & Cottrell, 1996). Not surprisingly, problem gambling

is associated with poor quality of life (Grant & Kim, 2005). Furthermore, approximately 20% of problem gamblers have committed illegal actions secondary to gambling problems and 11% report being arrested or incarcerated because of gambling (Ledgerwood, Weinstock, Morasco, & Petry, 2007; Potenza, Steinberg, McLaughlin, Rounsaville, & O'Malley, 2000). Committing illegal acts, however, is generally considered a less common symptom of problem gambling and has been removed from the DSM-5 as a diagnostic criterion.

Cognitive distortions and erroneous thoughts are common features of problem gambling, although they are not a diagnostic criterion. Common cognitive distortions include: an exaggerated belief of the ability to win, superstitious beliefs, attributional biases where wins are associated with skill and losses are ignored, selective memory for wins, the illusion of control where a game of chance involves skill, and the gamblers' fallacy where a win is perceived to be 'due' (Joukhador, Maccallum, & Blaszczynski, 2003; Toneatto, 1999; Toneatto, Blitz-Miller, Calderwood, Dragonetti, & Tsanos, 1997). Erroneous thoughts and cognitive distortions occur in problem, occasional and non-gamblers; however, the frequency of cognitive distortions is greater in problem gamblers (Myrseth, Brunborg, & Eidem, 2010), and problem gamblers are more convinced of the 'truth' of cognitive distortions (Ladouceur, 2004).

Problem gambling generally follows a fluctuating course of improving, relapsing and remission (Kessler et al., 2008), and it has been thought that a period of problematic gambling lasts on average one year (Slutske, 2006). However, the period of problematic gambling varies, and problem gambling may not always be a chronic disorder, as roughly a third of problem gamblers demonstrate recovery (Slutske, 2006). Problem gambling is reported to increase in periods of stress and with fluctuations in mood. Common triggers for gambling episodes include lack of structured time and negative emotional states (Morasco, Weinstock, Ledgerwood, & Petry, 2007).

1.1.3. Epidemiology

Various measurement tools exist for the diagnosis of problem gambling such as the South Oaks Gambling Screen (SOGS) (Lesieur & Blume, 1987), the Problem Gambling Severity Index (PGSI) from the Canadian Problem Gambling Index (Ferris & Wynne, 2001), and DSM criteria-based measurement tools such as the Diagnostic Interview Schedule and the National Opinion Research Centre DSM Screen for Gambling Problems (NODS) (Gerstein et al., 1999; Winters, Specker, & Stinchfield, 2002). In Australia, there has been a gradual shift over time from using the SOGS to the PGSI (Williams, Volberg, & stevens, 2012). The PGSI has now been adopted as the preferred diagnostic instrument for problem gambling (Neal et al., 2005).

Depending on diagnostic instrument, as well as study methodology, the prevalence estimates for problem gambling have varied across jurisdictions. The 12-month worldwide prevalence rate of adult problem gambling is estimated to be 2.3% when standardisation methods for different diagnostic tools are applied (Williams et al., 2012). The lifetime rate of adult problem gambling, according to DSM-IV criteria, is estimated to be between 0.4-0.6% (Kessler et al., 2008; Petry et al., 2005). However, the prevalence of problem gambling is higher within certain populations including substance abusers (e.g., 10.5%) (Toneatto & Brennan, 2002), incarcerated individuals (e.g., 16%) (Williams, Royston, & Hagen, 2005) and ethnic minorities (e.g., 3.2% in African Americans) (Gerstein et al., 1999; Petry et al., 2005). Furthermore, an additional 2.3-3.5% of the population endorse at least one DSM-IV problem gambling criterion (Kessler et al., 2008; Welte et al., 2002), suggesting that they may be experiencing negative symptoms associated with gambling and may be at-risk for developing problem gambling.

Problem gambling is a disorder that predominantly affects adults aged 30-50 years old (Kessler et al., 2008; Petry et al., 2005; Welte et al., 2002), although, high rates of problem

gambling have also been reported in adolescence (Shaffer & Hall, 1996; Welte, Barnes, Tidwell, & Hoffman, 2008). In general, problem gamblers will start gambling at a younger age than non-problem gamblers (Kessler et al., 2008). Moreover, men may be more likely to develop problem gambling than women (Kessler et al., 2008; Petry et al., 2005; Welte et al., 2002). However, the prevalence of female problem gambling has increased over time. In Australia, this has been linked to the increased availability of electronic gaming machines (EGMs) (Potenza et al., 2001; Volberg, 2003), which are more popular among women (LaPlante, Nelson, LaBrie, & Shaffer, 2006). Key clinical differences appear to exist between male and female problem gamblers. Males typically begin gambling at an earlier age and develop the disorder earlier than females (Grant, Odlaug, & Mooney, 2012b; Ibáñez, Blanco, Moreryra, & Sáiz-Ruiz, 2003). Women generally begin gambling later in life (Grant & Kim, 2002), but progress more quickly to problem gambling than men (Grant et al., 2012b; Ibáñez et al., 2003). This may be partly associated with women preferring non-strategic gambling forms (i.e., EGMs) which have been linked to a faster development of problem gambling (Tavares et al., 2003).

Problem gambling is more common among people who perceive a parent to be a problem gambler (Gupta & Derevensky, 1998) and among first-degree relatives of problem gamblers (Black, Monahan, Temkit, & Shaw, 2006). This suggests a genetic link and the heritability of problem gambling is estimated to be 50-60% (Lobo & Kennedy, 2009). There also appears to be a genetic vulnerability between problem gambling and antisocial behaviours, alcohol dependence and major depressive disorders (Lobo & Kennedy, 2009), which highlights that the presence of comorbid mental health disorders plays a role in problem gambling.

1.1.4. Comorbid mental health disorders

A key feature of problem gambling is the high prevalence of other mental health disorders, with 79.1-96.3% of problem gamblers meeting criteria for at least one comorbid mental health disorder during their lifetime (Kessler et al., 2008; Park et al., 2010). In community samples of problem gamblers, a meta-analysis found that the highest mean prevalence rate was for nicotine dependence (60.1%), followed by any alcohol/substance use disorder (57.5%), any mood disorder (37.9%), and any anxiety disorder (37.4%) (Lorains, Cowlishaw, & Thomas, 2011). However, the rates of comorbid disorders in treatment-seeking populations are often higher, with 48.8-60% of treatment-seeking problem gamblers in Australia having comorbid depression (Australian Productivity Commission, 1999; Battersby, Tolchard, Scurrah, & Thomas, 2006). In addition, there is a high prevalence of personality disorders in problem gambling (Odlaug, Schreiber, & Grant, 2013) including obsessive-compulsive (64%), borderline (62%), narcissistic (53%), antisocial (35%), paranoid (30%), and avoidant personality disorder (26%) (Bagby, Vachon, Bulmash, & Quilty, 2008). Problem gambling is also associated with high suicide rates. For example, in Australia, 27% of problem gamblers have considered suicide in the past year (Hare, 2009) and 44.8% of problem gamblers presenting to an inpatient psychiatric emergency department reported suicidal ideation (De Castella, Bolding, Lee, Cosic, & Kulkarni, 2011). Finally, there is some evidence that problem gamblers frequently meet criteria for more than one comorbid disorder simultaneously, which suggests that multimorbidity is another feature of problem gambling (Kessler et al., 2008).

Whether comorbid disorders develop before or after problem gambling is likely to vary individually and be further complicated by the evolving nature of both problem gambling and the comorbid disorders. Although there is evidence of mood disorders developing after problem gambling as a result of financial and psychological distress (Kim,

Grant, Eckert, Faris, & Hartman, 2006), Kessler et al. (2008) reported that comorbid anxiety disorders (except PTSD), major depressive disorder, and alcohol/drug abuse are more likely to occur before problem gambling. Therefore, there are likely to be multiple different pathways of comorbid mental health issues in problem gambling, which highlights the heterogeneity in this disorder.

1.2. Gambling and Problem Gambling in an Australian Context

The first EGM was introduced to Australia in 1956 and the first casino opened in the state of Tasmania in 1973 (Delfabbro & King, 2012). Since this time, the availability of gambling has gradually increased with all states and territories of Australia now having legalised gambling. However, the largest increase in gambling occurred in the 1990s when EGMs were legalised in community venues in all states and territories across Australia (except Western Australia). In 2010, Australia had almost 200,000 EGMs which equates to approximately 10 per 1000 adults (Productivity Commission, 2010) and is considerably higher than the USA, Canada, and the United Kingdom (Ziolowski, 2012). In contrast to the United Kingdom and Europe which have lower intensity electronic gaming machines (Delfabbro & King, 2012), Australian EGMs offer high-intensity fast play options with bet sizes ranging from a fraction of a cent to $10, which enable an individual to gamble between $600-1200 an hour (Productivity Commission, 2010).

In Australia, gambling is regulated by state and territory governments who also generate a substantial amount of revenue from gambling. In the 2008-2009 financial year, Australian gambling revenue was just over $19 billion, which equates to 3.1% of household expenditure and more than $1500 for each adult who gambled that year (Productivity Commission, 2010). This is roughly equivalent to Australia's retail alcohol expenditure (ABS, 2009). In addition, approximately 60% of this revenue was derived from EGMs and

approximately 40% is believed to be from problem gamblers (Productivity Commission, 2010). Overall, Australia's gambling expenditure, which is approximately $1200 per capita annually, is considerably higher than international expenditures such as in the USA, Britain and Canada which vary between $400-600 per capita annually (The Economist Online, 2011).

Similar to worldwide rates, the 12-month prevalence of adult problem gambling in Australia is estimated to be 2% using standardisation for multiple diagnostic tools (Williams et al., 2012). The lifetime rate of problem gambling using the PGSI is 1.13% (Hare, 2009). Most problem gamblers in Australia do not seek formal assistance, with 15-25% of problem gamblers believed to seek assistance annually and 10.5% presenting to Gambler's Help, which is the treatment service used for recruitment in my thesis (Hare, 2009; Productivity Commission, 2010). However, this is consistent with treatment-seeking rates of 7 to 12% found internationally (Slutske, 2006). Treatment facilities are available in all states and territories of Australia and are generally funded by state and territory governments (Delfabbro & King, 2012). In the state of Victoria, the main treatment service is Gambler's Help, and these treatment centres are mostly eclectic with various forms of therapy used based on clinician preference and experience (Delfabbro & King, 2012). Psychological treatments for problem gambling in Australia can include, but are not limited to, psychoanalytic therapies, behavioural and cognitive therapies, motivational interviewing, motivational enhancement therapy and acceptance and commitment therapy. The most efficacious treatment for problem gambling is currently cognitive behavioural therapy, although there is also some evidence for the efficacy of motivational interviewing (Cowlishaw et al., 2012).

Differences appear to exist in the demographic and clinical features of treatment-seeking problem gamblers in Australia compared to international reports. Whilst international

studies generally report larger samples of men in treatment-seeking populations (Ibáñez et al., 2003; Rush, Moxam, & Urbanoski, 2002; Soberay, Faragher, Barbash, Brookover, & Grimsley, 2013), in Australia, women comprise approximately half of treatment-seeking problem gamblers (Delfabbro, 2011). In addition, approximately 80% of treatment-seeking problem gamblers in Australia report EGMs as their primary form of gambling (Productivity Commission, 2010), which is higher than most international reports such as 49.7% in USA (Petry, 2003) and 37.7% in Canada (Rush et al., 2002). It has further been suggested that those problem gamblers who do seek treatment are generally more likely to have long-standing gambling problems and higher gambling severity (Hodgins & El-Guebaly, 2000), and may therefore be seeking treatment as they are at 'crisis point'. These findings highlight the unique and common aspects of gambling and problem gambling in Australia, including the high rates of gambling participation, relatively low problem gambling prevalence estimates and the diverse characteristics of treatment-seeking problem gamblers.

1.3. Theoretical Models of Problem Gambling Incorporating Heterogeneity

Problem gamblers demonstrate considerable variability in their demographics, motivations for gambling, preferred gambling activity, comorbid disorders and personality. It is not surprising, therefore, that the aetiology of problem gambling is not well known. Although Moran (1970) initially proposed five different subtypes of problem gamblers, until recently, theoretical conceptualisations of problem gambling were one dimensional focusing on a single underlying explanation for problem gambling such as cognitive, psychoanalytical, behavioural or psychological models of problem gambling (Lesieur & Rosenthal, 1991). However, more recent theoretical models of problem gambling have incorporated this notion of heterogeneity, and acknowledged that the development of complex psychiatric disorders

such as problem gambling are likely to be associated with multiple different pathways (Blaszczynski & Nower, 2002; Sharpe, 2002).

Blaszczynski and Nower's (2002) influential pathways model of problem and pathological gambling proposes three pathways for the development of gambling problems: (1) Behaviourally Conditioned Problem Gamblers who have little psychopathology and develop problem gambling as a consequence of the highly-addictive reinforcement schedule of gambling; (2) Emotionally Vulnerable Problem Gamblers who have a biological and emotional vulnerability to gambling with high levels of depression and/or anxiety, and who gamble as a form of emotional escape; and (3) Antisocial Impulsivist Problem Gamblers, the most severe subtype, who are characterised by a history of impulsivity and antisocial behaviour, and have neurological and neurochemical dysfunction. This model incorporates the heterogeneity in the problem gambling literature and defines each pathway according to clusters of symptoms including biological, personality, environmental, developmental, cognitive, and behavioural factors associated with problem gambling. Evidence suggests that these three problem gambling subtypes are likely to exist, although they may not be mutually exclusive, thus producing difficulties when attempting to sub-group participants (Milosevic & Ledgerwood, 2010; Nower, Martins, Lin, & Blanco, 2013).

In addition to Blaszczynski and Nower (2002)'s pathway model, Sharpe (2002) proposed the biopsychosocial model of problem gambling, which incorporates genetic and biological vulnerabilities, attitudes towards gambling and availability of gambling. This model also highlights potential subtypes of problem gamblers based on preferred gambling form. For example, most problem gamblers prefer a certain type of gambling (Petry, 2003), and gambling forms have been broadly classified into games which only involve chance (non-strategic gambling, e.g., EGMs, bingo, lottery) and games which involve some skill (strategic gambling, e.g., sports-betting, card games, poker, blackjack) (Grant, Odlaug,

Chamberlain, & Schreiber, 2012a). Sharpe (2002) proposed that problem gamblers who prefer EGMs are more likely to gamble as an emotional escape, whereas problem gamblers who prefer horse racing and/or casino games are more likely to experience low arousal levels and gamble for excitement, to alleviate boredom and to heighten arousal levels.

In support of Sharpe's (2002) model, non-strategic gambling is more common with women (Delfabbro, 2000; Grant & Kim, 2002; LaPlante et al., 2006), and women are more likely to report gambling to reduce or avoid negative emotions (Stewart & Zack, 2008) and as an emotional escape from depressive feelings, social isolation and psychological comorbidities (Holdsworth, Hing, & Breen, 2012). In contrast, strategic gambling is more common with men (Delfabbro, 2000; Grant & Kim, 2002; LaPlante et al., 2006), and men more frequently report gambling for sensory stimulation, the hope of winning (Grant & Kim, 2002) and to increase positive emotions (Stewart & Zack, 2008). Furthermore, female problem gamblers generally have higher rates of comorbid mood disorders whilst male problem gamblers generally have a higher prevalence of alcohol/substance use disorders (Blanco, Hasin, Petry, Stinson, & Grant, 2006; Dannon et al., 2006; Desai & Potenza, 2008; Echeburua, Gonzalez-Ortega, de Corral, & Polo-Lopez, 2011; Ibanez et al., 2001; Ibáñez et al., 2003; Tavares et al., 2003). Therefore, the interaction between gender and preferred gambling form appears particularly important in subtyping problem gamblers. Moreover, given that problem gambling is now considered a behavioural addiction, the theoretical models of addiction may be relevant and applicable to problem gambling. In the following Chapter, I examine the evidence for cognitive dysfunction in problem gambling using the neurocognitive models of addiction as a framework.

CHAPTER 2: A SYSTEMATIC REVIEW OF COGNITIVE ABILITIES UNDERLYING IMPAIRED CONTROL IN PATHOLOGICAL GAMBLERS: THE ROLE OF THE FRONTO-STRIATAL NETWORKS

Explanatory Note

Chapter 1 provided an overview to problem gambling as a clinical disorder and highlighted the importance of furthering our understanding of this disorder, particularly given the high social burden of problem gambling in Australia. In the following Chapter, I will examine problem gambling from a neuropsychological perspective, and apply the substance-based addiction models to problem gambling. In particular, I review the evidence for cognitive impairments associated with self-control in problem gambling and highlight the key role that the fronto-striatal network plays in this disorder. In this chapter I will use both 'problem' and 'pathological' gambling terms to highlight different severities of gambling problems. This Chapter consists of a manuscript which was submitted for publication to *Psychology of Addictive Behaviors* in October 2013.

Declaration for Thesis Chapter Two
Monash University

Declaration by candidate

In the case of Chapter 2, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Conducted the systematic search and screened articles for inclusion. Wrote drafts of paper and submitted final paper following feedback from supervisors	80%

The following co-authors contributed to the work. If co-authors are students at Monash University, the extent of their contribution in percentage terms must be stated:

Name	**Nature of contribution**	**Extent of contribution (%) for student co-authors only**
Prof Julie Stout	Development of systematic search criteria, feedback on contents and writing style	
Emeritus Prof John Bradshaw	Development of systematic search criteria, feedback on contents and writing style	
Dr Peter Enticott	Development of systematic search criteria, feedback on contents and writing style	
Assoc/Prof Nicki Dowling	Development of systematic search criteria, feedback on contents and writing style	

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work*.

Candidate's Signature		**Date**

Declaration by co-authors

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.

(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;

(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

(4) there are no other authors of the publication according to these criteria;

(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and

(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	Monash University, School of Psychology and Psychiatry, Clayton

Julie Stout	[redacted]	**10/10/2013**
Peter Enticott	[redacted]	**10/10/2013**
John Bradshaw	[redacted]	**10/10/2013**
Nicki Dowling	[redacted]	**10/10/2013**

A systematic review of cognitive abilities underlying impaired control in pathological gamblers: The role of the fronto-striatal networks

Felicity K Lorains [a], Peter G Enticott[b], Nicki A Dowling [a,c,d], John L Bradshaw[a], & Julie C Stout[a]

[a] School of Psychology and Psychiatry, Monash University, Clayton, Victoria, 3800, Australia.

[b] Monash Alfred Psychiatry Research Centre, The Alfred and Central Clinical School, Monash University, Melbourne, Victoria, 3004, Australia

[c] Problem Gambling Research and Treatment Centre, The University of Melbourne, Victoria, 3010, Australia

[d] School of Psychology, Faculty of Health, Deakin University, Burwood, 3125, Australia.

* Corresponding author at: Building 17, School of Psychology and Psychiatry, Monash University, Clayton, Victoria, 3800, Australia. Tel.: [redacted] fax: +61 3 9905 3948. E-mail address: [redacted] (J. Stout).

2.1. Abstract

Impaired control over gambling behaviour is a hallmark feature of pathological gambling. Impaired control is also a focus of substance-based addiction models, in which impaired control has been linked to dysfunction within the fronto-striatal networks. In substance-based addictions evidence indicates that fronto-striatal dysfunction is associated with increased salience of drug cues (i.e., attentional bias/cue reactivity), poor inhibitory control and impaired decision making. With the DSM-5's reclassification of pathological gambling as a behavioural addiction, the substance-based addiction models may be a useful framework for understanding this complex psychiatric disorder. We conducted a systematic review of the cognitive evidence for fronto-striatal dysfunction in pathological gambling. This review focuses on three key cognitive abilities: attentional bias/cue reactivity, inhibitory control, and decision making. For this review, we identified 61 articles examining attentional bias/cue reactivity, inhibitory control or decision making in problem or pathological gamblers. Our results suggest that problem and pathological gamblers demonstrate an attentional bias towards gambling stimuli, with slower response times to gambling stimuli and increased activation in prefrontal and subcortical regions compared to controls. Furthermore, problem and pathological gamblers display poor decision making with evidence of impaired reward processing. There was also some evidence of poor inhibitory control. Our findings provide support for a neurobiological conceptualisation of impaired control in pathological gambling, highlighting the involvement of the fronto-striatal networks and reward pathways in the aberrant behavioural control present in this disorder. In addition, we suggest avenues for future research and clinical applications from these findings.

2.2. Introduction

Pathological gambling has recently been re-classified to a new category of 'Substance Use and Addictive Disorders' in the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) (American Psychiatric Association (APA), 2013). This re-categorisation is consistent with evidence that pathological gambling more closely resembles substance and alcohol use disorders than the impulse control disorders where it was previously classified, and is more appropriately defined as a behavioural addiction (Brewer & Potenza, 2008; Grant, Brewer, & Potenza, 2006; Holden, 2001; Potenza, 2006). Similarities between pathological gambling and substance-based addictions have been noted in their clinical characteristics, diagnostic criteria and genetic origins (APA, 2000; Leeman & Potenza, 2012; Lobo & Kennedy, 2009). Pathological gambling and substance-based addictions have high rates of co-occurrence (Ibanez et al., 2001; Petry, Stinson, & Grant, 2005), and comorbid mental health disorders (Cunningham-Williams, Cottler, Compton, Spitznagel, & Ben-Abdallah, 2000; Lorains, Cowlishaw, & Thomas, 2011; Merikangas et al., 1998), are more common in males (Kessler et al., 2005; Potenza et al., 2001), adolescents or young adults (Shaffer, Hall, & Bilt, 1999; Wagner & Anthony, 2002), and are associated with high rates of treatment dropout and relapse (Hodgins & el-Guebaly, 2004; Slutske, 2006; Walitzer & Dearing, 2006). Another key similarity between pathological gambling and substance-based addictions is impairment in control over behaviour (APA, 2013; Bechara, 2005). Impaired control refers to a difficulty controlling addictive behaviour despite significant negative consequences and desire to stop. Moreover, impaired control is strongly related to increased gambling involvement (O'Connor & Dickerson, 2003) and has been linked to the high relapse rates that occur across addictions which may occur many months or years after abstinence (Bechara, 2005; Ledgerwood & Petry, 2006; Noël, Brevers, & Bechara, 2013).

The precise neural underpinnings of impaired control are not known, but historically, they have been linked to activation in the mesolimbic dopaminergic 'reward' system consisting of the ventral tegmental area, ventral striatum (nucleus accumbens), amygdala, septal nuclei, and prefrontal and cingulate cortices (Everitt, Dickinson, & Robbins, 2001; Robbins & Everitt, 1999). Drugs of abuse increase dopamine release in the nucleus accumbens (Pontieri, Tanda, & Di Chiara, 1995) and effectively 'hijack' the brain's reward system, causing an abnormal response to reward (Everitt et al., 2001). Activation of this system is associated with the pleasurable, reinforcing and rewarding effects of the drug, resulting in craving and motivational influences (Pierce & Kumaresan, 2006). However, mesolimbic dopamine activation fails to completely explain the impaired control in substance-based addictions whereby drug and alcohol users are unable to control their behaviour despite the absence of pleasurable effects, motivational influences and cravings (Lubman, Yücel, & Pantelis, 2004; Schoenbaum, Roesch, & Stalnaker, 2006). Therefore, the mesolimbic reward system appears to be only one aspect of the brain circuitry involved in impaired control. Neurocognitive and neuroimaging studies have now highlighted the development of dysfunction within the fronto-striatal circuitry and the prefrontal cortex which results in key cognitive deficits associated with impaired control in drug users (Bechara, 2005; Goldstein & Volkow, 2002, 2011; Jentsch & Taylor, 1999; Lubman et al., 2004).

Several theoretical models of substance-based addictions highlight the involvement of the fronto-striatal circuitry in cognitive dysfunction underlying impaired control (Bechara, 2005; Jentsch & Taylor, 1999; Lubman et al., 2004; Noël et al., 2013). Bechara (2005) proposed that two interacting systems become dysfunctional and result in drug users' aberrant behavioural control: the 'impulsive amygdala system' and the 'reflective prefrontal cortex system'. The 'impulsive amygdala system' is associated with a heightened attention towards

drug cues (i.e., attentional bias/cue reactivity) and the development of an increased motivational quality in drug-related stimuli, resulting in a greater behavioural control (Bechara, 2005). The 'reflective prefrontal cortex system' is associated with poor inhibitory control resulting in impulsivity and difficulty withholding unwanted actions, as well as poor decision making, leading to a preference for immediate rewards and difficulty in making decisions based on long-term outcomes (Bechara, 2005). Thus, dysfunction in the prefrontal cortex of drug users is associated with poor choices regarding drug use, and difficulty withholding urges. Consistent with Bechara's (2005) model, Jentsch and Taylor (1999) and Lubman et al. (2004) propose that the impaired control experienced in substance-based addictions is associated with fronto-striatal dysfunction, resulting in poor inhibitory control and an overvaluation of drug-related stimuli (i.e., attentional bias/cue reactivity). In support of these theories, substance users demonstrate poor performance on inhibitory control and decision making tasks, and an attentional bias or cue reactivity towards drug-related stimuli (Bechara & Damasio, 2002; Bonson et al., 2002; Grant, Contoreggi, & London, 2000). Moreover, substance user's display reduced activation in key regions of the fronto-striatal networks when performing inhibitory control and decision making tasks (Bolla, Eldreth, Matochik, & Cadet, 2005; Dao-Castellana et al., 1998).

Given that pathological gambling is now viewed as a behavioural addiction, the aberrant behavioural control displayed by pathological gamblers may result from dysfunction within the fronto-striatal networks which causes an increased salience towards gambling cues, and poor inhibitory control and decision making. In this review, we use the substance-based addiction models as a framework to evaluate problem gambler's cognitive functioning in three key areas associated with impaired control: attentional bias/cue reactivity, inhibitory control and decision making. We have focused on these cognitive processes given their central involvement in impaired control observed in substance-based addictions. However,

we acknowledge that other cognitive skills may also be involved in pathological gambling, including attention and working memory, learning and memory, emotion regulation, motivation, awareness, and insight. For an overview of neuropsychological and neuroimaging research in pathological gambling, the reader is referred to van Holst, van den Brink, Veltman, and Goudriaan (2010). In the following sections, we first evaluate the evidence that pathological gamblers demonstrate an attentional bias or cue-reactivity towards gambling-related stimuli which is proposed to be associated with dysfunction in an amygdala-prefrontal cortex system. We then evaluate the evidence for prefrontal cortex dysfunction in pathological gamblers and investigate whether pathological gamblers display impairments in inhibitory control and decision making. We conclude with a discussion of some relevant issues in this research area and suggestions for future research and clinical applications.

2.3. Method

To locate relevant articles, we conducted a systematic search from January 1993 to March 2013 using the databases PsycInfo and Medline. We used the following search terms: MESH term (explode gambling) in combination with keywords with wildcards ($): gamb$, neuropsychol$, neuroimag$, neurocog$, impulsivity, inhibition, reward, decision making, attentional bias, cue reactivity, electrophysiology, inhibitory, and limited the search to 'humans'. In addition, we hand-searched the reference lists from included studies and relevant review papers.

We included peer-reviewed empirical studies if the study: 1) involved neuropsychological or cognitive measures with or without neuroimaging, 2) examined cue reactivity, attentional bias, inhibitory control or decision making, 3) included diagnosed problem or pathological gamblers, 4) included a comparison group of either non-gamblers or

non-problem gamblers, and 5) had a primary aim to examine cognitive differences between problem/pathological gamblers and controls. The following exclusion criteria were applied; 1) participants under 18 years old, 2) problem gambling developing as part of Parkinson's disease or medication, 3) animal studies, 4) non-English language, and 5) review papers. After the removal of duplicate articles, our search retrieved 2381 unique articles, of which 61 were included in this review (see Figure 1). However, 12 of the included articles use the same dataset as another included article.

We extracted the following data from the included articles to provide information on methodological characteristics and quality: sample size, age and gender, whether the control group was matched on at least two variables, whether the control group was screened for gambling problems and what criterion was used, problem/pathological gambling diagnostic tool and criterion, problem/pathological gambling severity, whether diagnosed psychiatric disorders were excluded from the problem/pathological gambling sample, how the problem/pathological gamblers were recruited, preferred gambling activities of the problem/pathological gamblers and the cognitive and neuroimaging measures used (see Table 1). In our evaluation, we have focused more on the studies which involved larger sample sizes and matched groups, as well as those that screened for pathological gambling and psychiatric disorders among both groups. For a detailed description of the cognitive measures used in the included studies, the reader is referred to Table 2. Throughout this paper, we have used the term 'pathological gambling' instead of the renamed Disordered Gambling in the DSM-5 as no included studies used the DSM-5 criteria. Additionally to highlight different severities of gambling problems, we have used the term 'pathological gambling' to refer to the most severe form of the disorder, and the term 'problem gambling' to refer to a less severe form of the disorder (see Table 3).

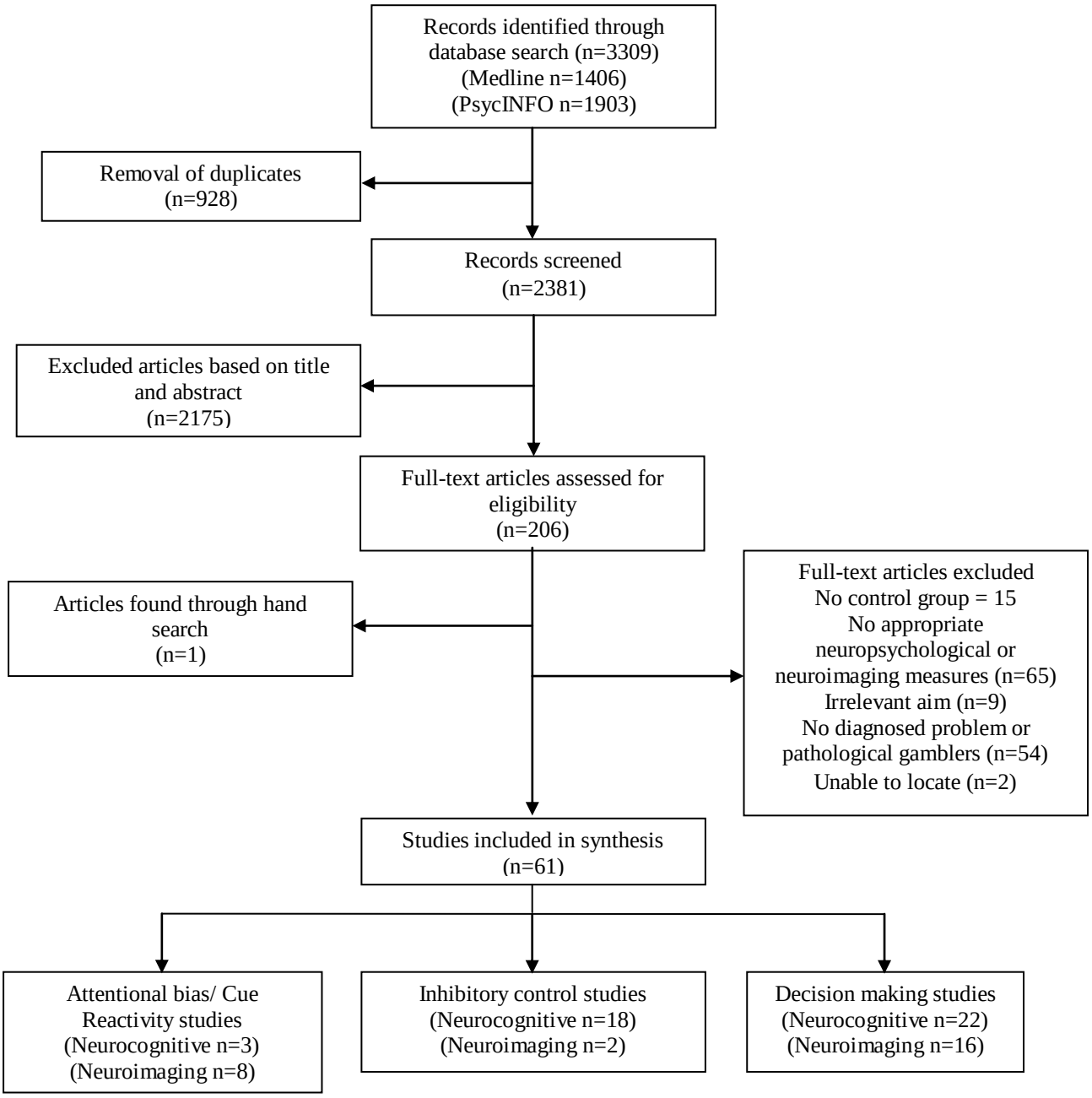

Figure I. Flow chart of the systematic search. n=number

Table 1. Study characteristics of included articles

Reference	Sample	Age	Gender (M:F)	mHC[a]	HC gambling[b]	PG Diagnosis	PG severity	Excluded Comorbidities	PG recruitment	Form[c]	Measures
Alvarez-Moya et al. (2009)	15 BN 15 PG 15 HC	BN=33.6 PG=44.4 HC=35.5	All F	N	?	DSM-IV	SOGS=11.2	Psychotic disorders & 3mth SUD	Tx centre	Mainly EGM	Stroop
Balodis et al. (2012)	14 PG 14 HC	PG=35.8 HC=37.1	PG=10:4 HC=10:4	Y	SOGS=0.3	DSM-IV	SOGS=12.6	All except ND	Community	?	MIDT fMRI
Brand, Kalbe, et al. (2005)	25 PG 25 HC	PG=40.1 HC=40.7	M	Y	?	ICD-10 & DSM-IV	?	All except ND	Tx centre	?	GDT Stroop
Brevers et al. (2011a)	40 PrG 35 HC	PrG=31 HC=32.8	PrG=22:18 HC=20:15	Y	17% gambled < weekly	≥3 on SOGS	SOGS=4.6	?	?	?	Flicker paradigm
Brevers et al. (2011b)	40 PrG 35 HC	PrG=31 HC=32.8	PrG=22:18 HC=20:15	Y	?	≥3 on SOGS	SOGS=4.6	?	Casino	?	Attentional blink
Cavedini et al. (2002)	20 PG 40 HC	PG=38.5 HC=30.3	PG=19:1 HC=18:22	N	SOGS=1.1	DSM-IV & SOGS	SOGS=15.8	None	Tx centre	?	IGT
Choi et al. (2012)	15 PG 13 OCD 15 HC	PG=27.9 OCD=24.9 HC=26.6	M	Y	?	DSM-IV & SOGS	SOGS=15.9	All	Outpatient Tx	?	MIDT fMRI
Crockford et al. (2005)	10 PG 10 HC	PG=39.3 HC=39.2	M	Y	SOGS=0	DSM-IV	SOGS=7.2	Lifetime SUD & 6mth MD	Community	?	fMRI study Visual cues
de Greck et al. (2010)	16 PG 12 HC	PG=33.2 HC=34	M	Y	?	?	KFG=34.4	?	Inpatient Tx	Mainly EGM	fMRI Visual cues
de Ruiter et al. (2011)	19 PrG 18 S 17 HC	PrG=35.3 S=33.8 HC=34.7	M	Y	≤ twice/yr	DSM-IV	SOGS=9.6	SZ, psychotic episodes, 12m manic disorder	Tx centre	?	SST fMRI
de Ruiter et al. (2009)	19 PrG 19 S 19 HC	PrG=34.3 S=34.8 HC=34.1	M	Y	≤ twice/yr	DSM-IV	SOGS=8.9	SZ, psychotic episodes, 12m manic disorder	Tx centre	?	PRLT
Dixon et al. (2003)	20 PG 20 HC	PG=40 HC=40	PG=15:5 HC=13:7	Y	<2 SOGS=0.7	>4 on SOGS	SOGS=5.9	?	Betting facility	?	DDT
Forbush et al. (2008)	25 PG 34 HC	PG=46.9 HC=41.9	PG=14:11 HC=9:25	N	0 on SOGS	DSM-IV & SOGS	?	BD	Community	?	Stroop IGT
Fuentes et al. (2006)	162 PG-C 52 PG 82 HC	PG-C=42.7 PG=40.1 HC=40.9	PG=102:112 HC=45:37	Y	?	DSM-IV & SOGS	?	All in PG group.	Outpatient Tx	?	Go/No-Go
Goudriaan et al. (2005)	48 PG 46 AD 47 TS 49 HC	PG=39 AD=47.4 TS=37 HC=35.8	PG=40:8 AD=36:10 TS=32:15 HC=34:15	Y	?	DSM-IV	SOGS=13.9	SZ, psychotic episodes & SUD	Outpatient Tx	Mixed	IGT Card Playing Task Go/No-Go

Reference	Sample	Age	Gender (M:F)	mHC[a]	HC gambling[b]	PG Diagnosis	PG severity	Excluded Comorbidities	PG recruitment	Form[c]	Measures
Goudriaan et al. (2006a)	49 PG 48 AD 46 TS 49 HC	PG=37.3 AD=47.2 TS=36.8 HC=35.6	PG=40:9 AD=37:11 TS=32:14 HC=35:15	Y	?	DSM-IV	SOGS=11.6	SUD, major psychiatric disorders	Outpatient Tx	?	SST CTT Stroop
Goudriaan et al. (2006b)	46 PG 47 HC	PG=37.8 HC=35.9	PG=39:7 HC=34:13	Y	?	DSM-IV	SOGS=14.4	SUD, major psychiatric disorders	Outpatient Tx	?	IGT
Goudriaan et al. (2010)	17 PrG 18 S 17 HC	PrG=35.3 S=33.8 HC=34.7	M	Y	≤twice/yr	DSM-IV 2 ≠criteria	SOGS=9.6	SZ, psychotic episodes, 12m manic disorder	Tx centre	?	fMRI Visual cues
Habib and Dixon (2010)	11 PrG 10 HC	PrG=19-26 HC=19-27	PrG=10:1 HC=4:6	?	<2 on SOGS	>2 on SOGS	?	?	Non-Tx seeking	?	Slot machine fMRI
Hewig et al. (2010)	21 PG 21 HC	PG=23 HC=23.5	M	Y	?	DSM-IV	SOGS=3.8	None	Student population	?	EEG Black Jack
Holt et al. (2003)	19 PrG 19 HC	PrG=19.6 HC=19.6	PrG=13:6 HC=13:6	Y	0-1 on SOGS=0.3	≥4 on SOGS	SOGS=6.5	?	Student population	?	DDT PDT
Hudgens-Haney et al. (2013)	36 PG 36 HC	?	PG=30:6 HC=13:23	?	≥ wk, <1 = DIGS&SOGS	DIGS & SOGS	?	6mth SUD	Student population	?	GGT MEG
Joutsa et al. (2012)	12 PG 12 HC	PG=30 HC=27	M	N	SOGS=0.5	DSM-IV	SOGS=14	SUD & major axis-I disorders	?	Mixed	Slot-machine PET
Kalechstein et al. (2007)	10 PG 29 Meth 19 HC	PG=53.7 Meth=34.8 HC=32.5	PG=9:1 Meth=18:7 HC=15:4	N	?	DSM-IV	?	Axis I and II disorders	Community	?	Stroop
Kertzman et al. (2006)	62 PG 83 HC	PG=40.6 HC=40.4	PG=44:20 HC=58:23	Y	?	DSM-IV & SOGS	?	Axis I & SUD	Outpatient Tx	?	Stroop
Kertzman et al. (2008)	83 PG 84 HC	PG=39.5 HC=36.8	PG=56:27 HC=56:28	Y	?	DSM-IV & SOGS	?	SUD & major psychiatric disorders	Outpatient Tx	?	Go/No-Go & CPT
Kertzman et al. (2010)	82 PG 82 HC	PG=39.2 HC=39.5	PG=58:24 HC=58:24	Y	Non-gamblers	DSM-IV & SOGS	?	SUD & major psychiatric disorders	Outpatient Tx	Mixed	MFFT
Kertzman et al. (2011)	51 PG 57 HC	PG=39.5 HC=37.7	PG=35:16 HC=36:21	Y	Non-gamblers	DSM-IV & SOGS	?	SUD & major psychiatric disorders	Outpatient Tx	Mixed	IGT, Go/No-Go, Stroop
Labudda et al. (2007)	22 PG 19 HC	PG=40.5 HC=42.9	M	Y	?	ICD-10 & DSM-IV	?	All	Inpatient Tx	?	GDT
Lakey et al. (2007)	79 PG 85 PrG 57 HC	Overall=19.2	PG=55:24 PrG=63:22 HC=48:9	?	≥ monthly	DIGS PrG=3-4	?	?	Student population	?	GGT IGT
Lawrence et al. (2009a)	21 PrG 23 AD 27 HC	PrG=37 AD=44.3 HC=41.5	M	Y	<2 on SOGS=0.3	>3 on SOGS	SOGS=9.7	All	Community & gambling help website	?	SST
Lawrence et al. (2009b)	21 PrG 21 AD 21 HC	PrG=37 AD=44.2 HC=40.2	M	Y	<2 on SOGS=0.2	>3 on SOGS	SOGS=9.7	All	Community & gambling help website	?	CGT IST

Reference	Sample	Age	Gender (M:F)	mHC[a]	HC gambling[b]	PG Diagnosis	PG severity	Excluded Comorbidities	PG recruitment	Form[c]	Measures
Ledgerwood et al. (2009)	31 PG-SUD 30 PG 40 HC	PG-SUD=44.5 PG=48.4 HC=45.7	PG-SUD=20:11 PG=14:16 HC=17:24	Y	<1 on NODS=0.2	NODS	NODS=7.1 & 7.4	Psychosis & current SD	Community & Tx program	?	DDT, SKIP GoStop, BART
Ledgerwood et al. (2012)	45 PG 45 HC	PG=46.1 HC=45.8	PG=24:21 HC=22:23	Y	<1 on NODS=0.2	NODS	NODS=7.5	Current mania, psychosis, SUD	Community & Tx	?	Stroop, IGT GoStop
Leiserson and Pihl (2007)	14 PG 28 PrG 23 HC	PG=26.4 PrG=22.6 HC=22.9	M	N	SOGS=0	SOGS	SOGS PG=9.4 PrG=2.3	Psychiatric disorders	Community advertising	?	Go/No-Go
Linnet et al. (2006)	61 PG 39 HC	PG=35.3 HC=26.6	PG=54:7 HC=11:28	N	<3 on SOGS=0.2	SOGS	SOGS=8.9	?	Tx centre	?	Modified IGT
Linnet et al. (2010a)	18 PG 16 HC	PG=33.6 HC=31.7	M	Y	<1 DSM-IV	DSM-IV	?	All current	Tx centre	?	IGT PET
Linnet et al. (2010b)	16 PG 14 HC	PG=33.9 HC=30.8	M	Y	<1 DSM-IV <2SOGS=0.1	DSM-IV	SOGS=13.2	All current	Tx centre	?	IGT PET
Linnet et al. (2010c)	16 PG 15 HC	PG=30.7 HC=34.1	M	Y	<1 DSM-IV SOGS=0.1	DSM-IV	SOGS=13.1	All current	Tx centre	?	IGT PET
Linnet et al. (2012)	18 PG 16 HC	PG=33.6 HC=31.7	M	Y	<1 DSM-IV	DSM-IV	?	All current	Tx centre	?	IGT PET
Madden et al. (2009)	19 PG 19 HC	PG=37.7 HC=37.2	M	Y	SOGS=0.8	DSM-IV	SOGS=13.3	Alcohol and drug abuse	Tx-seeking	?	DDT PDT
Michalczuk et al. (2011)	30 PG 28 HC	PG=40.1 HC=35.8	PG=28:2 HC=28:2	Y	PGSI=0-2	DSM-IV & PGSI	?	N	Tx centre	Mixed	DDT
Miedl et al. (2012)	16 PG 16 HC	PG=35 HC=38	PG=15:1 HC=15:1	Y	SOGS=0.2	DSM-IV	SOGS= 10.1	None	Community & self-help	?	DDT, PDT, fMRI
Miedl et al. (2010)	12 PrG 12 HC	PrG=39.5 HC=33.4	M	Y	<2 on SOGS= 0.7	>3DSM-IV&SOGS	SOGS= 10.7	All	Community	Mixed	fMRI Blackjack
Molde et al. (2010)	33 PG 22 HC	PG=40.5 HC=41.2	PG=26:7 HC=16:6	Y	No problems SOGS=0.6	NODS	SOGS=11.8	Psychosis, SD & AD	Tx-seeking	EGM	Emotional stroop
Oberg et al. (2011)	11 PrG 10 HC	PrG=23 HC=22	M	Y	PGSI=0.1 NODS=0	>3 PGSI	PGSI=5.4 NODS=2.8	?	University	?	Modified IGT, EEG
Odlaug, Chamberlain, et al. (2011)	46 PG 69 PrG 135 HC	PG=45.4 PrG=22.5 HC=23.4	PG=23:23 PrG=53:16 HC=80:55	N	≥5 times in 12m.YBOCS= 2.3	1-4 DSM-IV	YBOCS PG=20.6 PrG=4.4	All current	Community	?	SST
Patterson II et al. (2006)	18 PG 23 HC	PG=45 HC=41	?	Y	SOGS=0.2	SOGS	SOGS=14.3	None	Inpatient Tx	?	Modified IGT
Petry (2001a)	21 PG-SUD 39 PGs 26 HC	PG-SUD=43 PG=44 HC=39	PG-SUD=17:4 PG=23:16 HC=17:9	Y	SOGS=0.7	DSM-IV	SOGS PG-SUD=13.8 PG=12.0	?	Tx centre	?	DDT
Petry (2001b)	27 PG-SA 63 SA 21 HC	PG-SA=39.1 SA=42.0 HC=36.1	M	N	SOGS=0.9	SOGS	SOGS=9.3	Psychosis	Community & tx program	?	IGT

Reference	Sample	Age	Gender (M:F)	mHC[a]	HC gambling[b]	PG Diagnosis	PG severity	Excluded Comorbidities	PG recruitment	Form[c]	Measures
Petry and Casarella (1999)	29 SUD-PG 34 SUD 18 HC	SUD-PG=39.7 SUD=39.7 HC=36.2	SUD-PG=25:4 SUD=28:6 HC=15:3	Y	SUD SOGS=0-1	SOGS	?	Psychosis	Community & tx program	?	DDT
Potenza et al. (2003a)	14 PG 13 HC	PG=36.2 HC=30.1	M	Y	SOGS=0	DSM-IV	SOGS=12.6	All except ND	Advertising	?	Gambling cues, fMRI
Potenza et al. (2003b)	13 PG 11 HC	PG=35.2 HC=29	M	Y	?	DSM-IV	SOGS=12.6	All except ND	?	?	Modified Stroop, fMRI
Regard et al. (2003)	21 PG 19 HC	PG=33.6 HC=34.4	PG=20:1 HC=18:1	Y	?	DSM-IV	?	Substance abuse	Outpatient tx	?	EEG Stroop
Reuter et al. (2005)	12 PG 12 HC	PG=37.3 HC=32.3	M	Y	KFG=2.9	DSM-IV	KFG=35.6	None	Advertising & tx clinic	Mainly EGM	Guessing Game, fMRI
Roca et al. (2008)	11 PG 11 HC	?	?	Y	Non-gamblers	DSM-IV & SOGS	?	Psychosis & major psychiatric disorders	Casino.	?	IGT Go/No-Go
Rodriguez-Jimenez et al. (2006)	16 PG-adhd 39 PG 40 HC	PG-adhd=31.8 PG=34.6 HC=32	M	Y	<4 on SOGS= 0.3	DSM-IV & SOGS	SOGS=9.8 & 10.6	Psychotic & affective disorders & 12m SUD	Tx centre	?	SST DRLRR CPT
Tanabe et al. (2007)	20 SDPG 20 SD 16 HC	SDPG=35 SD=35 HC=37	SDPG=12:8 SD=10:10 HC=5:11	Y	SOGS ≤1 SD=0.2 HC=0.1	SOGS	SOGS=10.7	?	Inpatient Tx	?	IGT (modified) fMRI
Van Holst et al. (2012a)	16 PrG 15 HC	PrG=34.4 HC=36.2	M	Y	≤twice/yr SOGS=0.1	> 4DSM-IV&SOGS	SOGS=11.6	SZ psychotic episodes BD SUD OCD PTSD	Tx centre	?	Aff Go/No-Go, fMRI
van Holst et al. (2012b)	15 PrG 16 HC	PrG=38 HC=34.9	M	Y	SOGS=0.8	>3DSM-IV&SOGS	SOGS=10.0	SZ psychotic episodes BD SUD OCD PTSD	Tx centre	?	Guessing game, fMRI
Wölfling et al. (2011)	15 PG 15 HC	PG=34.9 HC=34.3	PG=12:3 HC=13:2	Y	?	DSM-IV & SOGS	?	SUD	Casino & newspaper	Mixed	Gambling cues, EEG

Note: [a] mHC = Controls matched on at least two variables (age, gender, IQ or education), [b] HC gambling: Gambling status of the control group. [c]Form = Preferred gambling activities of the problem/pathological gambling sample. AD: Alcohol dependence; adhd: Attention deficit hyperactivity disorder; Aff Go/No-Go: Affective Go/No-Go; BART: Balloon Analogue Risk Task; BD: Bipolar disorder; BN: Bulimia Nervosa; CGT: Cambridge Gambling Task; CPT: Continuous Performance Task; CTT: Circle tracing task; DIGS: Diagnostic Interview for Gambling Severity; DDT: Delay discounting task; DRLRR: Differential Reinforcement of Low Rate Responding Task; DSM-IV: Diagnostic and Statistical Manual of Mental Disorders; EGM: Electronic Gaming Machine; F: Female; GDT: Game of Dice task; GGT: Georgia Gambling Task; HC: Healthy control; ICD-10: International Classification of Disease; IGT: Iowa Gambling Task; IST: Information Sampling Test; KFG: Kurzfragebogen zum Glücksspielverhalten (German gambling screen); M: Male; Meth: Methamphetamine users; MD: Mood disorder; MFFT: Matching Familiar Figures Test; MIDT: Money Incentive Delay Task; N: No; ND: Nicotine Dependence; NODS: National Opinion Research Centre DSM Screen for Gambling Problems; OCD: Obsessive Compulsive Disorder; PDT: Probabilistic discounting task; PG: Pathological Gambler; PrG: problem gambler; PG-C: Pathological gamblers with comorbidities; PDT: Probabilistic Discounting Task; PGSI: Problem Gambling Severity Index; PRLT: Probabilistic Reversal learning Task; S: Smoker; PTSD: Post-traumatic stress disorder; SA: Substance abuse; SD: Substance dependence; SDPG: Substance-dependent pathological gamblers; SKIP: Single Key Impulsivity Paradigm; SOGS: South Oaks Gambling Screen SST: Stop Signal Task; SUD: Substance use disorder; SZ: Schizophrenia; TS: Tourette's syndrome; Tx: Treatment; Y: Yes; YBOCS: Yale-Brown Obsessive Compulsive Scale.

Table 2. Description of neuropsychological tasks

Neuropsychological Task	Description	Dependent variable(s)	Reference
Inhibitory Control			
Circle Tracing Task (CTT)	Participants are instructed to trace a pre-drawn circle with neutral tracing instructions, and as slowly as possible. Faster tracing speeds = greater impulsivity	Tracing speed	Bachorowski and Newman (1990)
Continuous Performance Test (AX version) (CPT)	Participants press a button when they see the letter 'X' after the letter 'A' which has a frequency of 10%. The letter 'A not followed by X' has a probability of 20%	Omission errors Commission errors	Rodriguez-Jimenez et al. (2006)
Differential Reinforcement of Low Rate Responding Task (DRLRR)	Participants press a key to obtain a reward. However, the delay between keypresses must be at least 6 seconds to obtain a reward.	Number of rewards minus number of key presses	Gordon and Mettelman (1988)
Go/No-Go Task	Participants are presented with two stimuli and must respond to the Go stimuli whilst withholding a response to No-Go stimuli.	Omission errors Commission errors	Newman, Widom, and Nathan (1985)
GoStop Impulsivity Paradigm	Participants are presented with a consecutive series of five-digit numbers. Participants respond to a target stimulus; but inhibit responses if the target stimuli changes colour.	Proportion of correctly inhibited responses	Dougherty et al. (2003)
Single-Key Impulsivity Paradigm (SKIP)	Participants press a button to obtain a monetary reward. The reward received is proportionate to the delay between responses with longer delay leading to greater rewards.	Longest time between two responses	Swann, Bjork, Moeller, and Dougherty (2002)
Stop Signal Task (SST)	Participants respond to the Go stimuli whilst withholding responses to Stop trials where an auditory stop signal is presented with a go trial.	Stop signal reaction time	Logan, Cowan, and Davis (1984)
Stroop Task	Participants name the ink colour of words printed in black ink, coloured rectangles and colour words printed in different colour ink.	Speed and errors of colour naming	Stroop (1935) Golden (1978)
Attentional Bias/Cue Reactivity			
Emotional Stroop Task	This task consists of neutral and emotional words (relevant to a target condition, e.g., gambling). Participants name the ink colour.	Reaction time for target words	Williams, Mathews, and MacLeod (1996)
Attentional blink paradigm	This is observed in rapid serial visual presentation whereby participant will often fail to detect a second salient target (T2) occurring closely to the first target .	T2 accuracy	Raymond, Shapiro, and Arnell (1992)
Flicker paradigm	Participants are presented with consecutive and repeated presentations of two identical visual scenes that differ in only one element. Participants have to detect the difference.	Number of repetitions required to detect the difference	Rensink, O'Regan, and Clark (1997)

Neuropsychological Task	Description	Dependent variable(s)	Reference
Decision Making			
Balloon Analogue Risk Task (BART)	Participants are required to press a key to pump up a simulated balloon with each pump earning more money. If the balloon is pumped too much, it explodes, and winnings are reset. Participant can collect winnings at any time.	Average number of pumps	Lejuez et al. (2002)
Card-Playing Task	Participants choose whether to play or quit a card which either wins or loses money. Initially, most cards win (9:1) and this gradually shifts to more losses. Participants are not informed of the ratio of wins to losses.	Number of cards played	Newman, Patterson, and Kosson (1987)
Cambridge Gambling Task (CGT)	Participants are presented with an array of 10 red and blue boxes with one box containing a token. Participants choose which colour hides the token and gamble a portion of points on each guess. The ratio of red: blue boxes vary over trials.	Points gambled Proportion of rational decisions Deliberation time Bankruptcies	Rogers et al. (1999)
Delay Discounting Task (DDT)	Participants are required to choose between an immediate monetary reward and a delayed larger monetary reward.	Degree of discounting	Green, Fry, and Myerson (1994), Kirby, Petry, and Bickel (1999)
Game of Dice Task (GDT)	Participants guess the number(s) rolled from four virtual dice. They can choose between a single number or a combination of two, three or four numbers. Each choice is associated with gains and losses depending on the probability.	Disadvantageous choices (1 or 2 numbers). Advantageous choices (3 or 4 numbers)	Brand, Fujiwara, et al. (2005a)
Georgia Gambling Task (GGT)	Participants choose between two alternatives on a general knowledge question and report confidence in their answer. Participants then choose between a gamble, e.g., win 133 points if correct and nothing if incorrect OR win 100 points if either correct or incorrect.	Accuracy, confidence, overconfidence and bet acceptance	Goodie (2003)
Information Sampling Task (IST)	Participants are presented with 25 grey boxes, each containing one of two colours. Participants decide which colour is the majority and can open boxes before deciding.	Probability of making the correct decision given information sampled Number of incorrect decisions	Clark, Robbins, Ersche, and Sahakian (2006)
Iowa Gambling Task (IGT)	Participants are presented with four card decks and instructed to accumulate as much money as possible. Decks differ in payoffs and penalties with two decks being advantageous and two being disadvantageous.	Number of advantageous and disadvantageous choices	Bechara, Damasio, Damasio, and Anderson (1994)
Matching Familiar Figures Test (MFFT)	Participants choose which stimulus out of 6 alternative options matches a	Short latencies indicate greater	Kagan, Rosman, Day, Albert, and

Neuropsychological Task	Description	Dependent variable(s)	Reference
	stimulus figure	impulsivity	Phillips (1964)
Monetary Incentive Delay Task (MIDT)	Participants view the potential monetary win or loss and press a key when a target appears. Feedback is provided	Reaction time and hit rate	Knutson, Adams, Fong, and Hommer (2001)
Probabilistic Reversal Learning Task (PRLT)	Participants are presented with two stimuli to choose from. Initially one is correct and wins points, and after some time this rule is reversed. Participants are not informed of the reversal.	Amount of money won Mean reaction time	O'Doherty et al. (2001)
Probabilistic Discounting Task (PDT)	Participants are required to choose between a certain monetary reward and larger reward delivered probabilistically.	Degree of discounting	Green and Myerson (2004)

Table 3. Classification criteria used for problem and pathological gambling

Assessment measure	Description	Criteria for Pathological Gambling	Criteria for Problem Gambling
Diagnostic and Statistical Manual of Mental Disorders (DSM-IV or DSM-IV-TR) (American Psychiatric Association (APA), 2000)	Clinical interview	At least 5 out of 10 criteria met	3-4 out of 10 criteria met
Diagnostic Interview for Gambling Severity (DIGS) (Winters, Specker, & Stinchfield, 2002)	20 item self-report questionnaire based on DSM-IV criteria	At least 5 out of 10 criteria met	3-4 out of 10 criteria met
International Classification of Disease (ICD-10) (World Health Organization, 2004)	Clinical interview	At least 5 out of 10 criteria met	N/A
National Opinion Research Centre DSM Screen for Gambling Problems (NODS) (Gerstein et al., 1999)	17 item self-report questionnaire based on DSM-IV criteria	5 out of 10 criteria met	3-4 out of 10 criteria met
Problem Gambling Severity Index (PGSI) from the Canadian Problem Gambling Index (Ferris & Wynne, 2001)	9-item self-report questionnaire	Score of 8 or more out of 27	Score between 3 - 7
South Oaks Gambling Screen (SOGS) (Lesieur & Blume, 1987)	20 item self-report questionnaire	At least 5 out of 20 criteria met	1-4 out of 20 criteria met
Structured Clinical Interview for Pathological Gambling (Grant, Steinberg, Kim, Rounsaville, & Potenza, 2004)	Structured interview based on DSM-IV criteria	At least 5 out of 10 criteria met	N/A

2.4. Attentional Bias and Cue Reactivity

According to substance-based addiction theories, addiction-related stimuli possess enhanced motivational quality and salience for drug users, and hence generate difficulties in controlling behaviour (Jentsch & Taylor, 1999; Lubman et al., 2004). This attentional bias or cue-reactivity develops due to dysfunction within the 'impulsive amygdale system' whereby repetitive activation of the amygdala and the mesolimbic dopamine system (ventral striatum, nucleus accumbens, dorsal striatum and pallidum) results in reinforcement of addictive behaviours, and strengthened association to additive stimuli (Bechara, 2005; Noël et al., 2013). In the following section, we examine problem/pathological gamblers' attentional bias towards gambling cues and evaluate cue-induced brain activation studies in problem/pathological gamblers.

2.4.1. Neurocognitive and neuroimaging evidence for attentional bias and cue reactivity in problem and pathological gamblers

We identified three studies investigating attentional bias in problem/pathological gamblers. All studies used similar sample sizes (n=33-40) with appropriately matched controls. On a pictorial emotional Stroop task, Molde et al. (2010) found that pathological gamblers responded more slowly to win-related gambling stimuli than controls, and responded more slowly to gambling stimuli than neutral stimuli during both subliminal and supraliminal trials. On an attentional blink paradigm, Brevers et al. (2011b) found that problem gamblers identified more gambling target words than neutral target words, whilst controls showed a trend towards identifying more neutral words. However, there were no group differences in this task. Finally, Brevers et al. (2011a) found that problem gamblers demonstrated an attentional bias towards gambling cues in a flicker paradigm, with a faster reaction time, greater gaze fixation and longer fixation length on gambling stimuli than controls. These findings suggest that gambling-related stimuli have a greater motivational

quality for problem/pathological gamblers and result in cognitive interference. In addition, interference from gambling-related stimuli appears to occur consciously as well as unconsciously, and may occur as early as the encoding stage.

Eight neuroimaging studies were identified that used gambling stimuli, games or an affective Go/No-Go task to examine cue-induced responses in problem/pathological gamblers. Using gambling pictures and scenarios, an early study conducted by Potenza et al. (2003b) found that pathological gamblers displayed reduced functional Magnetic Resonance Imaging (fMRI) activity in the frontal and orbitofrontal cortex (OFC), basal ganglia and thalamus compared to controls when viewing the initial section of the gambling scenario. No differences were found between pathological gamblers and controls in the happy or sad scenarios. Similarly, de Greck et al. (2010) reported that pathological gamblers demonstrate reduced fMRI activation in reward regions (left and right nucleus accumbens, left putamen) when evaluating the personal relevance of gambling, food and alcohol pictures.

In contrast to these studies, Crockford, Goodyear, Edwards, Quickfall, and El-Guebaly (2005) found increased fMRI activation in the right dorsolateral prefrontal cortex (DLPFC), right medial frontal gyrus, right parahippocampal gyrus and left fusiform gyrus of pathological gamblers whilst viewing gambling scenarios, compared to controls. Similarly, Goudriaan et al. (2010) found that problem gamblers displayed greater fMRI activation in the left occipital cortex, bilateral parahippocampal gyrus, right amygdala and right DLPFC when viewing gambling versus neutral pictures, compared to controls. Furthermore, subjective craving was positively related to activation in the bilateral ventrolateral prefrontal cortex (VLPFC), left anterior insula and left head of the caudate (Goudriaan et al., 2010). Similar to these neuroimaging findings, Wölfling et al. (2011) reported that pathological gamblers demonstrated greater cue reactivity to gambling stimuli than controls using electroencephalography (EEG). In this study, pathological gamblers' late positive potential,

which is proposed to reflect selective attention, was larger for gambling-related stimuli than for neutral stimuli, whereas controls had similar late positive potentials for gambling, neutral and emotional stimuli.

Collectively, despite some evidence of *reduced* fMRI activation when pathological gamblers view gambling scenarios or evaluate pictures for personal relevance, recent cue-reactivity studies have demonstrated *increased* fMRI activation in regions associated with memory and motivational influences (i.e., DLPFC and parahippocampal gyrus) (Krawczyk, 2002; Zola-Morgan & Squire, 1993) and areas involved in emotional processing and incentive learning (i.e., amygdala) (Goudriaan et al., 2010). These findings suggest that gambling stimuli are associated with heightened neural responses and possess a greater motivational value for pathological gamblers which may lead to difficulties controlling unwanted gambling behaviour. The different activation patterns across studies may be due to methodological factors, including perceived stimulus availability, treatment-seeking status, and rewarding properties of the stimulus, as these factors can influence cue-reactivity in substance-based addictions (Wilson, Sayette, & Fiez, 2004).

In addition to studies using pictures or scenarios, two studies with small sample sizes have investigated problem/pathological gamblers' cue-reactivity during gambling. Habib and Dixon (2010) examined near misses (i.e., outcomes proximal to a win) using an electronic gaming machine (EGM). Whilst viewing a near-miss, problem gamblers uniquely activated the uncus, right anterior medial temporal lobe and right inferior occipital gyrus, and this activation overlapped more with areas activated during win conditions. These findings suggest problem gamblers may view near-misses more as wins than controls; however, it was unclear whether the groups were age and gender matched. In addition, using [^{11}C]raclopride Positron Emission Tomography (PET), Joutsa et al. (2012) found no difference between pathological gamblers and controls in striatal dopamine release during high- and low-reward

conditions on an EGM. Greater gambling severity was, however, associated with greater dopamine release during the high reward condition. These findings suggest that pathological gamblers do not appear to demonstrate altered dopamine release in reward regions during EGM play. Near misses, however, activate different reward regions in problem gamblers and controls, which may be associated with the development of addictive behaviour in pathological gamblers.

Finally in a well designed study that included matched controls and excluded comorbidities in the problem gambling sample, Van Holst, Van Holstein, Van Den Brink, Veltman, and Goudriaan (2012) examined problem gamblers' cue-reactivity using an affective Go/No-Go task involving neutral, gambling, and emotional (positive and negative) pictures. Contrary to expectations, problem gamblers made fewer impulsive errors during the gamble and positive stimuli than controls; however, their reaction time was slower, suggesting a speed/accuracy trade-off. During gambling pictures, problem gamblers demonstrated increased fMRI activation in the DLPFC, anterior cingulate cortex (ACC) and ventral striatum compared to controls. These findings support the studies described above that used gambling pictures and scenarios and suggest that pathological gamblers demonstrated an increased neural response to gambling-related stimuli that may be associated with their difficulty resisting gambling urges.

2.5. Inhibitory Control

Impaired control in substance-based addictions is proposed to relate to poor inhibitory control (Bechara, 2005; Lubman et al., 2004). Inhibitory control is commonly measured by ability to inhibit a pre-potent motor response (response inhibition) or the ability to suppress a conflicting, competing response (interference control) (Nigg, 2000). Several prefrontal and

subcortical regions are proposed to be involved in inhibitory control including the DLPFC, VLPFC (also referred to as the inferior frontal cortex), dorsal ACC (Aron et al., 2007b; Garavan, Ross, Murphy, Roche, & Stein, 2002; Menon, Adleman, White, Glover, & Reiss, 2001) and the parietal cortex (Blasi et al., 2006). The right VLPFC may however be particularly important for response inhibition (Aron, Behrens, Smith, Frank, & Poldrack, 2007a; Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Chambers et al., 2007; Chambers et al., 2006; Garavan, Hester, Murphy, Fassbender, & Kelly, 2006; Rubia, Smith, Brammer, & Taylor, 2003), and may support a general inhibitory control process (Dillon & Pizzagalli, 2007). In this section, we evaluate the evidence for impaired inhibitory control in problem/pathological gamblers from studies using response inhibition and interference control tasks. In the subsequent section, we evaluate studies using neuroimaging to investigate problem/pathological gamblers' inhibitory control performances.

2.5.1. Neurocognitive evidence for inhibitory control dysfunction in problem and pathological gamblers

We identified 18 studies examining response inhibition or interference control in problem/pathological gamblers. Compared to controls, pathological gamblers have demonstrated poorer response inhibition with more commission errors (responding to a no-go signal) on the Go/No-Go task (Fuentes, Tavares, Artes, & Gorenstein, 2006; Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2005; Roca et al., 2008), the Stop Signal Task (SST) (Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2006a; Odlaug, Chamberlain, Kim, Schreiber, & Grant, 2011) and a combined Continuous Performance Test (CPT) and visual Go/No-Go task (Kertzman et al., 2008). Pathological gamblers have also demonstrated more omission errors (failure to respond to a go signal) than controls suggesting poor attention (Kertzman et al., 2008), although this has not been consistently found (Goudriaan et al., 2005; Roca et al., 2008). Mixed evidence exists for whether gambling severity is associated

with response inhibition. An early study with a small sample size found no differences between pathological gamblers, problem gamblers and controls on a Go/No-Go task (Leiserson & Pihl, 2007). However, more recently using a larger sample Odlaug et al. (2011) found that pathological gamblers performed more poorly on the SST than problem gamblers and controls, with no difference between problem gamblers and controls.

Consistent with the response inhibition findings, pathological gamblers also demonstrate poor interference control. Early studies that used small sample sizes found that pathological gamblers show greater interference than controls on the Stroop task (Forbush et al., 2008; Kalechstein et al., 2007; Regard, Knoch, Gutling, & Landis, 2003). More recently, several studies with larger sample sizes have corroborated these findings and demonstrated that pathological gamblers display a strong interference effect on the Stroop task (Goudriaan et al., 2006a; Kertzman, Lidogoster, Aizer, Kotler, & Dannon, 2011; Kertzman et al., 2006). In addition, pathological gamblers have also demonstrated a slower reading time than controls on the non-interference component of the Stroop task (Forbush et al., 2008; Kertzman et al., 2011; Kertzman et al., 2006), suggesting a general cognitive slowing. However, this contrasts the response inhibition findings where pathological gamblers demonstrated a faster reaction time on the Go/No-Go task than controls (Roca et al., 2008).

Despite these findings, there is also evidence for intact inhibitory control. Several studies have found no differences in response inhibition between pathological gamblers and controls on the SST (Lawrence, Luty, Bogdan, Sahakian, & Clark, 2009a), the CPT (Rodriguez-Jimenez et al., 2006), the Single Key Impulsivity Paradigm (Ledgerwood, Alessi, Phoenix, & Petry, 2009), the GoStop Impulsivity paradigm (Ledgerwood et al., 2012; Ledgerwood et al., 2009), and a reward/punishment Go/No-Go task (Leiserson & Pihl, 2007). Similarly, some studies have reported intact interference control with no difference between pathological gamblers and controls (Brand et al., 2005b; Ledgerwood et al., 2012) or

participants with bulimia nervosa (Alvarez-Moya et al., 2009) on the Stroop task. Most of these studies used appropriately matched control groups and consistent experimental paradigms; however, some contained smaller sample sizes.

Collectively, there are findings from well designed studies of both *poor* and *intact* inhibitory control in pathological gamblers. These discrepancies do not seem to be fully explained by the tasks, samples or gambling severity. Factors that may be associated with these differences include characteristics of the pathological gambling group (e.g., preferred gambling form, recruitment method and comorbidities) and the control group (e.g., controls matched for age, gender and screened for gambling problems), as well as small sample sizes resulting in insufficient power. Furthermore, recent evidence suggests that there may be subtypes of pathological gamblers that are not associated with high impulsivity (Blaszczynski & Nower, 2002; Ledgerwood & Petry, 2010; Lesieur, 2001; Milosevic & Ledgerwood, 2010). Therefore, further investigation is needed to understand heterogeneity in inhibitory control performance of pathological gamblers.

One factor that may be associated with the mixed findings, and has been examined in two studies, is comorbidities in the pathological gamblers. Using a large sample, Fuentes et al. (2006) found that pathological gamblers with and without comorbid disorders produced more commission errors on both visual and auditory Go/No-Go tasks than controls, but there was no difference between the two gambling groups. Therefore, contrary to expectations, poorer inhibitory control was not seen in pathological gamblers with comorbid disorders, which would have been expected given the findings of poor inhibitory control in comorbid disorders, particularly substance-based addictions (Feil et al., 2010; Verdejo-García, Perales, & Pérez-García, 2007). In contrast, Rodriguez-Jimenez et al. (2006) found that pathological gamblers with a history of childhood Attention Deficit Hyperactivity Disorder (ADHD) had slower stop signal reaction times and performed more poorly on a delay impulsivity task than

pathological gamblers without ADHD; however neither gambling group differed from controls. The findings of poor inhibitory control in pathological gamblers with comorbid ADHD suggest that comorbid ADHD may exacerbate response inhibition impairments. Such findings would be expected based on theoretical models (Barkley, 1997) and findings of behavioural disinhibition in ADHD (Cubillo et al., 2010; Lijffijt, Kenemans, Verbaten, & van Engeland, 2005). Together, these two studies provide preliminary evidence that poor inhibitory control is associated with pathological gambling rather than a consequence of comorbidities.

Lastly, we identified three studies that compared inhibitory control performances of pathological gamblers to other psychiatric conditions. In a well-designed study, Goudriaan et al. (2005, 2006a) reported that pathological gamblers, alcohol dependents and Tourette's syndrome participants all performed more poorly on the SST and a reward/punishment Go/No-Go task than controls; however no differences were found between the clinical groups. Whereas, on the Circle Tracing task pathological gamblers and Tourette's syndrome participants showed poorer inhibition and recorded faster tracing times than controls, whilst alcohol dependence did not differ from either clinical group (Goudriaan et al., 2006a). Lastly, on the Stroop task, pathological gamblers performed similarly to alcohol dependence, Tourette's syndrome (Goudriaan et al., 2006a), and methamphetamine users (Kalechstein et al., 2007), with all groups performing worse than controls. These preliminary findings suggest that pathological gamblers' inhibitory control performances are somewhat consistent with substance-based addictions and provide further similarities between these disorders.

2.5.2. Neuroimaging evidence for inhibitory control dysfunction in problem and pathological gamblers

Two neuroimaging studies were identified that investigated inhibitory control in problem/pathological gamblers. In an early study using the Stroop task, Potenza et al. (2003a)

found that pathological gamblers displayed reduced fMRI activation in the left ventromedial prefrontal cortex (VMPFC) and the superior aspect of the OFC compared to controls following the presence of incongruent stimuli (i.e., colour words written in a different colour ink). However, no differences in performance were found. This may have been associated with the modified Stroop task used which involved silently naming the colour words. Recently, de Ruiter et al. (2011) examined response inhibition during the SST in a sample of well matched problem gamblers, heavy smokers and controls. No behavioural differences were seen; nevertheless, a difference in cortical activation was present. During successful inhibition, problem gamblers and heavy smokers displayed reduced fMRI activation in the right dorsomedial prefrontal cortex (DMPFC), whilst reduced dorsal ACC activation was seen during failed inhibition (de Ruiter et al., 2011). In addition, greater gambling severity was associated with reduced right DMPFC activation during successful inhibition. Both studies used relatively small sample sizes which may relate to the non-significant behavioural findings. These findings suggest that pathological gamblers display *hypoactivation* in regions associated with the fronto-striatal networks during the presence of interference stimuli and inhibition, indicating that fronto-striatal dysfunction may underpin pathological gamblers' poor inhibitory control.

2.6. Decision Making

Poor decision making with a preference for immediate gains over long term outcomes is proposed to be a central component in addictive disorders, and may be dysfunctional in pathological gambling (Bechara, 2005; Noël et al., 2013). Decision making is a complex cognitive ability involving weighing up options to choose the alternative that is judged to be most appropriate. The OFC/VMPFC is particularly important for decision making (Bechara,

2005; Krawczyk, 2002; O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001) and this region integrates information from other cognitive processes including emotional processing, memory, knowledge, and attention during decision making (Krawczyk, 2002). In the following section, we examine decision making in problem/pathological gambling. We first evaluate studies using cognitive tasks where the outcomes are unknown and must be learnt over time, and then studies using impulsive decision making tasks and delay discounting.

2.6.1. Neurocognitive research on decision making in problem and pathological gamblers

Our systematic search identified 22 studies that examined problem/pathological gamblers' performance on decision making tasks. We first examine the 11 studies using one of the most commonly used decision making task involving risk and ambiguity; the Iowa Gambling Task (IGT). With one exception (Patterson II, Holland, & Middleton, 2006), pathological gamblers have been found to make more disadvantageous choices (choosing decks that have high penalty rates) on the IGT than controls (Cavedini, Riboldi, Keller, D'Annucci, & Bellodi, 2002; Forbush et al., 2008; Goudriaan et al., 2005; Kertzman et al., 2011; Lakey, Goodie, & Campbell, 2007; Ledgerwood et al., 2012; Linnet, Røjskjaer, Nygaard, & Maher, 2006). Moreover, on the IGT pathological gamblers are less likely to shift their choices to the advantageous decks over time (Cavedini et al., 2002; Forbush et al., 2008; Goudriaan et al., 2005; Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2006b; Ledgerwood et al., 2012; Roca et al., 2008), indicating that they are slower to learn the task. Together these findings provide strong support that pathological gamblers display poor decision making on the IGT, suggesting they demonstrate poor learning of appropriate choices under ambiguous risk/reward conditions.

Mixed evidence exists for whether gambling severity is associated with IGT performance. Lakey et al. (2007) reported that disadvantageous choices were associated with greater gambling severity in a large college student sample; however, Roca et al. (2008)

found no relationship between gambling severity and IGT performance in a small sample of non-treatment seeking pathological gamblers. In addition, pathological gamblers' IGT performance has been found to be uncorrelated with inhibitory control performance, suggesting an independent decision making impairment (Kertzman et al., 2011). The IGT has also been used in pathological gamblers to test the somatic marker hypothesis, which proposes that decision making is associated with "somatic markers" or unconscious physiological reactions (Bechara & Damasio, 2005). Goudriaan et al. (2006b) reported that pathological gamblers' heart rate decreased after both advantageous and disadvantageous choices, whereas controls' heart rate decreased after disadvantageous choices and increased after advantageous choices. Furthermore, pathological gamblers demonstrated no change in skin conductance rate when anticipating selections, whereas controls' skin conductance rate increased when anticipating disadvantageous decks. These findings illustrate how abnormal physiological responses may underlie decision making in pathological gambling, and provide further evidence of pathological gamblers' poor decision making on the IGT.

Two studies examined the influence of comorbid disorders on IGT performance (Cavedini et al., 2002; Petry, 2001b). In both studies, poor IGT performance appears to be associated with pathological gambling rather than comorbid disorders, although comorbidities may exacerbate poor performance. However, both studies contained relatively small sample sizes and unmatched control groups. Moreover, in a large study with well matched controls, pathological gamblers performed worse on the IGT than controls and Tourette's syndrome; however, no difference was found between pathological gamblers and alcohol dependence (Goudriaan et al., 2005). Taken together, these findings suggest that comorbidity exacerbates decision making impairments, but cannot alone account for poor performance and demonstrate additional evidence of similarities between pathological gamblers and substance-based addictions.

Five studies using other ambiguous decision making tasks have corroborated the findings of pathological gamblers' poor decision making in risky, ambiguous situations. On the Cambridge Gamble Task, problem gamblers performed worse than controls, but did not differ from alcohol-dependence (Lawrence, Luty, Bogdan, Sahakian, & Clark, 2009b). In addition, pathological gamblers performed worse than controls on the Card Playing Task, but did not differ from alcohol dependence or Tourette's syndrome (Goudriaan et al., 2005). On the Georgia Gambling Task, pathological gamblers were more overconfident, accepted more bets and scored less points than controls, but did not differ from problem gamblers in overconfidence (Lakey et al., 2007). Lastly, using decision making tasks with explicit risks, Brand et al. (2005b) and Labudda et al. (2007) found that pathological gamblers preferred disadvantageous choices, suggesting that even with knowledge, pathological gamblers still make risky choices. These findings provide further evidence of the conditions associated with pathological gamblers' decision making including overconfidence, risk-taking despite explicit knowledge, and poor decision making under different degrees of uncertainty.

In contrast to risky, ambiguous decision making tasks, seven studies have examined impulsive decision making, primarily using delay discounting tasks. On delay discounting tasks, pathological gamblers discount delayed rewards (accepting smaller immediate rewards) at a steeper rate than controls (Dixon, Marley, & Jacobs, 2003; Ledgerwood et al., 2009; Michalczuk, Bowden-Jones, Verdejo-Garcia, & Clark, 2011; Petry, 2001a), indicating an impulsive decision making style. However, two conflicting studies reported no difference between problem or pathological gamblers and controls on delay discounting tasks (Holt, Green, & Myerson, 2003; Madden, Petry, & Johnson, 2009). The Holt et al. (2003) study consisted of university students with lower mean age and gambling severity than most studies, and used a different delay discounting paradigm. However, this does not account for the findings from Madden et al. (2009) study which involved 19 treatment-seeking

pathological gamblers and appropriately matched controls. Moreover, it is unclear whether comorbid substance-use disorders influence pathological gamblers' delay discounting. Ledgerwood et al. (2009) found no difference between pathological gamblers with or without substance use disorders, whereas Petry (2001a) found that pathological gamblers with a history of substance-use disorders discounted rewards at a greater rate than pathological gamblers without a substance-use disorder history. Both studies contained similar sample sizes and had good methodological quality. Together, these results suggest that pathological gamblers perform more poorly on delay discounting tasks and are more impulsive during decision making. However, the impact of comorbidity remains unclear.

Problem and pathological gamblers have also performed worse on a probabilistic discounting task (i.e., to be more willing to sacrifice smaller certain rewards for a larger uncertain reward) than controls in two small studies (Holt et al., 2003; Madden et al., 2009). Additionally, Madden et al. (2009) reported that greater gambling severity is associated with poorer performance on a probabilistic discounting task. These results are not surprising given the similarities between probabilistic discounting tasks and gambling.

In addition to the delay and probabilistic discounting task studies, three studies used other impulsive decision making tasks in pathological gamblers. Ledgerwood et al. (2009) found that pathological gamblers with a history of substance-use disorders were more impulsive on the Balloon Analogue Risk Task than pathological gamblers without such a history; however, controls did not differ from either gambling group. Using the Information Sampling Test, Lawrence et al. (2009b) found that problem gamblers and alcohol dependent participants tolerated more uncertainty during decisions than controls, and problem gamblers made more errors than controls (with no difference to alcohol dependent participants). In addition, Kertzman et al. (2010) found that pathological gamblers recorded more errors than controls, with no difference in reaction time, on the Matching Familiar Figures Test. These

findings corroborate the delay and probabilistic discounting task findings and suggest that pathological gamblers demonstrate an impulsive decision making style characterised by rapid responses without appropriately evaluating information.

2.6.2. Neuroimaging research on decision making in problem and pathological gamblers

In this section, we evaluate the 16 neuroimaging studies using decision making tasks in problem/pathological gambling. Firstly, we discuss studies using the IGT, and then using other decision making tasks. We conclude with a discussion of studies using gambling-type tasks with various degrees of realism. Six studies have examined brain activation in pathological gamblers whilst undertaking the IGT. In an fMRI study, Tanabe et al. (2007) found no behavioural differences between substance dependent participants with or without pathological gambling and controls. However, differences in prefrontal cortex activation were present, perhaps suggesting a strategy or style difference which failed to affect crude performance measures. Compared to controls, substance-dependent participants with and without pathological gambling displayed reduced VMPFC activity during decision making. Substance-dependent participants with pathological gambling also demonstrated greater VMPFC activation than controls after playing a risky deck. Using a small sample of problem gamblers and a modified IGT, Oberg et al. (2011) examined IGT performance using EEG. Oberg et al. (2011) reported that reward feedback following a high-risk situation triggered a medial-frontal feedback-related negativity in both problem gamblers and controls. However, in problem gamblers, this feedback-related negativity was preceded by an early-latency hypersensitive fronto-central region, suggesting hypersensitivity to valence. Taken together, these findings suggest pathological gamblers' poor decision making on the IGT is associated with *reduced* fMRI activation in fronto-striatal pathways and altered reward processing.

In a series of papers, Linnet and colleagues reported findings from a PET study investigating pathological gamblers' ventral striatum dopamine release during decision

making (Linnet, Møller, Peterson, Gjedde, & Doudet, 2010a, 2010b; Linnet et al., 2012; Linnet, Peterson, Doudet, Gjedde, & Moller, 2010). Consistent with Tanabe and colleagues (2007) findings, pathological gamblers did not differ from controls in IGT performance (Linnet, Møller, et al., 2010b), however, differences in dopamine release were reported. Overall, pathological gamblers and controls demonstrated similar baseline dopamine binding and change in dopamine binding over time (Linnet et al., 2010c). However, pathological gamblers with increased dopamine release performed worse on the IGT than pathological gamblers with decreased dopamine release, whilst the opposite pattern was found for controls (Linnet et al., 2010b). In addition, pathological gamblers who lost money had higher dopamine release than controls, whilst pathological gamblers who won money did not differ (Linnet et al., 2010c). Pathological gamblers with dopamine release also displayed higher levels of self-reported excitement than controls with dopamine release (Linnet et al., 2010a). Finally, dopamine release in the ventral striatum of pathological gamblers was associated with uncertainty (Linnet et al., 2012). These findings suggest dopamine release influences decision making differently in pathological gamblers and controls, and that increased dopamine release is associated with poorer decision making, increased risk-taking, excitement and uncertainty in pathological gamblers.

We also identified three neuroimaging studies using other decision making tasks in problem/pathological gamblers. Using delay and probabilistic discounting tasks, Miedl, Peters, and Büchel (2012) examined neural representations of subjective value in pathological gamblers. Behaviourally, pathological gamblers discounted delayed rewards more steeply and demonstrated a trend towards discounting probabilistic rewards less steeply than controls. Functionally, pathological gamblers demonstrated enhanced neural value correlations in reward areas (ventral striatum, VMPFC, substantia nigra/ventral tegmental area) compared to controls during delay discounting; however, this was less pronounced during probabilistic

discounting. Therefore, pathological gamblers display altered reward system activation even with subjective value taken into consideration. On the Georgia Gambling Task, which involves indicating response confidence, Hudgens-Haney et al. (2013) found that pathological gamblers demonstrated higher confidence levels, but not accuracy or overconfidence, than controls. In addition, using magnetoencephalography, pathological gamblers demonstrated greater activation in temporal-parietal regions during early processing of judgment information, whilst controls demonstrated greater activation in the VLPFC. No group differences were seen during the outcome. Furthermore, during a Probabilistic Response Learning Task involving monetary gains and losses, de Ruiter et al. (2009) found that problem gamblers performed worse than smokers and controls, demonstrating an inability to alter decision making after feedback. Problem gamblers also demonstrated reduced VLPFC activation during monetary gain and loss, relative to controls. Together, these studies indicate that problem/pathological gamblers display altered activation in reward regions (e.g., ventral striatum, VMPFC, VLPFC) which appears particularly relevant to pathological gamblers' poor decision making.

We also included two studies investigating reward processing using the Monetary Incentive Delay Task, despite minimal decision making. Both fMRI studies involved well matched groups and experimental paradigms. No behavioural differences were seen; however, fMRI demonstrated reduced ventral striatum activation during reward anticipation, reduced VMPFC activation during reward outcome and reduced insula activation during loss outcomes in pathological gamblers compared to controls (Balodis et al., 2012). Similarly, Choi et al. (2012) reported reduced fMRI activation in the ventromedial caudate nucleus during anticipation of both gains and losses in pathological gamblers compared to controls and obsessive-compulsive disorder. In pathological gamblers, gambling severity was also associated with activity in the anterior insula during loss anticipation. These findings suggest

that altered reward processing, with reduced responsiveness to both gains and losses, may be a key aspect to pathological gamblers' decision making.

Five additional neuroimaging studies have investigated decision making using gambling-type tasks with varying degrees of realism to available gambling activities. In a well-designed study using a simple two-choice guessing game, pathological gamblers displayed reduced right ventral striatum and VMPFC activation compared to controls, and gambling severity was negatively correlated with activation in these areas (Reuter et al., 2005). This finding was replicated by de Greck et al. (2010), who also reported that problem gamblers displayed reduced activation in reward areas during loss conditions. In contrast, on a simple guessing game examining reward expectation, van Holst, Veltman, Büchel, van den Brink, and Goudriaan (2012) found that problem gamblers demonstrated greater activation in the bilateral dorsal striatum during large monetary amounts, and greater activation in the dorsal striatum and left OFC during gain related expectations. No differences in loss related expectations were seen. Although this study used a similar sample size to the de Greck et al. (2010) and Reuter et al. (2005) studies, and appropriately matched control group, reward expectation was specifically examined. The differences in neural activation patterns may be associated with differences in study design, including decision phase (i.e., anticipation, selection or outcome), level of risk or reward, and personal relevance of the task.

Studies using more realistic gambling tasks have demonstrated *increased* neural activation in pathological gamblers during decision making. Hewig et al. (2010) used a computerised Blackjack task to examine event-related potentials (ERP) associated with risky decision making. Pathological gamblers made more risky decisions after a previous loss than controls, and a positive outcome was associated with a positive ERP in the frontocentral region with level of risk-taking correlated with ERP amplitude. The positive ERP was proposed to indicate dopamine release in the ACC, suggesting risky decisions during

gambling are associated with increased dopamine levels of pathological gamblers in prefrontal cortex regions. Similarly, Miedl et al. (2010) examined blood oxygen level dependent fMRI signals during high and low-risk conditions during Blackjack. Problem gamblers displayed increased activation in the superior temporal gyrus, right inferior frontal/orbitofrontal gyrus and right medial pulvinar during high-risk choices and decreased activation during low-risk choices, whilst the opposite pattern was found in controls. Additionally, during winning compared to losing trials, problem gamblers had increased activation in fronto-parietal regions (right superior frontal, left inferior parietal and left superior parietal). The differences in activation patterns between simple guessing games and more realistic gambling tasks may be due to task differences. As Blackjack is a more realistic gambling activity it may elicit a stronger cue-reactivity response, whereas simple guessing games may demonstrate pathological gamblers' generally blunted reward system, which is then heightened during gambling.

2.7. General Methodological Limitations of the Literature

Some important methodological limitations need to be considered when evaluating the included studies. Firstly, there was considerable variability in the presence of comorbid mental health disorders in the problem/pathological gambling samples. Comorbidities are common in pathological gambling (c.f., Lorains et al., 2011) with most pathological gamblers having at least one comorbid disorder during their lifetime (Kessler et al., 2008). Therefore, whilst excluding comorbidities enables a clearer evaluation of cognitive dysfunction in problem/pathological gambling, there may be difficulties generalising to the wider problem/pathological gambling population. In addition, variability existed in whether studies reported comorbidities in the problem/pathological gambling sample, thus creating

difficulties when comparing findings across studies. Secondly, most studies did not report pathological gamblers' preferred gambling forms. There may be subtypes of pathological gamblers with different gambling preferences (Blaszczynski & Nower, 2002; Milosevic & Ledgerwood, 2010; Nower, Martins, Lin, & Blanco, 2013) and cognitive differences may exist in types of pathological gamblers (as discussed below) (Goudriaan et al., 2005). Thirdly, variability was present in the control groups. Most studies matched the control group on at least two variables (e.g., age, gender, IQ or education); however, many studies did not report how frequently the controls gambled or whether the controls were screened for gambling problems. It is not clear whether social gambling influences cognitive abilities, and between-study comparisons can be difficult with potential variations in control groups. Furthermore, laboratory tasks do not contain emotional cues present in everyday life and cognitive tasks may not generalise well to problem gamblers' performance in the real-world. Finally, many early studies used small sample sizes and employed different recruitment methods and gambling assessment tools, which all make comparisons between studies difficult. Furthermore, it is important to note that many neuropsychological tasks may not represent

2.8. Key Findings

In this systematic review, we evaluated the neuropsychological evidence of impaired control in pathological gambling in three key areas; attentional bias/cue reactivity, inhibitory control and decision making. Pathological gamblers display an attentional bias towards gambling cues, indicating gambling cues have a heightened motivational quality for pathological gamblers. In the presence of gambling stimuli, pathological gamblers show cognitive interference and slower reaction times, and generally demonstrate increased activation in regions associated with the reward pathways and fronto-striatal networks (i.e., DLPFC, OFC, parahippocampal gyrus and amygdala). Although evidence exists for poor

inhibitory control in pathological gamblers, findings are somewhat inconsistent and inconclusive, and require further investigation. In contrast, pathological gamblers display robust decision making impairments characterised by impulsivity, insensitivity to future rewards, over-confidence and risk-taking. Although limited, some studies have shown similar performances on inhibitory control and decision making tasks between pathological gamblers and substance-based addictions, supporting similarities between these disorders. Furthermore, whilst pathological gamblers demonstrated increased activation in the presence of gambling cues, reduced activation was demonstrated in many of the brain regions implicated in the mesolimbic reward pathway (e.g., VMPFC, VLPFC and ventral striatum) when performing inhibitory control and decision making tasks. The brain regions activated during inhibitory control, decision making and cue-reactivity tasks involve the fronto-striatal networks and reward pathways, and given that pathological gamblers generally displayed reduced activation in these areas during inhibitory control or decision making tasks, they may display a blunted response to reward which is then heightened in the presence of gambling stimuli or during gambling. The heightened motivational quality of gambling stimuli, poor decision making and possible inhibitory control impairments in pathological gamblers are likely to produce difficulties suppressing unwanted gambling urges and behaviour, and be a key factor in their impaired control over gambling.

2.9. Issues for Consideration

2.9.1. Does fronto-striatal dysfunction predate gambling problems?

It is unclear whether cognitive differences predate the development of pathological gambling and/or are a consequence of the disorder. High levels of self-reported impulsivity early in life has been related to greater frequency of gambling behaviour (Liu et al., 2013;

Pagani, Derevensky, & Japel, 2009) and has predicted gambling problems later in life (Shenassa, Paradis, Dolan, Wilhelm, & Buka, 2012; Vitaro, Arseneault, & Tremblay, 1999). Self-reported impulsivity is often equated with inhibitory control deficits (Enticott, Ogloff, & Bradshaw, 2006; Verdejo-García, Lawrence, & Clark, 2008) and these findings suggest self-reported impulsivity may be a predictor of developing pathological gambling.

There is some evidence that regular gambling behaviour may result in changes within brain networks before pathological gambling develops, as behaviours associated with pathological gambling activate the brains reward regions. Chasing losses (i.e., attempting to recover losses by continually gambling) is a central feature of pathological gambling and is strongly associated with impaired control over gambling (Campbell-Meiklejohn, Woolrich, Passingham, & Rogers, 2008) and impulsivity (Breen & Zuckerman, 1999). In healthy controls, chasing losses increases VMPFC and subgenual cingulate cortex activation (Campbell-Meiklejohn et al., 2008), whilst making risky choices following a loss increases activation in the fronto-parietal region and decreases activation in the VMPFC and amygdala (Xue, Lu, Levin, & Bechara, 2011). In addition, near-misses increase activation in the ventral striatum and anterior insula (Clark, Lawrence, Astley-Jones, & Gray, 2009), and gambling severity positively correlates with activation in the midbrain during a near-miss (Chase & Clark, 2010). Near-misses, therefore, recruit similar brain circuitry to wins, and may promote continuation of gambling behaviour through activation of the mesolimbic dopamine reward pathway. Collectively, these results suggest that features of pathological gambling (i.e., chasing losses) and characteristics of gambling activities (i.e., near-misses) promote dysfunction in areas involved in reward-based learning, decision making and cognitive control. However, controlled longitudinal follow-up studies are necessary to determine whether cognitive impairments predate pathological gambling.

2.9.2. Is heterogeneity in pathological gambling associated with cognitive differences?

Gambling refers to a variety of activities (e.g., EGMs, blackjack, roulette, sports betting, and lotteries) and differences exist between gambling forms in the reinforcement schedules, temporal characteristics of the pay-off, possible bet size, level of game involvement, gambling environment and amount of skill involved (Dowling, Smith, & Thomas, 2005). Some pathological gamblers prefer certain types of gambling (Petry, 2003), and characteristics including age, gender and socioeconomic status are associated with certain gambling forms (Odlaug, Marsh, Kim, & Grant, 2011; Stevens & Young, 2010). Preferred gambling form may influence the development of pathological gambling and result in differences in cognitive functioning. Accordingly, current theoretical models of pathological gambling (Blaszczynski & Nower, 2002; Sharpe, 2002) have incorporated the concept of heterogeneity, and there is evidence of pathological gambling subtypes (Milosevic & Ledgerwood, 2010; Nower et al., 2013).

Very few studies have examined cognitive difficulties in sub-groups of pathological gamblers; however, those that have reported interesting results. Goudriaan et al. (2005) found that EGM pathological gamblers displayed poorer response inhibition on the CPT, and made poorer choices on the IGT than pathological gamblers who prefer casino games. However, this study did not control for gender effects. Furthermore, pathological gamblers' attentional bias is stronger for words associated with their preferred gambling form on an emotional Stroop task (McCusker & Gettings, 1997). However, male and female pathological gamblers (Grant, Chamberlain, Schreiber, & Odlaug, 2012), and strategic (i.e., sports betting) and non-strategic (i.e., EGMs) pathological gamblers (Grant, Odlaug, Chamberlain, & Schreiber, 2012) were found to perform similarly on the SST and the intra-dimensional/extra-dimensional set-shift task. In addition, Billieux et al. (2012) recently highlighted a high degree of variability in pathological gamblers' performances across self-reported and

neurocognitive impulsivity tasks, with some pathological gamblers showing no impairments, some demonstrating only specific impulsivity impairments, and some showing global impulsivity impairments. These results provide further evidence that pathological gambling is a heterogeneous disorder, and that these differences are likely to extend to cognitive functioning. However, further research is required to determine the most appropriate pathological gambling subtypes and their cognitive characteristics.

2.10. Future Directions and Clinical Applications

The somewhat conflicting results in the literature may be associated with heterogeneity within samples, which results in low statistical power. Investigating endophenotypes of pathological gambling may bridge the gap between observable behaviour and the underlying genotype. Endophenotypes are heritable traits that are associated with a disorder, state independent (i.e., present regardless of whether the illness is active), and present to some extent in non-affected family members (Gottesman & Gould, 2003; Kendler & Neale, 2010). Endophenotypes are less genetically complex than the disorder, and as such can result in greater statistical power (Gottesman & Gould, 2003). ADHD and schizophrenia have illustrated the usefulness of neurocognitive measures as endophenotypes (Doyle et al., 2005; Preston & Weinberger, 2005). Thus, neurocognitive measures that tap the fronto-striatal networks may be a promising avenue for uncovering endophenotypes associated with pathological gambling, and can be used to investigate commonalities between pathological gambling and substance-based addictions.

Further research is required to clarify the conflicting inhibitory control findings. Pathological gamblers' inhibitory control may differ according to context, with intact inhibitory control to irrelevant stimuli, but dysfunctional inhibitory control with

motivationally-salient stimuli. Contrary to expectations, Van Holst et al. (2012a) found that pathological gamblers' inhibitory control improved in the presence of gambling stimuli. Future research could adopt affective inhibitory control paradigms to explore inhibitory control in cue-induced states. Furthermore, current mood state may influence pathological gamblers' inhibitory control. Negative mood states are often reported as triggers for gambling (Morasco, Weinstock, Ledgerwood, & Petry, 2007), and gambling may be used as an emotional escape or to modify arousal levels (Ricketts & Macaskill, 2003). In healthy individuals, positive mood states are associated with impaired updating, planning and set-shifting (Mitchell & Phillips, 2007), thus pathological gamblers' current mood state may influence their inhibitory control.

Another avenue for future research includes investigating the role of the insula in the fronto-striatal networks of problem/pathological gamblers. Recently, Noël et al. (2013) revised their model to incorporate a third 'insula system' that modifies the functioning of the 'amygdala' and 'prefrontal cortex' systems. The insula is proposed to respond to interoceptive signals and relate to urges and motivation for drug use. Subjective craving has been associated with insula activation in problem gamblers (Goudriaan et al., 2010), and pathological gamblers have demonstrated reduced insula activation during loss outcomes (Balodis et al., 2012), with gambling severity associated with anterior insula activity during loss anticipation (Choi et al., 2012). Additionally, the insula is associated with self-awareness and insight in substance abuse (Goldstein et al., 2009). Akin to substance abusers (Verdejo-García & Pérez-García, 2008), problem gamblers demonstrate impaired insight and awareness during decision making (Brevers et al., 2012) and reduced insight may partly account for the low treatment-seeking rates in pathological gambling (Slutske, 2006). Given impaired insight may be associated with problem gamblers' poor decision making; future research should investigate the role of the insula in pathological gambling.

Several possible clinical applications arise from these findings, including using neurocognitive measures to predict treatment outcomes, and targeting cognitive dysfunction using retraining techniques. Similar to substance-based addictions, pathological gamblers have high relapse rates, which can occur many months after abstinence (Hodgins & el-Guebaly, 2004; Ledgerwood & Petry, 2006). Goudriaan et al. (2008) found that the SST, but not the Stroop task, predicted relapse in pathological gamblers. In addition, cognitive bias modification (Eberl et al., 2013) and attentional bias modification (Schoenbaum et al., 2006) techniques have reduced relapse rates in alcohol dependence (see Wiers, Gladwin, Hofmann, Salemink, & Ridderinkhof, 2013 for review). Furthermore, a combined goal management training and mindfulness meditation treatment has been associated with improvements on the IGT, Stroop and a working memory task in polysubstance abusers (Alfonso, Caracuel, Delgado-Pastor, & Verdejo-García, 2011). These findings suggest that there may be potential therapeutic techniques and training programs that could alter pathological gamblers' cognitive functioning.

Similarly, pharmacological agents could be used to target cognitive dysfunction in pathological gamblers. Stimulants improve cognitive control and impulsivity in healthy individuals (Pietras, Cherek, Lane, Tcheremissine, & Steinberg, 2003; Turner et al., 2003) and in cocaine dependence (Li et al., 2010). Zack and Poulos (2009) found that modafinil, an atypical stimulant, reduced motivation to gamble during a gambling session, decreased salience of gambling words, reduced risky decision making and improved inhibitory control in pathological gamblers with high self-reported impulsivity. However, the opposite effects were observed in pathological gamblers with low self-rated impulsivity, suggesting modafinil has a bi-directional effect that is mediated by impulsivity. Additionally, memantine, an N-methyl-aspartate receptor antagonist, has reduced gambling severity and improved cognitive flexibility in pathological gamblers (Grant, Chamberlain, Odlaug, Potenza, & Kim, 2010).

These findings suggest that pathological gamblers' poor inhibitory control, decision making and increased attentional bias may be able to be targeted with pharmacological treatments.

Overall, this review provides substantial evidence that fronto-striatal dysfunction is associated with problem/pathological gamblers' impaired control. Pathological gamblers demonstrate an attentional bias towards gambling stimuli which likely results in craving, urges, and an inability to resist gambling. Moreover, dysfunction within the reward system is likely to result in impulsive decision making and the inability to correctly process rewards. There is also evidence of inhibitory control impairments in pathological gamblers; however, further research is required. These findings highlight the underlying cognitive processes involved in pathological gamblers' impaired control and findings can be used to develop targeted treatments and interventions.

2.11. References

Alfonso, J.P., Caracuel, A., Delgado-Pastor, L.C., & Verdejo-García, A. (2011). Combined goal management training and mindfulness meditation improve executive functions and decision-making performance in abstinent polysubstance abusers. *Drug and Alcohol Dependence, 117*(1), 78-81.

Alvarez-Moya, E., Jimenez-Murcia, S., Moragas, L., Gomez-Pena, M., Aymami, M., Ochoa, C., Sanchez-Diaz, I., Menchon, J., & Fernandez-Aranda, F. (2009). Executive functioning among female pathological gambling and bulimia nervosa patients: Preliminary findings. *Journal of the International Neuropsychological Society, 15*(2), 302-306.

American Psychiatric Association (APA). (2000). *Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR)*. Washington, DC: APA.

American Psychiatric Association (APA). (2013). *Diagnostic and Statistical Manual of Mental Disorders (DSM-5)*: American Psychiatric Publishing.

Aron, A.R., Behrens, T.E., Smith, S., Frank, M.J., & Poldrack, R.A. (2007a). Triangulating a cognitive control network using diffusion-weighted Magnetic Resonance Imaging (MRI) and Functional MRI. *Journal of Neuroscience, 27*(14), 3743-3752.

Aron, A.R., Durston, S., Eagle, D.M., Logan, G.D., Stinear, C.M., & Stuphorn, V. (2007b). Converging evidence for a fronto-basal-ganglia network for inhibitory control of action and cognition. *The Journal of Neuroscience, 27*(44), 11860-11864.

Aron, A.R., Fletcher, P.C., Bullmore, E.T., Sahakian, B.J., & Robbins, T.W. (2003). Stop-signal inhibition disrupted by damage to right inferior frontal gyrus in humans. *Nature Neuroscience, 6*(2), 115-116.

Bachorowski, J.-A., & Newman, J.P. (1990). Impulsive motor behavior: Effects of personality and goal salience. *Journal of Personality and Social Psychology, 58*(3), 512-518.

Balodis, I.M., Kober, H., Worhunsky, P.D., Stevens, M.C., Pearlson, G.D., & Potenza, M.N. (2012). Diminished frontostriatal activity during processing of monetary rewards and losses in pathological gambling. *Biological Psychiatry, 71*(8), 749-757.

Barkley, R.A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Psychological Bulletin, 121*(1), 65-94.

Bechara, A. (2005). Decision making, impulse control and loss of willpower to resist drugs: a neurocognitive perspective. *Nature Neuroscience, 8*(11), 1458-1463.

Bechara, A., & Damasio, A.R. (2005). The somatic marker hypothesis: A neural theory of economic decision. *Games and Economic Behavior, 52*(2), 336-372.

Bechara, A., Damasio, A.R., Damasio, H., & Anderson, S.W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition, 50*(1-3), 7-15.

Bechara, A., & Damasio, H. (2002). Decision-making and addiction (part I): Impaired activation of somatic states in substance dependent individuals when pondering decisions with negative future consequences. *Neuropsychologia, 40*(10), 1675-1689.

Billieux, J., Lagrange, G., Van der Linden, M., Lançon, C., Adida, M., & Jeanningros, R. (2012). Investigation of impulsivity in a sample of treatment-seeking pathological gamblers: A multidimensional perspective. *Psychiatry Research, 198*(2), 291-296.

Blasi, G., Goldberg, T.E., Weickert, T., Das, S., Kohn, P., Zoltick, B., Bertolino, A., Callicott, J.H., Weinberger, D.R., & Mattay, V.S. (2006). Brain regions underlying response inhibition and interference monitoring and suppression. *European Journal of Neuroscience, 23*(6), 1658-1664.

Blaszczynski, A., & Nower, L. (2002). A pathways model of problem and pathological gambling. *Addiction, 97*(5), 487-499.

Bolla, K.I., Eldreth, D.A., Matochik, J.A., & Cadet, J.L. (2005). Neural substrates of faulty decision-making in abstinent marijuana users. *Neuroimage, 26*(2), 480-492.

Bonson, K.R., Grant, S.J., Contoreggi, C.S., Links, J.M., Metcalfe, J., Weyl, H.L., Kurian, V., Ernst, M., & London, E.D. (2002). Neural systems and cue-induced cocaine craving. *Neuropsychopharmacology, 26*(3), 376-386.

Brand, M., Fujiwara, E., Borsutzky, S., Kalbe, E., Kessler, J., & Markowitsch, H.J. (2005a). Decision-making deficits of Korsakoff patients in a new gambling task With explicit rules: Associations with executive functions. *Neuropsychology, 19*(3), 267-277.

Brand, M., Kalbe, E., Labudda, K., Fujiwara, E., Kessler, J., & Markowitsch, H.J. (2005b). Decision-making impairments in patients with pathological gambling. *Psychiatry Research, 133*(1), 91-99.

Breen, R.B., & Zuckerman, M. (1999). 'Chasing' in gambling behavior: personality and cognitive determinants. *Personality and Individual Differences, 27*(6), 1097-1111.

Brevers, D., Cleeremans, A., Bechara, A., Greisen, M., Kornreich, C., Verbanck, P., & Noël, X. (2012). Impaired self-awareness in pathological gamblers. *Journal of Gambling Studies*, 1-11.

Brevers, D., Cleeremans, A., Bechara, A., Laloyaux, C., Kornreich, C., Verbanck, P., & Noel, X. (2011a). Time course of attentional bias for gambling information in problem gambling. *Psychology of Addictive Behaviors*.

Brevers, D., Cleeremans, A., Tibboel, H., Bechara, A., Kornreich, C., Verbanck, P., & Noel, X. (2011b). Reduced attentional blink for gambling-related stimuli in problem gamblers. *Journal of Behavior Therapy and Experimental Psychiatry, 42*(3), 265-269.

Brewer, J.A., & Potenza, M.N. (2008). The neurobiology and genetics of impulse control disorders: Relationships to drug addictions. *Biochemical Pharmacology, 75*(1), 63-75.

Campbell-Meiklejohn, D.K., Woolrich, M.W., Passingham, R.E., & Rogers, R.D. (2008). Knowing when to stop: The brain mechanisms of chasing losses. *Biological Psychiatry, 63*(3), 293-300.

Cavedini, P., Riboldi, G., Keller, R., D'Annucci, A., & Bellodi, L. (2002). Frontal lobe dysfunction in pathological gambling patients. *Biological Psychiatry, 51*(4), 334-341.

Chambers, C.D., Bellgrove, M.A., Gould, I.C., English, T., Garavan, H., McNaught, E., Kamke, M., & Mattingley, J.B. (2007). Dissociable mechanisms of cognitive control in prefrontal and premotor cortex. *Journal of Neurophysiology, 98*(6), 3638-3647.

Chambers, C.D., Bellgrove, M.A., Stokes, M.G., Henderson, T.R., Garavan, H., Robertson, I.H., Morris, A.P., & Mattingley, J.B. (2006). Executive "Brake Failure" following deactivation of human frontal lobe. *Journal of Cognitive Neuroscience, 18*(3), 444-455.

Chase, H.W., & Clark, L. (2010). Gambling severity predicts midbrain response to near-miss outcomes. *The Journal of Neuroscience, 30*(18), 6180-6187.

Choi, J.-S., Shin, Y.-C., Jung, W.H., Jang, J.H., Kang, D.-H., Choi, C.-H., Choi, S.-W., Lee, J.-Y., Hwang, J.Y., & Kwon, J.S. (2012). Altered brain activity during reward anticipation in pathological gambling and obsessive-compulsive disorder. *Plos One, 7*(9), e45938.

Clark, L., Lawrence, A.J., Astley-Jones, F., & Gray, N. (2009). Gambling near-misses enhance motivation to gamble and recruit win-related brain circuitry. *Neuron, 61*(3), 481-490.

Clark, L., Robbins, T.W., Ersche, K.D., & Sahakian, B.J. (2006). Reflection impulsivity in current and former substance users. *Biological Psychiatry, 60*(5), 515-522.

Crockford, D.N., Goodyear, B., Edwards, J., Quickfall, J., & El-Guebaly, N. (2005). Cue-induced brain activity in pathological gamblers. *Biological Psychiatry, 58*(10), 787-795.

Cubillo, A., Halari, R., Ecker, C., Giampietro, V., Taylor, E., & Rubia, K. (2010). Reduced activation and inter-regional functional connectivity of fronto-striatal networks in adults with childhood Attention-Deficit Hyperactivity Disorder (ADHD) and persisting symptoms during tasks of motor inhibition and cognitive switching. *Journal of Psychiatric Research, 44*(10), 629-639.

Cunningham-Williams, R.M., Cottler, L.B., Compton, W.M., Spitznagel, E.L., & Ben-Abdallah, A. (2000). Problem gambling and comorbid psychiatric and substance use disorders among drug users recruited from drug treatment and community settings. *Journal of Gambling Studies, 16*(4), 347-376.

Dao-Castellana, M.H., Samson, Y., Legault, F., Martinot, J.L., Aubin, H.J., Crouzel, C., Feldman, L., Barrucand, D., Rancurel, G., Feline, A., & Syrota, A. (1998). Frontal dysfunction in neurologically normal chronic alcoholic subjects: metabolic and neuropsychological findings. *Psychological Medicine, 28*(5), 1039-1048.

de Greck, M., Enzi, B., Prorsch, U., Gantman, A., Tempelmann, C., & Northoff, G. (2010). Decreased neuronal activity in reward circuitry of pathological gamblers during processing of personal relevant stimuli. *Human Brain Mapping, 31*(11), 1802-1812.

de Ruiter, M.B., Oosterlaan, J., Veltman, D.J., van den Brink, W., & Goudriaan, A.E. (2011). Similar hyporesponsiveness of the dorsomedial prefrontal cortex in problem gamblers and heavy smokers during an inhibitory control task. *Drug and Alcohol Dependence, 121*(1-2), 81-89.

de Ruiter, M.B., Veltman, D.J., Goudriaan, A.E., Oosterlaan, J., Sjoerds, Z., & Van Den Brink, W. (2009). Response perseveration and ventral prefrontal sensitivity to reward and punishment in male problem gamblers and smokers. *Neuropsychopharmacology, 34*(4), 1027-1038.

Dillon, D.G., & Pizzagalli, D.A. (2007). Inhibition of action, thought, and emotion: A selective neurobiological review. *Applied and Preventive Psychology, 12*(3), 99-114.

Dixon, M.R., Marley, J., & Jacobs, E.A. (2003). Delay discounting by pathological gamblers. *Journal of Applied Behavior Analysis, 36*(4), 449-458.

Dougherty, D.M., Bjork, J.M., Andrew Harper, R., Marsh, D.M., Gerard Moeller, F., Mathias, C.W., & Swann, A.C. (2003). Behavioral impulsivity paradigms: a

comparison in hospitalized adolescents with disruptive behavior disorders. *Journal of Child Psychology and Psychiatry, 44*(8), 1145-1157.

Dowling, N., Smith, D., & Thomas, T. (2005). Electronic gaming machines: are they the 'crack-cocaine' of gambling? *Addiction, 100*(1), 33-45.

Doyle, A.E., Willcutt, E.G., Seidman, L.J., Biederman, J., Chouinard, V.-A., Silva, J., & Faraone, S.V. (2005). Attention-Deficit/Hyperactivity Disorder Endophenotypes. *Biological Psychiatry, 57*(11), 1324-1335.

Eberl, C., Wiers, R.W., Pawelczack, S., Rinck, M., Becker, E.S., & Lindenmeyer, J. (2013). Approach bias modification in alcohol dependence: Do clinical effects replicate and for whom does it work best? *Developmental Cognitive Neuroscience, 4*(0), 38-51.

Enticott, P.G., Ogloff, J.R.P., & Bradshaw, J.L. (2006). Associations between laboratory measures of executive inhibitory control and self-reported impulsivity. *Personality and Individual Differences, 41*(2), 285-294.

Everitt, B.J., Dickinson, A., & Robbins, T.W. (2001). The neuropsychological basis of addictive behaviour. *Brain Research Reviews, 36*(2-3), 129-138.

Feil, J., Sheppard, D., Fitzgerald, P.B., Yücel, M., Lubman, D.I., & Bradshaw, J.L. (2010). Addiction, compulsive drug seeking, and the role of frontostriatal mechanisms in regulating inhibitory control. *Neuroscience and Biobehavioral Reviews, 35*(2), 248-275.

Ferris, J., & Wynne, H. (2001). The Canadian Problem Gambling Index: Final Report: Canadian Centre on Substance Abuse (CCSA).

Forbush, k.T., Shaw, M., Graeber, M.A., Hovick, L., Meyer, V.L., Moser, D.J., Bayless, J., Watson, D., & Black, D.W. (2008). Neuropsychological characteristics and personality traits in pathological gambling. *CNS Spectrum, 13*(4), 306-315.

Fuentes, D., Tavares, H., Artes, R., & Gorenstein, C. (2006). Self-reported and neuropsychological measures of impulsivity in pathological gambling. *Journal of the International Neuropsychological Society, 12*(6), 907-912.

Garavan, H., Hester, R., Murphy, K., Fassbender, C., & Kelly, C. (2006). Individual differences in the functional neuroanatomy of inhibitory control. *Brain Research, 1105*(1), 130-142.

Garavan, H., Ross, T.J., Murphy, K., Roche, R.A.P., & Stein, E.A. (2002). Dissociable executive functions in the dynamic control of behavior: Inhibition, error detection, and correction. *Neuroimage, 17*(4), 1820-1829.

Gerstein, D., Murphy, S., Toce, M., Hoffman, J., Palmer, A., & Johnson, R. (1999). Gambling impact and behaviour study: report to the national gambling impact study commission. Chicago: National Opinion Research Centre.

Golden, C.J. (1978). Stroop color and word test.

Goldstein, R.Z., Craig, A.D., Bechara, A., Garavan, H., Childress, A.R., Paulus, M.P., & Volkow, N.D. (2009). The neurocircuitry of impaired insight in drug addiction. *Trends in Cognitive Sciences, 13*(9), 372-380.

Goldstein, R.Z., & Volkow, N.D. (2002). Drug addiction and its underlying neurobiological basis: Neuroimaging evidence for the involvement of the frontal cortex. *American Journal of Psychiatry, 159*(10), 1642-1652.

Goldstein, R.Z., & Volkow, N.D. (2011). Dysfunction of the prefrontal cortex in addiction: Neuroimaging findings and clinical implications. *Nature Reviews Neuroscience, 12*(11), 652-669.

Goodie, A.S. (2003). The effects of control on betting: Paradoxical betting on items of high confidence with low value. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*(4), 598-610.

Gordon, M., & Mettelman, B.B. (1988). The assessment of attention: I. standardization and reliability of a behavior-based measure. *Journal of Clinical Psychology, 44*(5), 682-690.

Gottesman, II, & Gould, T.D. (2003). The endophenotype concept in psychiatry: etymology and strategic intentions. *American Journal of Psychiatry, 160*(4), 636-645.

Goudriaan, A.E., de Ruiter, M.B., van den Brink, W., Oosterlaan, J., & Veltman, D.J. (2010). Brain activation patterns associated with cue reactivity and craving in abstinent problem gamblers, heavy smokers and healthy controls: an fMRI study. *Addiction Biology, 15*(4), 491-503.

Goudriaan, A.E., Oosterlaan, J., de Beurs, E., & van den Brink, W. (2005). Decision making in pathological gambling: A comparison between pathological gamblers, alcohol dependents, persons with Tourette syndrome, and normal controls. *Cognitive Brain Research, 23*(1), 137-151.

Goudriaan, A.E., Oosterlaan, J., de Beurs, E., & van den Brink, W. (2006a). Neurocognitive functions in pathological gambling: A comparison with alcohol dependence, Tourette syndrome and normal controls. *Addiction, 101*(4), 534-547.

Goudriaan, A.E., Oosterlaan, J., de Beurs, E., & van den Brink, W. (2006b). Psychophysiological determinants and concomitants of deficient decision making in pathological gamblers. *Drug and Alcohol Dependence, 84*(3), 231-239.

Goudriaan, A.E., Oosterlaan, J., de Beurs, E., & van den Brink, W. (2008). The role of self-reported impulsivity and reward sensitivity versus neurocognitive measures of disinhibition and decision-making in the perdiction of relapse in pathological gamblers. *Psychological Medicine, 38*, 41-50.

Grant, J., Brewer, J., & Potenza, M. (2006). The neurobiology of substance and behavioral addictions. *CNS spectrums, 11*(12), 924-930.

Grant, J.E., Chamberlain, S.R., Odlaug, B.L., Potenza, M.N., & Kim, S.W. (2010). Memantine shows promise in reducing gambling severity and cognitive inflexibility in pathological gambling: A pilot study. *Psychopharmacology, 212*(4), 603-612.

Grant, J.E., Chamberlain, S.R., Schreiber, L.R.N., & Odlaug, B.L. (2012). Gender-related clinical and neurocognitive differences in individuals seeking treatment for pathological gambling. *Journal of Psychiatric Research, 46*(9), 1206-1211.

Grant, J.E., Odlaug, B.L., Chamberlain, S.R., & Schreiber, L.R.N. (2012). Neurocognitive dysfunction in strategic and non-strategic gamblers. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 38*(2), 336-340.

Grant, J.E., Steinberg, M.A., Kim, S.W., Rounsaville, B.J., & Potenza, M.N. (2004). Preliminary validity and reliability testing of a structured clinical interview for pathological gambling. *Psychiatry Research, 128*(1), 79-88.

Grant, S., Contoreggi, C., & London, E.D. (2000). Drug abusers show impaired performance in a laboratory test of decision making. *Neuropsychologia, 38*(8), 1180-1187.

Green, L., Fry, A.F., & Myerson, J. (1994). Discounting of delayed rewards: A life-span comparison. *Psychological Science, 5*(1), 33-36.

Green, L., & Myerson, J. (2004). A discounting framework for choice with delayed and probabilistic rewards. *Psychological Bulletin, 130*(5), 769-792.

Habib, R., & Dixon, M.R. (2010). Neurobehavioral evidence for the "Near-Miss" effect in pathological gamblers. *Journal of the Experimental Analysis of Behavior, 93*(3), 313-328.

Hewig, J., Kretschmer, N., Trippe, R.H., Hecht, H., Coles, M.G., Holroyd, C.B., & Miltner, W.H. (2010). Hypersensitivity to reward in problem gamblers. *Biological Psychiatry, 67*(8), 781-783.

Hodgins, D.C., & el-Guebaly, N. (2004). Retrospective and prospective reports of precipitants to relapse in pathological gambling. *Journal of Consulting and Clinical Psychology, 72*(1), 72-80.

Holden, C. (2001). 'Behavioral' addictions: Do they exist? *Science, 294*(5544), 980-982.

Holt, D.D., Green, L., & Myerson, J. (2003). Is discounting impulsive? Evidence from temporal and probability discounting in gambling and non-gambling college students. *Behavioural Processes, 64*(3), 355-367.

Hudgens-Haney, M.E., Hamm, J.P., Goodie, A.S., Krusemark, E.A., McDowell, J.E., & Clementz, B.A. (2013). Neural correlates of the impact of control on decision making in pathological gambling. *Biological Psychology, 92*(2), 365-372.

Ibanez, A., Blanco, C., Donahue, E., Lesieur, H.R., Perez de Castro, I., Fernandez-Piqueras, J., & Saiz-Ruiz, J. (2001). Psychiatric comorbidity in pathological gamblers seeking treatment. *American Journal of Psychiatry, 158*(10), 1733-1735.

Jentsch, J.D., & Taylor, J.R. (1999). Impulsivity resulting from frontostriatal dysfunction in drug abuse: implications for the control of behavior by reward-related stimuli. *Psychopharmacology, 146*(4), 373-390.

Joutsa, J., Johansson, J., Niemelä, S., Ollikainen, A., Hirvonen, M.M., Piepponen, P., Arponen, E., Alho, H., Voon, V., Rinne, J.O., Hietala, J., & Kaasinen, V. (2012). Mesolimbic dopamine release is linked to symptom severity in pathological gambling. *Neuroimage, 60*(4), 1992-1999.

Kagan, J., Rosman, B.L., Day, D., Albert, J., & Phillips, W. (1964). Information processing in the child: Significance of analytic and reflective attitudes. *Psychological Monographs: General and Applied, 78*(1), 1-37.

Kalechstein, A.D., Fong, T., Rosenthal, R.J., Davis, A., Vanyo, H., & Newton, T.F. (2007). Pathological gamblers demonstrate frontal lobe impairment consistent with that of methamphetamine-dependent individuals. *Journal of Neuropsychiatry and Clinical Neurosciences, 19*(3), 298-303.

Kendler, K.S., & Neale, M.C. (2010). Endophenotype: a conceptual analysis. *Molecular Psychiatry, 15*(8), 789-797.

Kertzman, S., Lidogoster, H., Aizer, A., Kotler, M., & Dannon, P.N. (2011). Risk-taking decisions in pathological gamblers is not a result of their impaired inhibition ability. *Psychiatry Research, 188*(1), 71-77.

Kertzman, S., Lowengrub, K., Aizer, A., Nahum, Z.B., Kotler, M., & Dannon, P.N. (2006). Stroop performance in pathological gamblers. *Psychiatry Research, 142*(1), 1-10.

Kertzman, S., Lowengrub, K., Aizer, A., Vainder, M., Kotler, M., & Dannon, P.N. (2008). Go-no-go performance in pathological gamblers. *Psychiatry Research, 161*(1), 1-10.

Kertzman, S., Vainder, M., Vishne, T., Aizer, A., Kotler, M., & Dannon, P.N. (2010). Speed-accuracy tradeoff in decision-making performance among pathological gamblers. *European Addiction Research, 16*(1), 23-30.

Kessler, R.C., Berglund, P., Demler, O., Jin, R., Merikangas, K.R., & Walters, E.E. (2005). Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the National Comorbidity Survey Replication. *Archives of General Psychiatry, 62*(6), 593-602.

Kessler, R.C., Hwang, I., LaBrie, R., Petukhova, M., Sampson, N.A., Winters, K.C., & Shaffer, H.J. (2008). DSM-IV pathological gambling in the National Comorbidity Survey Replication. *Psychological Medicine, 38*(9), 1351-1360.

Kirby, K.N., Petry, N.M., & Bickel, W.K. (1999). Heroin addicts have higher discount rates for delayed rewards than non-drug-using controls. *Journal of Experimental Psychology: General, 128*(1), 78-87.

Knutson, B., Adams, C.M., Fong, G.W., & Hommer, D. (2001). Anticipation of increasing monetary reward selectively recruits nucleus accumbens. *The Journal of Neuroscience, 21*(16), 159RC.

Krawczyk, D.C. (2002). Contributions of the prefrontal cortex to the neural basis of human decision making. *Neuroscience and Biobehavioral Reviews, 26*(6), 631-664.

Labudda, K., Wolf, O.T., Markowitsch, H.J., & Brand, M. (2007). Decision-making and neuroendocrine responses in pathological gamblers. *Psychiatry Research, 153*(3), 233-243.

Lakey, C.E., Goodie, A.S., & Campbell, W. (2007). Frequent card playing and pathological gambling: The utility of the Georgia Gambling Task and Iowa Gambling Task for predicting pathology. *Journal of Gambling Studies, 23*(3), 285-297.

Lawrence, A.J., Luty, J., Bogdan, N.A., Sahakian, B.J., & Clark, L. (2009a). Impulsivity and response inhibition in alcohol dependence and problem gambling. *Psychopharmacology, 207*(1), 163-172.

Lawrence, A.J., Luty, J., Bogdan, N.A., Sahakian, B.J., & Clark, L. (2009b). Problem gamblers share deficits in impulsive decision-making with alcohol-dependent individuals. *Addiction, 104*(6), 1006-1015.

Ledgerwood, D., Orr, E., Kaploun, K., Milosevic, A., Frisch, G., Rupcich, N., & Lundahl, L. (2012). Executive function in pathological gamblers and healthy controls. *Journal of Gambling Studies, 28*(1), 89-103.

Ledgerwood, D.M., Alessi, S.M., Phoenix, N., & Petry, N.M. (2009). Behavioral assessment of impulsivity in pathological gamblers with and without substance use disorder histories versus healthy controls. *Drug and Alcohol Dependence, 105*(1-2), 89-96.

Ledgerwood, D.M., & Petry, N.M. (2006). What do we know about relapse in pathological gambling? *Clinical Psychology Review, 26*(2), 216-228.

Ledgerwood, D.M., & Petry, N.M. (2010). Subtyping pathological gamblers based on impulsivity, depression, and anxiety. *Psychology of Addictive Behaviors, 24*(4), 680-688.

Leeman, R., & Potenza, M. (2012). Similarities and differences between pathological gambling and substance use disorders: a focus on impulsivity and compulsivity. *Psychopharmacology, 219*(2), 469-490.

Leiserson, V., & Pihl, R.O. (2007). Reward-sensitivity, inhibition of reward-seeking, and dorsolateral prefrontal working memory function in problem gamblers not in treatment. *Journal of Gambling Studies, 23*(4), 435-455.

Lejuez, C.W., Read, J.P., Kahler, C.W., Richards, J.B., Ramsey, S.E., Stuart, G.L., Strong, D.R., & Brown, R.A. (2002). Evaluation of a behavioral measure of risk taking: The Balloon Analogue Risk Task (BART). *Journal of Experimental Psychology: Applied, 8*(2), 75-84.

Lesieur, H.R. (2001). *Cluster analysis of types of inpatient pathological gamblers.* (62), ProQuest Information & Learning, US.

Lesieur, H.R., & Blume, S.B. (1987). The South Oaks gambling screen (SOGS)—a new instrument for the identification of pathological gamblers. *American Journal of Psychiatry, 144*, 1184-1188.

Li, C.-S.R., Morgan, P.T., Matuskey, D., Abdelghany, O., Luo, X., Chang, J.L.K., Rounsaville, B.J., Ding, Y.-S., & Malison, R.T. (2010). Biological markers of the effects of intravenous methylphenidate on improving inhibitory control in cocaine-

dependent patients. *Proceedings of the National Academy of Sciences of the United States of America, 107*(32), 14455-14459.

Lijffijt, M., Kenemans, J., Verbaten, M., & van Engeland, H. (2005). A meta-analytic review of stopping performance in attention-deficit/hyperactivity disorder: deficient inhibitory motor control? *Journal of Abnormal Psychology, 114*(2), 216-222.

Linnet, J., Møller, A., Peterson, E., Gjedde, A., & Doudet, D. (2010a). Dopamine release in ventral striatum during Iowa Gambling Task performance is associated with increased excitement levels in pathological gambling. *Addiction, 106*(2), 383-390.

Linnet, J., Møller, A., Peterson, E., Gjedde, A., & Doudet, D. (2010b). Inverse association between dopaminergic neurotransmission and Iowa Gambling Task performance in pathological gamblers and healthy controls. *Scandinavian Journal of Psychology, 52*(1), 28-34.

Linnet, J., Mouridsen, K., Peterson, E., Moller, A., Doudet, D.J., & Gjedde, A. (2012). Striatal dopamine release codes uncertainty in pathological gambling. *Psychiatry Research: Neuroimaging, 204*(1), 55-60.

Linnet, J., Peterson, E., Doudet, D., Gjedde, A., & Moller, A. (2010c). Dopamine release in ventral striatum of pathological gamblers losing money. *Acta Psychiatrica Scandinavica, 122*(4), 326-333.

Linnet, J., Røjskjaer, S., Nygaard, J., & Maher, B.A. (2006). Episodic chasing in pathological gamblers using the Iowa gambling task. *Scandinavian Journal of Psychology, 47*(1), 43-49.

Liu, W., Lee, G.P., Goldweber, A., Petras, H., Storr, C.L., Ialongo, N.S., & Martins, S.S. (2013). Impulsivity trajectories and gambling in adolescence among urban male youth. *Addiction, 108*, 780-788

Lobo, D.S.S., & Kennedy, J.L. (2009). Genetic aspects of pathological gambling: a complex disorder with shared genetic vulnerabilities. *Addiction, 104*(9), 1454-1465.

Logan, G.D., Cowan, W.B., & Davis, K.A. (1984). On the ability to inhibit simple and choice reaction time responses: A model and a method. *Journal of Experimental Psychology: Human Perception and Performance, 10*(2), 276-291.

Lorains, F.K., Cowlishaw, S., & Thomas, S.A. (2011). Prevalence of comorbid disorders in problem and pathological gambling: systematic review and meta-analysis of population surveys. *Addiction, 106*(3), 490-498.

Lubman, D.I., Yücel, M., & Pantelis, C. (2004). Addiction, a condition of compulsive behaviour? Neuroimaging and neuropsychological evidence of inhibitory dysregulation. *Addiction, 99*(12), 1491-1502.

Madden, G.J., Petry, N.M., & Johnson, P.S. (2009). Pathological gamblers discount probabilistic rewards less steeply than matched controls. *Experimental and Clinical Psychopharmacology, 17*(5), 283-290.

McCusker, C.G., & Gettings, B. (1997). Automaticity of cognitive biases in addictive behaviours: further evidence with gamblers. *British Journal of Clinical Psychology, 36*, 543-554.

Menon, V., Adleman, N.E., White, C.D., Glover, G.H., & Reiss, A.L. (2001). Error-related brain activation during a Go/NoGo response inhibition task. *Human Brain Mapping, 12*(3), 131-143.

Merikangas, K.R., Mehta, R.L., Molnar, B.E., Walters, E.E., Swendsen, J.D., Aguilar-Gaziola, S., Bijl, R., Borges, G., Caraveo-Anduaga, J.J., Dewit, D.J., Kolody, B., Vega, W.A., Wittchen, H.-U., & Kessler, R.C. (1998). Comorbidity of substance use disorders with mood and anxiety disorders: Results of the international consortium in psychiatric epidemiology. *Addictive Behaviors, 23*(6), 893-907.

Michalczuk, R., Bowden-Jones, H., Verdejo-Garcia, A., & Clark, L. (2011). Impulsivity and cognitive distortions in pathological gamblers attending the UK National Problem Gambling Clinic: a preliminary report. *Psychological Medicine, 41*(12), 2625-2635.

Miedl, S.F., Fehr, T., Meyer, G., & Herrmann, M. (2010). Neurobiological correlates of problem gambling in a quasi-realistic blackjack scenario as revealed by fMRI. *Psychiatry Research, 181*(3), 165-173.

Miedl, S.F., Peters, J., & Büchel, C. (2012). Altered neural reward representations in pathological gamblers revealed by delay and probability discounting. *Archives of General Psychiatry, 69*(2), 177-186.

Milosevic, A., & Ledgerwood, D.M. (2010). The subtyping of pathological gambling: A comprehensive review. *Clinical Psychology Review, 30*(8), 988-998.

Mitchell, R.L.C., & Phillips, L.H. (2007). The psychological, neurochemical and functional neuroanatomical mediators of the effects of positive and negative mood on executive functions. *Neuropsychologia, 45*(4), 617-629.

Molde, H., Pallesen, S., Sætrevik, B., Hammerborg, D.K., Laberg, J.C., & Johnsen, B.-H. (2010). Attentional biases among pathological gamblers. *International Gambling Studies, 10*(1), 45 - 59.

Morasco, B.J., Weinstock, J., Ledgerwood, D.M., & Petry, N.M. (2007). Psychological factors that promote and inhibit pathological gambling. *Cognitive and Behavioral Practice, 14*(2), 208-217.

Newman, J.P., Patterson, C.M., & Kosson, D.S. (1987). Response perseveration in psychopaths. *Journal of Abnormal Psychology, 96*(2), 145-148.

Newman, J.P., Widom, C.S., & Nathan, S. (1985). Passive avoidance in syndromes of disinhibition: Psychopathy and extraversion. *Journal of Personality and Social Psychology, 48*(5), 1316-1327.

Nigg, J.T. (2000). On inhibition/disinhibition in developmental psychopathology: views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*(2), 220-246.

Noël, X., Brevers, D., & Bechara, A. (2013). A neurocognitive approach to understanding the neurobiology of addiction. *Current Opinion in Neurobiology*(0).

Nower, L., Martins, S.S., Lin, K.-H., & Blanco, C. (2013). Subtypes of disordered gamblers: Results from the National Epidemiologic Survey on Alcohol and Related Conditions (NESARC). *Addiction, 108*(4), 789-798.

O'Doherty, J., Kringelbach, M.L., Rolls, E.T., Hornak, J., & Andrews, C. (2001). Abstract reward and punishment representations in the human orbitofrontal cortex. *Nature Neuroscience, 4*(1), 95-102.

Oberg, S.A.K., Christie, G.J., & Tata, M.S. (2011). Problem gamblers exhibit reward hypersensitivity in medial frontal cortex during gambling. *Neuropsychologia, 49*(13), 3768-3775.

O'Connor, J., & Dickerson, M. (2003). Impaired control over gambling in gaming machine and off-course gamblers. *Addiction, 98*, 53-60.

Odlaug, B., Marsh, P., Kim, S., & Grant, J. (2011a). Strategic vs nonstrategic gambling: characteristics of pathological gamblers based on gambling preference. *Annals of Clinical Psychiatry, 23*(2), 105-112.

Odlaug, B.L., Chamberlain, S.R., Kim, S.W., Schreiber, L.R.N., & Grant, J.E. (2011b). A neurocognitive comparison of cognitive flexibility and response inhibition in

gamblers with varying degrees of clinical severity. *Psychological Medicine, 41*(10), 2111-2119.

Pagani, L.S., Derevensky, J.L., & Japel, C. (2009). Predicting gambling behavior in sixth grade from kindergarten impulsivity: A tale of developmental continuity. *Archives of Pediatrics and Adolescent Medicine, 163*(3), 238-243.

Patterson II, J.C., Holland, J., & Middleton, R. (2006). Neuropsychological performance, impulsivity, and comorbid psychiatric illness in patients with pathological gambling undergoing treatment at the CORE inpatient treatment center. *Southern Medical Journal, 99*(1), 36-43.

Petry, N.M. (2001a). Pathological gamblers, with and without substance use disorders, discount delayed rewards at high rates. *Journal of Abnormal Psychology, 110*(3), 482-487.

Petry, N.M. (2001b). Substance abuse, pathological gambling, and impulsiveness. *Drug and Alcohol Dependence, 63*(1), 29-38.

Petry, N.M. (2003). A comparison of treatment-seeking pathological gamblers based on preferred gambling activity. *Addiction, 98*(5), 645-655.

Petry, N.M., & Casarella, T. (1999). Excessive discounting of delayed rewards in substance abusers with gambling problems. *Drug and Alcohol Dependence, 56*(1), 25-32.

Petry, N.M., Stinson, F.S., & Grant, B.F. (2005). Comorbidity of DSM-IV pathological gambling and other psychiatric disorders: Results from the national epidemiologic survey on alcohol and related conditions. *Journal of Clinical Psychiatry, 66*(5), 564-574.

Pierce, R.C., & Kumaresan, V. (2006). The mesolimbic dopamine system: The final common pathway for the reinforcing effect of drugs of abuse? *Neuroscience and Biobehavioral Reviews, 30*(2), 215-238.

Pietras, C., Cherek, D., Lane, S., Tcheremissine, O., & Steinberg, J. (2003). Effects of methylphenidate on impulsive choice in adult humans. *Psychopharmacology, 170*(4), 390-398.

Pontieri, F.E., Tanda, G., & Di Chiara, G. (1995). Intravenous cocaine, morphine, and amphetamine preferentially increase extracellular dopamine in the "shell" as compared with the "core" of the rat nucleus accumbens. *Proceedings of the National Academy of Sciences of the United States of America, 92*(26), 12304-12308.

Potenza, M.N, Leung, H.-C., Blumberg, H., P, Peterson, B., S, Fulbright, R.K., Lacadie, C.M., Skudlarski, P., & Gore, J.C. (2003a). An fMRI stroop task study of ventromedial prefrontal cortical function in pathological gamblers. *American Journal of Psychiatry, 160*(11), 1990.

Potenza, M.N. (2006). Should addictive disorders include non-substance-related conditions? *Addiction, 101*(s1), 142-151.

Potenza, M.N., Steinberg, M.A., McLaughlin, S.D., Wu, R.M.S., Rounsaville, B.J., & O'Malley, S.S. (2001). Gender-related differences in the characteristics of problem gamblers using a gambling helpline. *American Journal of Psychiatry, 158*(9), 1500-1505.

Potenza, M.N., Steinberg, M.A., Skudlarski, P., Fulbright, R.K., Lacadie, C.M., Wilber, M.K., Rounsaville, B.J., Gore, J.C., & Wexler, B.E. (2003b). Gambling urges in pathological gambling: A functional magnetic resonance imaging study. *Archives of General Psychiatry, 60*(8), 828-836.

Preston, G.A., & Weinberger, D.R. (2005). Intermediate phenotypes in schizophrenia: a selective review. *Dialogues in Clinical Neuroscience, 7*(2), 165-179.

Raymond, J.E., Shapiro, K.L., & Arnell, K.M. (1992). Temporary suppression of visual processing in an RSVP task: an attentional blink? *Journal of experimental psychology. Human perception and performance, 18*(3), 849-860.

Regard, M., Knoch, D., Gutling, E., & Landis, T. (2003). Brain damage and addictive behavior: a neuropsychological and electroencephalogram investigation with pathologic gamblers. *Cognitive and Behavioral Neurology, 16*(1), 47-53.

Rensink, R.A., O'Regan, J.K., & Clark, J.J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science, 8*(5), 368-373.

Reuter, J., Raedler, T., Rose, M., Hand, I., Glascher, J., & Buchel, C. (2005). Pathological gambling is linked to reduced activation of the mesolimbic reward system. *Nature Neuroscience, 8*(2), 147-148.

Ricketts, T., & Macaskill, A. (2003). Gambling as emotion management: developing a grounded theory of problem gambling. *Addiction Research and Theory, 11*(6), 383-400.

Robbins, T.W., & Everitt, B.J. (1999). Drug addiction: bad habits add up. *Nature, 398*(6728), 567-570.

Roca, M., Torralva, T., Lopez, P., Cetkovich, M., Clark, L., & Manes, F. (2008). Executive functions in pathologic gamblers selected in an ecologic setting. *Cognitive and Behavioral Neurology, 21*(1), 1-4.

Rodriguez-Jimenez, R., Avila, C., Jimenez-Arriero, M.A., Ponce, G., Monasor, R., Jimenez, M., Aragues, M., Hoenicka, J., Rubio, G., & Palomo, T. (2006). Impulsivity and sustained attention in pathological gamblers: influence of childhood ADHD history. *Journal of Gambling Studies, 22*(4), 451-461.

Rogers, R.D., Everitt, B.J., Baldacchino, A., Blackshaw, A.J., Swainson, R., Wynne, K., Baker, N.B., Hunter, J., Carthy, T., Booker, E., London, M., Deakin, J.F.W., Sahakian, B.J., & Robbins, T.W. (1999). Dissociable deficits in the decision-making cognition of chronic amphetamine abusers, opiate abusers, patients with focal damage to prefrontal cortex, and tryptophan-depleted normal volunteers: Evidence for monoaminergic mechanisms. *Neuropsychopharmacology, 20*(4), 322-339.

Rubia, K., Smith, A.B., Brammer, M.J., & Taylor, E. (2003). Right inferior prefrontal cortex mediates response inhibition while mesial prefrontal cortex is responsible for error detection. *Neuroimage, 20*(1), 351-358.

Schoenbaum, G., Roesch, M.R., & Stalnaker, T.A. (2006). Orbitofrontal cortex, decision-making and drug addiction. *Trends in Neurosciences, 29*(2), 116-124.

Shaffer, H.J., Hall, M.N., & Bilt, J.V. (1999). Estimating the prevalence of disordered gambling behavior in the United States and Canada: A Research Synthesis. *American Journal of Public Health, 89*(9), 1369-1375.

Sharpe, L. (2002). A reformulated cognitive-behavioral model of problem gambling: A biopsychosocial perspective. *Clinical Psychology Review, 22*(1), 1-25.

Shenassa, E.D., Paradis, A.D., Dolan, S.L., Wilhelm, C.S., & Buka, S.L. (2012). Childhood impulsive behavior and problem gambling by adulthood: a 30-year prospective community-based study. *Addiction, 107*(1), 160-168.

Slutske, W.S. (2006). Natural recovery and treatment-seeking in pathological gambling: Results of two U.S. national surveys. *American Journal of Psychiatry, 163*(2), 297-302.

Stevens, M., & Young, M. (2010). Who plays what? Participation profiles in chance versus skill-based gambling. *Journal of Gambling Studies, 26*(1), 89-103.

Stroop, J.R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*(6), 643-662.

Swann, A.C., Bjork, J.M., Moeller, F.G., & Dougherty, D.M. (2002). Two models of impulsivity: Relationship to personality traits and psychopathology. *Biological Psychiatry, 51*(12), 988-994.

Tanabe, J., Thompson, L., Claus, E., Dalwani, M., Hutchison, K., & Banish, M.T. (2007). Prefrontal cortex activity is reduced in gambling and nongambling substance users during decision-making. *Human Brain Mapping, 28*, 1276-1286.

Turner, D., Robbins, T., Clark, L., Aron, A., Dowson, J., & Sahakian, B. (2003). Cognitive enhancing effects of modafinil in healthy volunteers. *Psychopharmacology, 165*(3), 260-269.

van Holst, R.J., van den Brink, W., Veltman, D.J., & Goudriaan, A.E. (2010). Why gamblers fail to win: A review of cognitive and neuroimaging findings in pathological gambling. *Neuroscience and Biobehavioral Reviews, 34*(1), 87-107.

Van Holst, R.J., Van Holstein, M., Van Den Brink, W., Veltman, D.J., & Goudriaan, A. (2012a). Response inhibition during cue reactivity in problem gamblers: An fMRI Study. *Plos One, 7*(3).

van Holst, R.J., Veltman, D.J., Büchel, C., van den Brink, W., & Goudriaan, A.E. (2012b). Distorted expectancy coding in problem gambling: Is the addictive in the anticipation? *Biological Psychiatry, 71*(8), 741-748.

Verdejo-García, A., Lawrence, A.J., & Clark, L. (2008). Impulsivity as a vulnerability marker for substance-use disorders: Review of findings from high-risk research, problem gamblers and genetic association studies. *Neuroscience and Biobehavioral Reviews, 32*(4), 777-810.

Verdejo-García, A., & Pérez-García, M. (2008). Substance abusers' self-awareness of the neurobehavioral consequences of addiction. *Psychiatry Research, 158*(2), 172-180.

Verdejo-García, A.J., Perales, J.C., & Pérez-García, M. (2007). Cognitive impulsivity in cocaine and heroin polysubstance abusers. *Addictive Behaviors, 32*(5), 950-966.

Vitaro, F., Arseneault, L., & Tremblay, R.E. (1999). Impulsivity predicts problem gambling in low SES adolescent males. *Addiction, 94*(4), 565-575.

Wagner, F., A. , & Anthony, J., C. . (2002). From first drug use to drug dependence: Developmental periods of risk for dependence upon marijuana, cocaine, and alcohol. *Neuropsychopharmacology, 26*(4), 479.

Walitzer, K.S., & Dearing, R.L. (2006). Gender differences in alcohol and substance use relapse. *Clinical Psychology Review, 26*(2), 128-148.

Wiers, R.W., Gladwin, T.E., Hofmann, W., Salemink, E., & Ridderinkhof, K.R. (2013). Cognitive bias modification and cognitive control training in addiction and related psychopathology: Mechanisms, clinical perspectives, and ways forward. *Clinical Psychological Science*.

Williams, J.M.G., Mathews, A., & MacLeod, C. (1996). The emotional Stroop task and psychopathology. *Psychological Bulletin, 120*(1), 3-24.

Wilson, S.J., Sayette, M.A., & Fiez, J.A. (2004). Prefrontal responses to drug cues: a neurocognitive analysis. *Nature Neuroscience, 7*(3), 211-214.

Winters, K.C., Specker, S., & Stinchfield, R.S. (2002). Measuring pathological gambling with the Diagnostic Interview for Gambling Severity (DIGS). In J. J. Marotta, J. A. Cornelius & W. R. Eadington (Eds.), *The downside: Problem and pathological gambling* (pp. 143-148). Reno, NV: University of Nevada.

Wölfling, K., Mörsen, C.P., Duven, E., Albrecht, U., Grüsser, S.M., & Flor, H. (2011). To gamble or not to gamble: At risk for craving and relapse - learned motivated attention in pathological gambling. *Biological Psychology, 87*(2), 275-281.

World Health Organization. (2004). *The International Classification of Diseases (ICD-10)*. Geneva: World Health Organization.

Xue, G., Lu, Z., Levin, I.P., & Bechara, A. (2011). An fMRI study of risk-taking following wins and losses: Implications for the gambler's fallacy. *Human Brain Mapping, 32*(2), 271-281.

Zack, M., & Poulos, C. (2009). Effects of the atypical stimulant modafinil on a brief gambling episode in pathological gamblers with high vs. low impulsivity. *Journal of Psychopharmacology, 23*(6), 660-671.

Zola-Morgan, S., & Squire, L.R. (1993). Neuroanatomy of Memory. *Annual Review of Neuroscience, 16*(1), 547-563.

RATIONALE FOR THESIS

In light of the information provided in the preceding Chapters, the studies in my thesis were derived from the following themes in the literature:

- Problem gambling is associated with a large social cost and significant harms to the individual and their family; however, the aetiology of this disorder is not well known.
- A central feature of problem gambling is an impaired ability to control gambling behaviour despite negative consequences and desire to stop. According to neurocognitive models of substance-based addictions, impaired control is associated with dysfunction in the fronto-striatal circuitry resulting in heightened attention to addiction-related cues, poor inhibitory control and impaired decision making. In my thesis, we have focused on the role of *inhibitory control* and *decision making* in problem gambling.
- Inhibitory control is a multi-faceted construct with different types of inhibition. Inconsistencies exist in the literature as to whether problem gamblers demonstrate impaired inhibitory control and what type of inhibition is dysfunctional.
- Problem gamblers demonstrate poor decision making; however, decision making is a complex cognitive skill which engages other cognitive processes such as learning, reward processing, attention, and motivation. There is limited research on the cognitive processes driving problem gamblers' poor decision making.
- Heterogeneity appears to be a key aspect of problem gambling with evidence of potential subtypes of problem gamblers. However, it is unclear whether cognitive differences exist in problem gambling subtypes.
- Problem gambling subtypes have not been definitively determined and several subtyping methods are available. We used the criteria reported by Grant et al (2012a)

and Odlaug, Marsh, Kim, and Grant (2011) and subtyped participants into 'strategic' and 'non-strategic' problem gamblers based on preferred gambling form. Although a useful model, we did not use Blaszczynski and Nower's (2002) pathway model as evidence suggests these subtypes are not mutually exclusive.

- Finally, problem gambling is a highly comorbid disorder and subtypes may be associated with different comorbidities. Please refer to Appendix A for an article on the prevalence of comorbid disorders in problem gambling which I published during my doctoral candidature. As such, we included problem gamblers with comorbid mental health issues in our sample to increase generalisability.

Given the above information, the broad aims of the research presented in my thesis are:

1) To carefully investigate the nature and extent of inhibitory control functioning in problem gamblers using a range of inhibitory control tasks including novel paradigms not previously used in this population.
2) To characterise problem gamblers' decision making under risk and ambiguity, and investigate important underlying cognitive and motivational factors associated with decision making.
3) To determine whether subtypes of problem gamblers, based on preferred gambling type, differ on measures of inhibitory control and decision making.

CHAPTER 3: EXPANDED METHODOLOGY

The following Chapter outlines the general methodology of this thesis including participants, clinical measures, experimental tasks, procedures and data analysis. In addition, this Chapter provides further information on the rationale for each experimental task, and the development of the novel experimental tasks used in my thesis (the emotional Stroop task and the Loss Aversion Task). The information provided in this Chapter is designed to supplement the information in the two experimental papers (Chapters 4 and 5) and provide a more detailed overview of the overall study methodology.

3.1. General Participant and Study Information

3.1.1. Participant recruitment

This study involved two groups of participants:

a) Treatment-seeking problem gamblers

b) Age, gender and estimated-IQ matched healthy controls

Problem gamblers were recruited between May 2011 and September 2012 through six Gambler's Help centres in Victoria, Australia. Gambler's Help centres are government-funded outpatient treatment services that offer free counselling and psychological services to people experiencing gambling problems and their family members. For this study, we placed advertising flyers in the waiting rooms of Gambler's Help centres, and counsellors/psychologists distributed flyers to clients. The advertising flyers sought people who "feel they have a problem with gambling" to participate in a research study. Healthy control participants were recruited during the same time period through advertising on the Monash University campus and in a community website displaying local classified advertisements (www.gumtree.com.au). The advertisements for the control group sought people who gambled less than monthly and did not feel they had a problem with gambling.

3.1.2. Inclusion/exclusion criteria and screening procedures

To be included as a problem gambler, participants were required to be classified in the problem gambling category on the Problem Gambling Severity Index (PGSI) (score ≥ 8) from the Canadian Problem Gambling Index (Ferris & Wynne, 2001). For inclusion in the control group, participants were required to gamble less than monthly on all gambling forms except lottery/scratch tickets, and score within the non-problem gambling or low-risk gambling categories on the PGSI (score ≤ 2).

Participants were required to be aged between 18 and 65 years, have no history of previous head injury or stroke, and not have been diagnosed with any neurological disorders, pervasive developmental disorders or clinically relevant medical disorders. Participants were also required not to have consumed alcohol or used illicit drugs in the 12 hours prior to the testing session and to be fluent in English. In addition, to enable a clear comparison between the groups, control participants were excluded if they met criteria for any current or lifetime mental health disorder, which was measured by the Mini-International Neuropsychiatric Interview (Sheehan et al., 1998). As there is high prevalence of comorbid mental health disorders in problem gambling (c.f., Lorains et al., 2011, and refer to Section 1.1.4. of Chapter 1), we included problem gamblers with comorbidities to enhance the generalisability of the findings. However, we excluded problem gamblers with comorbid schizophrenia or psychotic episodes as these comorbidities are associated with significant cognitive impairment (Heinrichs & Zakzanis, 1998). We also excluded problem gamblers with current manic or hypomanic episodes, as manic episodes are an exclusion criteria for pathological gambling in the DSM-IV (APA, 2000).

Potential participants contacted the research team by phone or email to express interest in participating in the study. Participants then completed a telephone screening interview involving a short explanation of the study aims and procedures and a questionnaire

designed to evaluate the inclusion/exclusion criteria. During the telephone screening interview potential participants completed the PGSI to determine eligibility into either the control or problem gambling group.

During participant recruitment, control participants were matched to the problem gambling participants to ensure groups were consistent in age, gender and estimated-IQ (measured by the National Adult Reading Test; Nelson & Willison, 1991). However, our final sample included two additional control participants. The following clinical measures, self-reported impulsivity scales, inhibitory control and decision making tasks were administered during a face-to-face session with participants.

3.2. Clinical Measures

3.2.1. Problem Gambling Measures

We used the Problem Gambling Severity Index (PGSI) from the Canadian Problem Gambling Index to diagnose problem gambling and measure problem gambling severity (see Table 1). The PGSI provides a measure of current (last 12 months) problem gambling, and was based on the DSM-IV criteria for pathological gambling (APA, 2000) and the South Oaks Gambling Screen (SOGS) for pathological gambling (Lesieur & Blume, 1987). The PGSI is the recommended diagnostic screen for problem gambling in Australia and has been adopted as the preferred measure for Australian prevalence studies (Neal et al., 2005). The PGSI is a self-report scale with items measured on a four-alternative scale. Based on total score, which can range from 0 to 27, four categories of gambling behaviour are determined; non-problem gambler (0), low-risk gambler (1-2), moderate risk gambler (3-7) and problem gambler (8-27).

Table 1. Problem Gambling Severity Index from the Canadian Problem Gambling Index (Ferris & Wynne, 2001)

The following questions relate to your gambling behaviour in the last 12 months. Thinking about the past 12 months…	**Never**	**Sometimes**	**Most of the time**	**Almost always**
1. Have you bet more than you could really afford to lose?	0	1	2	3
2. Have you needed to gamble with larger amounts of money to get the same feeling of excitement?	0	1	2	3
3. When you gambled, did you go back another day to try to win back the money you lost?	0	1	2	3
4. Have you borrowed money or sold anything to get money to gamble?	0	1	2	3
5. Have you felt that you might have a problem with gambling?	0	1	2	3
6. Has gambling caused you any health problems, including stress or anxiety?	0	1	2	3
7. Have people criticised your betting or told you that you had a gambling problem?	0	1	2	3
8. Has your gambling caused any financial problems for you or your household?	0	1	2	3
9. Have you felt guilty about the way you gamble or what happens when you gamble?	0	1	2	3

Although the PGSI was originally developed for use in the general population, it has demonstrated good psychometric properties in both general population and clinical samples. In general population samples, the PGSI demonstrates good concurrent validity and correlates well with the DSM-IV (r = 0.83) and the SOGS (r = 0.83) (Ferris & Wynne, 2001). In addition, the 12-month prevalence rate of problem gambling obtained with the PGSI (0.9%) is more consistent with the DSM-IV (0.7%) than the SOGS (1.3%) (Ferris & Wynne, 2001). In terms of factor structure, the PGSI is uni-dimensional and displays good item-response characteristics (Ferris & Wynne, 2001; Holtgraves, 2009; Orford, Wardle, Griffiths, Sproston, & Erens, 2010). Furthermore, the PGSI demonstrates high internal reliability (α = 0.84-0.9) (Ferris & Wynne, 2001; Holtgraves, 2009; Orford et al., 2010), good test-retest

reliability (0.78), and good sensitivity (83% convergence with DSM-IV) and specificity (Ferris & Wynne, 2001). Finally, the PGSI has demonstrated better convergence with clinical opinion than the SOGS (Young & Wohl, 2011).

To further characterise the problem gambling sample, we also included a measure of current urge to gamble, the Gambling Urge Scale (GUS; Raylu & Oei, 2004). The GUS is a self-report questionnaire that consists of six items on a seven point Likert scale and was developed by modifying the Alcohol Urge Questionnaire (Bohn, Krahn, & Staehler, 1995). The GUS has been shown to consist of one factor which accounts for 55.2% of variance in a community sample (Raylu & Oei, 2004) and 75.54% of variance in a clinical sample (Smith, Pols, Battersby, & Harvey, 2013). The GUS has demonstrated good psychometric properties, including reliability (α = 0.81-0.93) and validity in both the general population and clinical samples (Raylu & Oei, 2004; Smith et al., 2013). For example, the GUS demonstrates good concurrent validity (i.e., 0.43 correlation with the SOGS), predictive validity (i.e., the GUS accounts for 18% variance in SOGS score) and criterion-related validity (81-87% of problem gamblers classified correctly) (Raylu & Oei, 2004; Smith et al., 2013).

3.2.2. Measures of comorbid mental health disorders

To measure the prevalence of current mental health disorders in our problem gambling sample, we used the Mini-International Neuropsychiatric Interview (MINI) version 5.0.0 (Sheehan et al., 1998). The MINI is a structured clinical interview for the diagnosis of mental health disorders according to the DSM-IV-TR and the International Classification of Diseases (ICD-10). The MINI focuses on current mental health disorders and was designed to be shorter than existing detailed clinical interviews, but more comprehensive and accurate than short screening measures (Sheehan et al., 1998). We administered all core modules of the MINI 5.0.0, as well as the optional antisocial personality disorder module, as there is support for an antisocial personality disorder subtype of problem gambling which is

associated with high impulsivity (Mishra, Lalumière, Morgan, & Williams, 2011). We did not assess any other personality disorders. The MINI demonstrates good psychometric properties and concordance with other structured clinical interviews. Compared to the Structured Clinical Interview for DSM-III-R and the Composite International Diagnostic Interview, the MINI demonstrates good or very good kappa values for concordance (0.69-0.82), high sensitivity (≥ 0.7 for almost all diagnoses) and high specificity (≥0.72 for all diagnoses) (Lecrubier et al., 1997; Sheehan et al., 1997). The MINI also displays good inter-rater (>0.75) and test re-test reliability (>0.75 for most diagnoses; Sheehan et al., 1998).

We also chose to further characterise the problem gambling sample by measuring the severity of some of the more common comorbid disorders we expected in the sample. We anticipated a high frequency of affective symptoms in our problem gambling sample given the high rate of women seeking treatment for gambling problems in Australia (Delfabbro, 2011), and evidence that female problem gamblers more commonly experience affective symptoms than men (Blanco et al., 2006; Dannon et al., 2006; Desai & Potenza, 2008; Echeburua et al., 2011; Ibáñez et al., 2003; Tavares et al., 2003). In addition, there is evidence that depression is one of the most common comorbid mental health disorders among treatment-seeking problem gamblers in Australia (Australian Productivity Commission, 1999; Battersby et al., 2006). We therefore included a continuous measure of psychological distress, depression, anxiety and stress; The Depression Anxiety and Stress Scale (DASS)-21 (Lovibond & Lovibond, 1995).

The DASS-21 is a shortened version of the original DASS-42 and contains 21 items measured on a four point scale; 0=did not apply to me at all, 1=applied to me to some degree or some of the time, 2=applied to me a considerable degree or a good part of time, 3=applied to me very much or most of the time. The DASS-21 includes the full range of symptoms measured by the DASS-42 and the two scales scores have been shown to be consistent

(Henry & Crawford, 2005). The DASS-21 has demonstrated good construct validity, indicating that the three subscales accurately measure depression, anxiety and stress, as well as a general measure of psychological distress (Henry & Crawford, 2005). The DASS correlates well with similar self-report questionnaires including the Beck Depression Inventory, the Beck Anxiety Inventory, and the State-Trait Anxiety Inventory (Antony, Bieling, Cox, Enns, & Swinson, 1998). In addition, the DASS-21 subscales and total score have demonstrated good internal consistency ($\alpha = 0.82$-0.94) and test-retest reliability ($r =$ 0.71-0.81) in clinical and non-clinical samples (Antony et al., 1998; Brown, Chorpita, Korotitsch, & Barlow, 1997; Henry & Crawford, 2005).

We also included a measure of severity of alcohol use and related problems as there is a high prevalence of harmful alcohol use in problem gambling (Kessler et al., 2008; Lorains et al., 2011), and chronic alcohol abuse can influence cognitive functioning (Goldstein & Volkow, 2011; Oscar-Berman & Marinković, 2007). The Alcohol Use Disorders Identification Test (AUDIT) is a 10-item self-report questionnaire that measures past year alcohol use and alcohol related problems (World Health Organization, 2001). Each question is scored from 0 to 4 with the total score ranging from 0 to 40. The AUDIT total score is used to classify participants into low risk (0-7), risky or hazardous levels (8-15), high-risk or harmful levels (16-19) and definite harm (20-40). The AUDIT has demonstrated good sensitivity (median = 0.86) and specificity (median = 0.89), which is comparable or superior to other screening measures (Reinert & Allen, 2002). In addition, the AUDIT has demonstrated good test re-test reliability (correlations between 0.6-0.8; Selin, 2003) and internal consistency ($\alpha > 0.8$ across multiple studies; Reinert & Allen, 2002).

3.3. Self-reported Impulsivity Measures

We included two questionnaires to measure trait impulsivity, the Barratt Impulsiveness Scale 11th revision (BIS-11; Patton, Stanford, & Barratt, 1995), and the UPPS-P Impulsivity Scale (Whiteside & Lynam, 2001). We included the BIS-11 as it is a widely used self-report impulsivity questionnaire and enabled us to compare our results to past research in problem gambling (i.e., Fuentes, Tavares, Artes, & Gorenstein, 2006; Lawrence, Luty, Bogdan, Sahakian, & Clark, 2009; Ledgerwood, Alessi, Phoenix, & Petry, 2009; Petry, 2001; Rodriguez-Jimenez et al., 2006). The UPPS-P is a more recently developed self-report impulsivity questionnaire and was chosen because the negative and positive urgency subscales appear particularly relevant for understanding problem gambling subtypes. These subscales measure impulsive actions under conditions of negative or positive emotions, and evidence suggests that non-strategic problem gamblers often report gambling for an emotional escape (Holdsworth et al., 2012), whilst strategic problem gamblers may gamble for excitement (Grant & Kim, 2002). Further details on the items, subscales and psychometric properties of BIS-11 and UPPS-P scales are described in Chapter 4.

3.4. Inhibitory Control Tasks

In my thesis, we focused on two main types of inhibitory control; response inhibition and interference control. Response inhibition refers to the ability to suppress a prepotent motor response, whilst interference control refers to the ability to inhibit interference from competing stimuli (Nigg, 2000). In addition to the process of inhibiting a response on a certain trial, an important cognitive aspect of inhibitory control is the presence of after-effects. After-effects refer to participant response slowing that occurs to stimuli that follow an inhibition trial, regardless of inhibition success (Enticott, Bradshaw, Bellgrove, Upton, & Ogloff, 2009; Upton, Enticott, Croft, Cooper, & Fitzgerald, 2010; Verbruggen, Logan,

Liefooghe, & Vandierendonck, 2008). To our knowledge, after-effects during inhibition have not been thoroughly examined in problem gamblers.

The exact mechanism by which inhibitory control occurs is unknown. Converging evidence suggests that the right ventrolateral prefrontal cortex (VLPFC; also referred to as the inferior frontal cortex) is critical for inhibitory control (Aron, Behrens, Smith, Frank, & Poldrack, 2007a; Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Chambers et al., 2007; Chambers et al., 2006; Garavan, Hester, Murphy, Fassbender, & Kelly, 2006; Rubia, Smith, Brammer, & Taylor, 2003), and may support a general inhibitory control process (Dillon & Pizzagalli, 2007). However, several other prefrontal cortical and subcortical regions are proposed to be involved including the dorsolateral prefrontal cortex (DLPFC), the dorsal anterior cingulate cortex (dACC) (Aron et al., 2007b; Garavan, Ross, Murphy, Roche, & Stein, 2002; Menon, Adleman, White, Glover, & Reiss, 2001) and the parietal cortex (Blasi et al., 2006). Different types of inhibitory control, measured using different experimental paradigms, will also recruit unique, yet overlapping, areas of the prefrontal cortex (Dillon & Pizzagalli, 2007).

Finally, other cognitive skills, particularly attention and working memory, are closely involved in inhibitory control (Chambers, Garavan, & Bellgrove, 2009). For example, increasing working memory load is associated with poorer response inhibition (Hester & Garavan, 2005), and inhibitory control and working memory activate similar neural regions including the right VLPFC (McNab et al., 2008). Furthermore, sustained attention tasks activate regions proposed to be involved in inhibitory control (Fassbender et al., 2004; Fassbender et al., 2006). Chambers et al. (2009) suggest that DMPFC activation during inhibitory control tasks may be partly due to increased attentional processes.

Given these findings, we chose a range of experimental tasks to examine inhibitory control in problem gamblers. In particular, we chose tasks which: (1) examined both motor

and cognitive response inhibition (Stop Signal Task, Sustained Attention to Response Task and Random Number Generation task) and interference control (emotional Stroop Task); (2) investigated after-effects; (3) recruited different prefrontal cortex areas; and (4) incorporated sustained attention and working memory. Furthermore, we included two inhibitory control tasks, the Sustained Attention to Response Task and the Random Number Generation task, that to our knowledge have not been examined in problem gamblers. We also developed an emotional Stroop task to investigate interference control during cue-relevant information. Below we describe the rationale for each inhibitory control task and the development of the emotional Stroop task. Task parameters are described in Chapter 4.

3.4.1. Stop Signal Task (SST)

We included the Stop Signal Task (SST) (Logan, Cowan, & Davis, 1984) as it is one of the most commonly used inhibitory control tasks and has been proposed to be a pure measure of response inhibition (Logan et al., 1984). The SST requires participants to respond manually to a visual 'go' stimulus and withhold their response when an auditory 'stop signal' tone is presented in conjunction with the 'go' stimuli. The SST was also used to measure after-effects associated with response inhibition. Response inhibition during the SST primarily activates the inferior frontal gyrus (Aron et al., 2003; Aron, Robbins, & Poldrack, 2004). We used the SST described by Upton et al. (2010), which has demonstrated the presence of inhibition after-effects in healthy samples.

3.4.2. Emotional Stroop Task

We developed an emotional Stroop task to measure problem gamblers' ability to suppress interference from gambling-related stimuli and to measure after-effects associated with interference control. Emotional Stroop tasks consist of neutral and emotional words relevant to a target condition. Past research suggests that people with mental health issues respond more slowly to target words associated with their mental health disorder (Cox,

Fadardi, & Pothos, 2006; Williams, Mathews, & MacLeod, 1996), and this slowing is believed to be due to interference caused from the salience of the stimuli. Inhibiting competing information during an emotional Stroop task recruits the ACC (Mitterschiffthaler et al., 2008) and the DLPFC (Compton et al., 2003).

Our emotional Stroop task consisted of both a blocked and pseudorandom presentation to allow us to measure interference on the current response and after-effects respectively (see Figure 1). Blocked presentations consist of a sequence of words from one category (e.g., neutral) followed by a sequence of words from another category (e.g., emotional), and measure the influence of the emotional stimuli on the current response. This is proposed to reflect an automatic attentional bias to the target stimuli (McKenna & Sharma, 2004). However, recent studies have shown the presence of after-effects in the emotional Stroop task, whereby participants respond slower to stimuli presented after the target stimulus, for example a neutral word presented after an emotional word (McKenna & Sharma, 2004). The target stimulus is proposed to disrupt responding beyond its presentation, and these 'after-effects' may indicate a general cognitive slowing associated with the emotional stimuli (Algom, Chajut, & Lev, 2004). A pseudorandom presentation is required to detect after-effects.

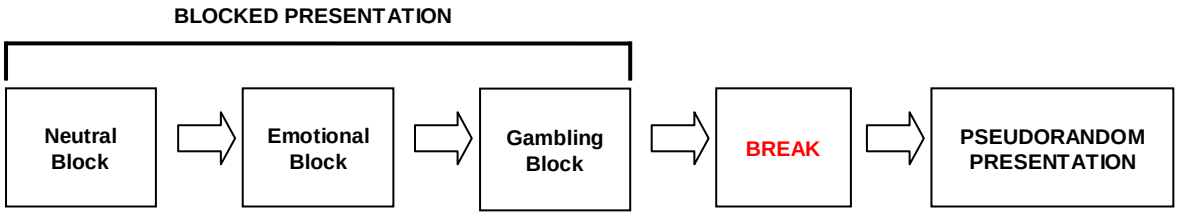

Figure 1. Diagram of the order of blocks in the emotional Stroop task.

To develop an emotional Stroop task, task parameters need to be carefully chosen to isolate the interference effect. Firstly, the categories of words are important. Many emotional Stroop tasks include two word lists: one word list containing neutral words and one word list containing emotional words which are relevant to a target condition. However, words relevant to a target condition are likely to be processed differently because of the emotional content associated with the words. Therefore, the inclusion of a third category of words that are emotional but unrelated to the target condition is recommended to ensure any observed effects can be attributed solely to the interference from the target condition (Field & Cox, 2008). A previous study using an emotional Stroop task with problem gamblers used drug-related words as a comparison category (McCusker & Gettings, 1997). However, considering the high prevalence of substance use disorders in problem gambling (Kessler et al., 2008), we did not feel drug-related words were an appropriate third category. Instead we chose to include a list of emotional words that were unrelated to gambling or substance use, thus creating three word categories in our emotional Stroop task; neutral, gambling and emotional. To ensure consistency between the word lists (Cox et al., 2006), our neutral words all belonged to the single category of household objects.

Secondly, the words in each category should be as similar as possible. The number of words in each category should be consistent to reduce any effects from word list size, and the lexical characteristics of the word lists need to be closely matched. Important lexical characteristics include word frequency, word length, number of syllables and orthogonal neighbourhood size (Larsen, Mercer, & Balota, 2006). Orthogonal neighbourhood size refers to the number of words into which a single word can be transformed by changing one letter within the word. We included the same number of words in each category and ensured that the neutral and emotional words closely resembled the gambling words in lexical

characteristics using the English Lexical Project information (Balota et al., 2007) and the Hyperspace Analogue to Language study for word frequency (Lund & Burgess, 1996).

To determine the most appropriate words for our Emotional Stroop task, we developed a list of 15 gambling-related words, which were then matched to 15 neutral words and 15 emotional words using the English Lexical Project data (Balota et al., 2007). The word lists (see Appendix B) were given to individuals working in problem gambling research and therapy to rate the words according to category (gambling, neutral or emotional) and relevance to gambling (5-point likert scale). Based on the results, we used the six gambling words which were ranked highest in relevance to gambling and were categorised correctly, as well as six neutral and emotional words which matched the gambling words in lexical characteristics.

3.4.3. Sustained Attention to Response Task (SART)

To examine response inhibition in a task involving sustained attention, we used the Sustained Attention to Response Task (SART) (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). The SART involves participants continually responding to a 'go' stimulus and withholding their response when a target 'stop' stimulus is displayed. Similar to the SST, the SART involves inhibiting a prepotent motor response. However, the target is less frequent and the task requires greater sustained attention. The right inferior frontal gyrus is recruited during response inhibition on the SART, which is consistent with the SST (Molenberghs et al., 2009). We adopted the original task parameters described by Robertson et al. (1997).

3.4.4. Random Number Generation task (RNG)

We included the Random Number Generation task (RNG) to measure inhibition in a task involving working memory. The RNG task requires participants to generate a random list of numbers using a particular response set such as 0-9, whilst avoiding patterns such as counting. The process of generating random numbers involves suppressing habitual or

stereotyped responses (i.e., counting) and is associated with the ability to inhibit a prepotent cognitive response (Miyake et al., 2000). Poor performance on the RNG task appears to be associated with difficulties in inhibition more than working memory (Joppich et al., 2004). The left DLPFC is recruited during the RNG task (Jahanshahi & Dirnberger, 1998; Knoch, Brugger, & Regard, 2005).

3.5. Decision Making Tasks

3.5.1. Iowa Gambling Task (IGT)

We used the Iowa Gambling Task (IGT) (Bechara, Damasio, Damasio, & Anderson, 1994) as a measure of decision making under risk and ambiguity. The IGT requires participants to choose from four decks of cards to win money (see Figure 2). Unknown to participants, some decks are better than others and participants must learn to choose the better decks over time. The IGT is a commonly used decision making task and is proposed to simulate real-life decision making where there is a complex environment of reward, motivation, and learning with uncertain outcomes (Bechara et al., 1994). Although the IGT has been previously used with problem gamblers (see section 2.6. of Chapter 2 for a review), our group has created a cognitive modelling procedure to understand the underlying cognitive and psychological processes involved in IGT performance. The Prospect Valence Learning model breaks IGT performance down into constituent psychological processes, and enables an examination of reward and loss processing, choice consistency and learning during the task (Ahn, Busemeyer, Wagenmakers, & Stout, 2008). To our knowledge, this is the first time a cognitive modelling technique has been used to understand problem gamblers' decision making on the IGT.

Figure 2. Screen shot from the Iowa Gambling Task

3.5.2. Loss Aversion task

We developed a Loss Aversion task to investigate loss aversion and decision making under risk. Unlike the IGT which involves unknown gains and losses and where participants must learn to make good choices over time, the Loss Aversion task involved explicit gains and losses and enabled us to investigate decision making under risk without ambiguity. In addition, this task enabled us to calculate a behavioural measure of loss aversion which could be compared to the Prospect Valence Learning model analysis of how losses are processed during the IGT.

The Loss Aversion task involves participants choosing to accept or reject a series of mixed gambles (e.g., win $25 or lose $15, Figure 3). Our Loss Aversion task was modelled on the task described by De Martino, Camerer, and Adolphs (2010). The De Martino et al. (2010) task, which involved neuroimaging, consisted of 256 trials with potential wins and losses ranging from $20 to $50 in $2 increments. Given our study did not using neuroimaging, we reduced the number of trials whilst still using a broad range of win/loss combinations. Research suggests that people are twice as sensitive to losses as to wins (Tversky & Kahneman, 1991), therefore we chose a range of wins and losses to attempt to elicit a wide range of responses from each participant. Our Loss Aversion task consisted of

49 trials involving pretend monetary wins and losses. Potential wins ranged from $15 to $45 (in $5 increments) and losses ranged from $5 to $35 (in $5 increments).

Figure 3. Example of a gamble presented in the Loss Aversion Task

3.6. Procedure

Participants were tested individually during a single session which was located at either the University of Melbourne or Monash University. The study protocol and the order of tasks during the testing session are displayed in Table 2. The order of tasks was fixed for all participants so that more difficult tasks were distributed between less demanding tasks. In addition, to avoid performances on the inhibitory control tasks influencing participants' responses on the self-report questionnaires, the self-report impulsivity questionnaires were completed prior to the inhibitory control tasks that involved response inhibition (SART, Stop Signal Task and the RNG). The testing session was approximately two hours in length. All tasks were conducted on a Dell Latitude D600 laptop computer and were administered in a quiet environment with participants seated approximately 40cm from the computer screen, although no restrictions were placed on the participants' movement. All participants provided signed informed consent and were reimbursed with a $50 gift voucher to a local department store. The study protocol was approved by the Monash University Human Research Ethics Committee (CF10/2772 – 2010001572) and the Department of Justice (Victoria, Australia) Research Ethics Committee (Cf/11/20525).

Table 2. Study protocol indicating the order of activities undertaken during the testing session

Order	Task
1	Explanation of study procedures and consent obtained
2	Pre-testing checklist consisting of inclusion/exclusion criteria
3	Background demographics and gambling questionnaire containing the PGSI
4	Gambling Urge Scale
5	Emotional Stroop task
6	National Adult Reading Test
7	Iowa Gambling Task (IGT)
8	UPPS-P Impulsivity Scale & the Barratt Impulsiveness Scale
9	Sustained Attention to Response Task (SART)
10	Mini International Neuropsychiatric Interview
11	Loss Aversion task
12	Stop Signal Task (SST)
13	Depression Anxiety and Stress Scale-21 & the Alcohol Use Disorders Identification Test
14	Random Number Generation (RNG) task

3.7. General Data and Statistical Analysis

Details of the statistical analyses conducted in this study are outlined within the method section of each experimental paper (Chapters 4 and 5). The Statistical Package for Social Sciences (SPSS) version 19.0 for Windows, SPSS Inc was used to analyse all data in this study. In addition to calculate the variables of interest from the RNG task, we used the RgCalc program (Towse & Neil, 1998). Finally, to analyse IGT performance according to the Prospect Valence Learning model, we used MATLAB v. R2010a (http://www.mathworks.com) and WinBUGS (http://www.mrc-bsu.cam.ac.uk/bugs/winbugs/contents.shtml)

CHAPTER 4: SELF-REPORTED IMPULSIVITY AND INHIBITORY CONTROL IN PROBLEM GAMBLERS

Explanatory Note

According to the substance-based addiction models, poor inhibitory control is a key feature of the impaired control displayed in addictive disorders. Laboratory tasks measuring inhibitory control are often equated with impulsivity measured using self-report scales. However, self-reported impulsivity and inhibitory control are both multi-faceted constructs, and different measurement tools are likely to reflect different aspects of 'real-world' impulsive behaviour. Impulsivity and inhibitory control have been investigated previously in problem gambling. However, we have added to the literature by using multiple measurement tools including self-report scales and laboratory tasks to attempt to delineate which aspects of the multi-faceted construct of impulsivity are associated with problem gambling. Moreover, as strategic problem gamblers are suggested to have higher impulsivity levels than non-strategic problem gamblers, we investigated whether impulsivity and inhibitory control differ between subtypes of problem gamblers.

Chapter 4 reports our investigations into self-reported impulsivity and inhibitory control in problem gamblers. Specifically, we used multiple impulsivity and inhibitory control tools to ascertain which facets of impulsive behaviour are associated with problem gambling, and determine the relationship between types of impulsivity in problem gambling. We also assessed whether impulsivity and inhibitory control performances differentiated problem gamblers who prefer strategic (i.e., sports betting) gambling activities and those that prefer non-strategic (i.e., EGMs). This chapter consists of a manuscript that is under review during a second submission to *the Journal of Clinical and Experimental Neuropsychology*.

Declaration for Thesis Chapter 4

Monash University

Declaration by candidate

In the case of Chapter 4, the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Conceptualisation and design of study, data collection, analysis and manuscript preparation	80%

The following co-authors contributed to the work. If co-authors are students at Monash University, the extent of their contribution in percentage terms must be stated:

Name	**Nature of contribution**	**Extent of contribution (%) for student co-authors only**
Julie Stout	Conceptualisation of study, supervision and revision of drafts	
Peter Enticott	Conceptualisation of study, supervision and revision of drafts	
John Bradshaw	Conceptualisation of study, supervision and revision of drafts	
Nicki Dowling	Conceptualisation of study, supervision and revision of drafts	

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work*.

Candidate's Signature		**Date**

Declaration by co-authors

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.

(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;

(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

(4) there are no other authors of the publication according to these criteria;

(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and

(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	Monash University, School of Psychology and Psychiatry, Clayton

Julie Stout	[redacted]	**10/10/2013**
Peter Enticott	[redacted]	**10/10/2013**
John Bradshaw	[redacted]	**10/10/2013**
Nicki Dowling	[redacted]	**10/10/2013**

Running head: IMPULSIVITY IN PROBLEM GAMBLERS

Self-Reported Impulsivity and Inhibitory Control in Problem Gamblers

Felicity K Lorains[a], Julie C Stout[a], John L Bradshaw[a], Nicki A Dowling[b,c,a], & Peter G Enticott[d]

[a] School of Psychology and Psychiatry, Monash University, Clayton, Victoria, 3800, AUSTRALIA. Felicity [redacted]

[b] School of Psychology, Deakin University, 221 Burwood Highway, Burwood, Victoria, 3125, AUSTRALIA. [redacted]

[c] Problem Gambling Research and Treatment Centre, The University of Melbourne, Level 5, 100 Leicester Street, Victoria, 3010, AUSTRALIA.

[d] Monash Alfred Psychiatry Research Centre, The Alfred and Central Clinical School, Monash University, Level 4, 607 St Kilda Road, Melbourne, Victoria, 3004, AUSTRALIA. [redacted]

Correspondence concerning this article should be addressed to Felicity K Lorains, School of Psychology and Psychiatry, Faculty of Medicine, Nursing and Health Sciences, Monash University, Clayton, Building 17, Victoria, 3800 AUSTRALIA. Email: [redacted]

4.1. Abstract

Impulsivity is considered a core feature of problem gambling, however, self-reported impulsivity and inhibitory control may reflect disparate constructs. We examined self-reported impulsivity and inhibitory control in 39 treatment-seeking problem gamblers and 41 matched controls using a range of inhibitory control tasks. We also investigated differences between treatment-seeking problem gamblers who prefer strategic (e.g., sports-betting) and non-strategic (e.g., electronic gaming machines) gambling activities. Treatment-seeking problem gamblers demonstrated elevated self-reported impulsivity, more go errors on the Stop Signal Task and a lower gap score on the Random Number Generation task than matched controls. However, overall we *did not* find strong evidence that treatment-seeking problem gamblers are more impulsive on inhibitory control measures. Furthermore, strategic and non-strategic problem gamblers did not differ from their respective controls on either type of measure. Contrary to expectations, our results suggest that inhibitory dyscontrol may not be a key component for some treatment-seeking problem gamblers.

4.2. Introduction

Problem gambling is characterised by an inability to control gambling behaviour despite negative consequences or desire to stop (American Psychiatric Association (APA), 2000). Impulsivity is considered to be a key feature of problem gambling (Alessi & Petry, 2003; Verdejo-García, Lawrence, & Clark, 2008), yet it is a multi-faceted construct which is often poorly defined. Impulsivity can be measured through self-report questionnaires or laboratory inhibitory control tasks. Despite being used interchangeably, the relationship between these tools is generally small (Aichert et al., 2012; Cyders & Coskunpinar, 2011, 2012), suggesting that they may measure disparate aspects of impulsive behaviour (Cyders & Coskunpinar, 2011, 2012; Dalley, Mar, Economidou, & Robbins, 2008). In this regard, self-reported impulsivity scales may measure general impulsive behaviour over time and therefore reflect more stable trait level personality characteristics of impulsivity (*trait impulsivity*). In contrast, laboratory inhibitory control tasks may measure in the moment behaviour and reflect a snapshot of behaviour in a certain situation which is influenced by context and surroundings. In addition, self-reported impulsivity measures reflect behaviour observable to the individual whilst laboratory tasks may reflect impulsivity unobservable to the individual (Cyders & Coskunpinar, 2011). In further support of the multi-faceted nature of impulsivity, different types of impulsivity have predicted different stages of addictive behaviour in animal studies (Diergaarde et al., 2008) and some rats have demonstrated selective deficits in types of impulsivity (Robinson et al., 2009). Therefore, although, impulsivity is often considered to relate to problem gamblers' inability to control their gambling behaviour, this complex heterogeneous construct requires further defining and delineating in this population.

Self-reported trait impulsivity is a multi-faceted construct which can include sensation seeking, risk-taking, lack of planning, perseverance and acting on impulses (Whiteside & Lynam, 2001). Problem gamblers demonstrate high levels of trait impulsivity including non-

planning, attentional (Ledgerwood, Alessi, Phoenix, & Petry, 2009), and motor impulsivity (Lawrence, Luty, Bogdan, Sahakian, & Clark, 2009a) on the Barratt Impulsiveness Scale, and high levels of negative urgency and lack of premeditation on the UPPS Impulsivity scale (MacLaren, Fugelsang, Harrigan, & Dixon, 2011). Furthermore, self-reported impulsivity has been linked to gambling engagement (Pagani, Derevensky, & Japel, 2009), gambling severity and treatment drop-out (Leblond, Ladouceur, & Blaszczynski, 2003). Whilst it is commonly accepted that problem gamblers demonstrate high levels of trait impulsivity, the evidence for poor inhibitory control is less clear.

Different types of inhibitory control include, but are not limited to, the ability to inhibit a pre-potent response (response inhibition) and the ability to suppress a conflicting, competing response (interference control) (Friedman & Miyake, 2004; Nigg, 2000). In some studies, problem gamblers have demonstrated poor response inhibition (Billieux et al., 2012; Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2006; Kertzman et al., 2008), greater interference (Forbush et al., 2008; Goudriaan et al., 2006; Regard, Knoch, Gutling, & Landis, 2003), and reduced activation in brain regions associated with impulse control than controls (de Ruiter, Oosterlaan, Veltman, van den Brink, & Goudriaan, 2011; Potenza et al., 2003). However, despite using similar experimental paradigms and problem gambling samples, inconsistent findings are present in the literature for both response inhibition and interference control (Brand et al., 2005; de Ruiter et al., 2011; Lawrence et al., 2009a; Ledgerwood et al., 2012; Ledgerwood et al., 2009).

Other inhibitory control tasks are required to investigate problem gambling and have the potential to resolve some of the conflicting findings in the literature. Several lines of evidence suggest that other cognitive skills, particularly attention and working memory, are closely involved in the ability to inhibit behaviour (Chambers, Garavan, & Bellgrove, 2009). In this regard, response inhibition declines with increasing working memory load (Hester &

Garavan, 2005) and inhibitory control and working memory activate similar regions of the prefrontal cortex including the right ventrolateral prefrontal cortex (McNab et al., 2008). Furthermore, it has been suggested that dorsomedial prefrontal cortex activation during inhibitory control tasks may be in part due to an increase in attentional processes (Chambers et al., 2009), and sustained attention tasks activate areas associated with inhibitory control (Fassbender et al., 2004; Fassbender et al., 2006). Problem gamblers do not appear to demonstrate impairments in working memory (Brevers et al., 2012a; Goudriaan et al., 2006; Lawrence, Luty, Bogdan, Sahakian, & Clark, 2009b), auditory attention span (Lawrence et al., 2009b), sustained attention (Rodriguez-Jimenez et al., 2006) or divided attention (Forbush et al., 2008), however, investigation of inhibitory control tasks incorporating these cognitive skills may assist in resolving the mixed findings in the literature. Furthermore, the presence of inhibitory control after-effects, whereby participants demonstrate slowing following an inhibition trial, regardless of inhibition success, requires investigation (Enticott, Bradshaw, Bellgrove, Upton, & Ogloff, 2009; Upton, Enticott, Croft, Cooper, & Fitzgerald, 2010; Verbruggen, Logan, Liefooghe, & Vandierendonck, 2008).

The possible relationship between trait impulsivity and inhibitory control in problem gamblers also requires further examination. In healthy populations, response inhibition is associated with non-planning impulsivity (Enticott, Ogloff, & Bradshaw, 2006), whilst interference control is associated with sensation-seeking, lack of planning (Cyders & Coskunpinar, 2012), and attentional and motor impulsivity (Enticott et al., 2006). However, in problem gambling samples, response inhibition has not been associated with any type of self-reported impulsivity (Lawrence et al., 2009a; Ledgerwood et al., 2009). Therefore, whilst problem gamblers may report elevated trait impulsivity, this may not relate to their in the moment impulsive behaviour.

Recent theories suggest heterogeneity amongst problem gamblers with evidence of possible different subtypes based on preferred gambling form, comorbidities, or gambling motivations (Blaszczynski & Nower, 2002; Odlaug, Marsh, Kim, & Grant, 2011). In this regard, Goudriaan, Oosterlaan, de Beurs, and van den Brink (2005) found that problem gamblers who prefer electronic gaming machines (EGMs) display poorer response inhibition than those who prefer casino games. In contrast, Grant, Odlaug, Chamberlain, and Schreiber (2012b) reported no differences in response inhibition between problem gamblers who prefer strategic gambling activities (e.g., casino games) and problem gamblers who prefer non-strategic gambling activities (e.g., EGMs). It is important to note, however, that gamblers preferring non-strategic gambling activities are more likely to be women, and gamblers preferring strategic activities are more likely to be men (Dowling, In Press; Odlaug et al., 2011; Potenza et al., 2001). The role of gender, therefore, needs to be carefully considered when subgrouping based on preferred gambling form.

As the literature has evolved, there is an appreciation that self-reported impulsivity measures and inhibitory control are multi-faceted and may measure distinct aspects of impulsive behaviour. However, the complex nature of impulsivity and inhibitory control has not been fully investigated in problem gambling. Therefore, our aim was to examine trait impulsivity and inhibitory control in problem gamblers to delineate which of the related constructs are associated with problem gambling. In this regard, we compared treatment-seeking problem gamblers and matched controls using two self-report trait impulsivity questionnaires and four inhibitory control tasks which measured both response inhibition and interference control, as well as incorporating other relevant cognitive skills (i.e., sustained attention and working memory) and measuring inhibition after-effects. Furthermore, we examined the relationship between self-reported impulsivity and inhibitory control in problem gamblers, and conducted a preliminary analysis of whether self-reported impulsivity

and inhibitory control differ between subtypes of problem gamblers based on preferred gambling form using gender-matched control groups.

4.3. Method

4.3.1. Participants and procedures

Two groups of participants were recruited: treatment-seeking problem gamblers (*n*=39) and age-, gender- and estimated IQ- (measured by the National Adult Reading Test; (Nelson & Willison, 1991) matched controls (*n*=41). Problem gamblers were recruited between May 2011 and September 2012 through advertising placed in six government-funded outpatient counselling centres in Victoria, Australia. Problem gamblers were required to score within the problem gambling category (≥8) on the Problem Gambling Severity Index (PGSI) of the Canadian Problem Gambling Index (Ferris & Wynne, 2001). Control participants were recruited through community advertising which sought people who gamble less than monthly. Control participants were required to score within the non-problem or low-risk gambling category on the PGSI (≤3) and gamble less than monthly. Across both groups, exclusion criteria included age over 65 years, previous significant head injury, neurological disorders, major psychiatric disorders (schizophrenia or psychosis) and self-reported alcohol or illicit drug use (past 12 hours). Control participants were also excluded if they met criteria for any current or lifetime mental health disorders (assessed by the Mini-International Neuropsychiatric Interview (MINI) (Sheehan et al., 1998)). Due to the high prevalence of comorbid disorders in problem gambling (c.f., Lorains, Cowlishaw, & Thomas, 2011), problem gamblers with psychiatric comorbidities were not excluded; however, psychiatric comorbidities were recorded. Using the MINI, the problem gambling participants were found to meet criteria for current depressive disorders (major depressive episode/disorder and

dysthymia, *n* = 25, 64%), current or past anxiety disorders (*n* = 20, 51%), past manic or hypomanic episode (*n* = 8, 21%), and current alcohol or substance use disorder (*n* = 7, 18%).

Problem gamblers were allocated into strategic (*n* = 15) or non-strategic gambling (*n* = 24) subgroups based on their most problematic gambling form. Strategic gambling activities included games where skill or knowledge may have some impact on the outcome (e.g., blackjack, sports betting, horse/dog races), whilst non-strategic gambling activities included games that involve little or no skill (e.g., EGMs, bingo) (Grant et al., 2012b). Because all of the strategic problem gamblers were men and most of the non-strategic problem gamblers were women, this resulted in problem gambling groups that differed on attributes other than gambling form. Therefore, to ensure comparison to relevant healthy controls, we created separate strategic and non-strategic age-, gender- and estimated-IQ-matched control subgroups from the overall control group. In this regard, given the strategic problem gamblers were all male, their matched control group was all male and matched on age and estimated-IQ.

Participants were tested in a quiet room and completed self-reported impulsivity measures and inhibitory control tasks (discussed below), as well as questionnaires measuring gambling severity, gambling urges, and psychiatric comorbidities (see Table 1). Specifically, to assess urge to gamble, participants completed the Gambling Urge Scale (Raylu & Oei, 2004); to assess self-reported depression and anxiety symptoms, they completed the Depression Anxiety and Stress Scale (Lovibond & Lovibond, 1995); and to assess alcohol use and related problems, they completed the Alcohol Use Disorders Identification Test (World Health Organization, 2001). The order of tasks was fixed so that more difficult tasks were distributed between less demanding tasks to ensure the test session (approximately 2 hours) was as tolerable as possible. All participants provided signed informed consent and were reimbursed with a gift voucher to a local department store. The study protocol was

approved by the Monash University Human Research Ethics Committee and the Department of Justice (Victoria, Australia) Research Ethics Committee.

Table 1

Means, standard deviations and group differences for demographic and clinical data

	PGs **n=39**	**Control** **n=41**	**Test Statistic**
Gender (M/F)	19/20	21/20	
Age	46.64 (9.46)	44.34 (11.43)	$t(77) = -0.98$, NS
Years of education	12.88 (2.09)	14.76 (2.28)	$t(78) = 3.82$, $p<0.001$
Estimated IQ (NART)	103.54 (6.99)	106.87 (9.44)	$t(78) = 1.81$, NS
Gambling Severity (PGSI)	18.31 (4.79)	0.27 (0.7)	$t(40) = -23.27$, $p<0.001$
Urge to Gamble (GUS)	7.44 (9.28)	0.12 (0.5)	$t(38) = -4.92$, $p<0.001$
Self-Reported Years of PG	14.92 (9.61)		
DASS - Depression	15.59 (12.42)	3.41 (3.56)	$t(44) = -5.90$, $p<0.001$
DASS - Anxiety	11.85 (11.35)	1.37 (1.86)	$t(40) = -5.70$, $p<0.001$
DASS - Stress	17.90 (11.71)	5.66 (4.19)	$t(47) = -6.16$, $p<0.001$
AUDIT Total	5.32 (6.16)	4.56 (4.2)	$t(65) = -0.63$, NS

Note: Comparison significant at $p<0.005$ corrected for multiple comparisons using Bonferroni correction method. PGs: problem gamblers; M: male, F: female; NART: National Adult Reading Test; PGSI: Problem Gambling Severity Index; GUS: Gambling Urge Scale; DASS: Depression, Anxiety and Stress Scale; AUDIT; Alcohol Use Disorders Identification Test.

4.3.2. Self-reported trait impulsivity measures

We used two self-reported impulsivity questionnaires to measure trait impulsivity; the UPPS-P impulsivity scale (Whiteside & Lynam, 2001) and the Barratt Impulsiveness Scale-11 (11th revision (BIS-11) Patton, Stanford, & Barratt, 1995). The UPPS-P is a 59-item questionnaire which assesses impulsive traits according to five facets of impulsivity: Negative Urgency, Premeditation, Perseverance, Sensation Seeking and Positive Urgency. Negative Urgency refers to an individual's tendency to give in to strong impulses, specifically when associated with negative emotions. Premeditation refers to thinking through

consequences of behaviour before acting. Perseverance refers to an individual's ability to remain focused on a difficult or uninteresting task. Sensation Seeking assesses an individual's preference for excitement and stimulation. Lastly, Positive Urgency refers to an individual's tendency to give in to impulses during high positive affect. The BIS-11 is a 30-item self-report questionnaire which contains three subscales: Attentional Impulsiveness, Motor Impulsiveness and Non-Planning Impulsiveness. Attentional Impulsiveness refers to the ability to focus and cognitive instability. Motor Impulsiveness refers to rash actions and perseverance. Non-Planning Impulsiveness refers to self-control and cognitive complexity. Both scales have demonstrated good internal consistency (BIS-11: $\alpha = 0.79\text{-}0.83$; UPPS-P: $\alpha = 0.82\text{-}0.91$) and convergent and divergent validity (Patton et al., 1995; Whiteside & Lynam, 2001).

4.3.3. Inhibitory control tasks

4.3.3.1. Stop Signal Task (SST)

The SST (Logan, Cowan, & Davis, 1984) is considered to be a measure of response inhibition. The SST consisted of a 32-trial practice run followed by 5 blocks of 64 experimental trials of two types: go trials and stop trials (see Upton et al., 2010). For go trials, participants respond as quickly as possible to the symbol "O" with their left index finger and the symbol "X" with their right index finger. This mapping rule was reversed for half of the participants. Stop trials were intermixed with go trials, and occurred for 25% of trials. For stop trials, an auditory "stop" signal tone (750 Hz, 50Db, 75ms) occurred after the "go" symbol onset, and signalled participants to withhold their response. The visual stimuli were white, 1cm in height and width, and were presented centrally on a black background. Each trial began with a white fixation cross "+" for 500ms, which was replaced by either an "O" or "X" (in equal proportions), displayed for 1500ms or until a response was made. A 1000ms interval separated each trial. Feedback was presented at the end of each experimental block.

The 'staircase' algorithm described by Verbruggen and Logan (2008b) and Verbruggen and Logan (2008a) was used to individually adjust the timing of the presentation of the stop signal based on the participant's last response. Specifically, based on each successful or failed inhibition trial, the stop signal onset/delay (SSD) would increase or decrease by 25ms, respectively. The SST was conducted using E-Prime software (Version 2.0). Participants were instructed to be as fast and accurate as possible, not to hesitate when responding to the stimuli and were informed of the SSD 'staircase' algorithm.

To determine participants' response inhibition, we calculated the Stop Signal Reaction Time (SSRT) using the block-based integration method described by Verbruggen, Chambers, and Logan (2013). Specifically, the mean SSD is subtracted from the *n*th reaction time for each block separately and then averaged across the entire task. The *n*th reaction time is equivalent to the reaction time at the percentile that corresponds to an individual's percentage of failed inhibitions (for example, the reaction time at the 53rd percentile of the distribution for a participant with 53% unsuccessful stop signal trials). Verbruggen et al. (2013) recommend the block-based integration method when participants demonstrate gradual slowing across the task, which was demonstrated in our problem gambling sample. We also recorded the mean go reaction time and go errors (i.e., incorrect responses during go trials). To evaluate after-effects (i.e., slowing following an inhibition trial), we calculated the reaction time for each of the six response trial conditions (e.g., a go trial followed by successful inhibition).

4.3.3.2. Emotional Stroop Task

The emotional Stroop task was developed to measure interference control and attentional bias towards target information (Cox, Fadardi, & Pothos, 2006; Phaf & Kan, 2007). The emotional Stroop task was administered on E-Prime software (Version 2.0) and consisted of three word categories (neutral, gambling and emotional) which each contained

six words. To determine the most appropriate stimuli for this task, we created a list of 15 gambling-related words and generated 15 neutral and 15 negative emotional words that matched the gambling words in word length, word frequency (according to the Hyperspace Analogue to Language study (Lund & Burgess, 1996)), number of syllables and orthogonal neighbours using the English Lexical Project data (Balota et al., 2007). To ensure consistency between the word lists (Cox et al., 2006), the neutral words were from a single category (household items). The word lists were given to seven independent raters with experience in problem gambling research and therapy to classify the words according to category (gambling, neutral or emotional), and to rate on relevance to gambling (5-point likert scale). Based on the results, six gambling words (bet, gamble, jackpot, luck, debt and money) which ranked the highest in relevance and were categorized correctly were chosen, as well as six neutral (pillow, bathtub, bed, door, bowl and books) and emotional words (hurt, resent, worrying, fear, ruin and anguish) that matched the gambling words. There were no differences in lexical characteristics between the word lists, including word length ($F(2,15) = 0.36$, $p>0.05$), frequency of use ($F(2,15) = 0.81$, $p>0.05$), number of syllables ($F(2,15) = 0.76$, $p>.05$) and orthogonal neighbours ($F(2,15) = 0.28$, $p>0.05$).

The task consisted of a 20 trial practice block, a blocked presentation and a pseudorandom presentation. Feedback was provided during the practice block only. During each trial, a word (18-point Bold Courier New font) was displayed centrally in one of four colours (green, blue, red, or yellow) on a black background. The practice block stimuli consisted of the letters "XXXX". Participants used the index finger of their preferred hand to press one of four specified buttons on the keyboard that corresponded to the colour of the word (h:blue, i:red, l:yellow and m:green). Participants were instructed to be as fast and accurate as possible; however, words remained on screen until a response was made. The blocked presentation consisted of 144 trials grouped into 6 blocks of 24 trials. Each block

contained words from a single category (in the order: neutral, emotional, gambling) presented twice. Within each block, the stimuli were presented in a random order with a restriction of no more than two trials of the same colour or word presented consecutively. The pseudorandom presentation was designed to measure after-effects, whereby participants may demonstrate slowing to words presented after the target word (i.e., increased reaction time for a neutral word after the presentation of a gambling word). The pseudorandom presentation contained 16 trials of each of the nine combinations of two categories consecutively (i.e., a gambling word followed by a neutral word) with a total of 114 trials presented in a single block. The pseudorandom order was fixed for all participants; however, the stimuli (word and colour) were randomly determined.

To measure interference control, we calculated the mean reaction time for the word lists (neutral, gambling and emotional) in the blocked presentation, and total errors. To measure after-effects (i.e., slowing to words presented after the target word), we calculated the mean reaction time for a neutral word following the presentation of a gambling word (gambling – neutral) in the pseudorandom presentation.

4.3.3.3. Sustained Attention to Response Task (SART)

To examine response inhibition in a task involving sustained attention, we used the SART (Robertson, Manly, Andrade, Baddeley, & Yiend, 1997). The SART was administered using E-Prime software (Version 2.0) and involved the presentation of nine digits (1-9) visually. Participants were required to respond with a keypress to all digits except when the target digit "3" was presented, where they were required to withhold their response. The stimuli were black and presented centrally on a white background. The digits were presented randomly and in one of five randomly allocated font sizes; 48, 72, 94, 100 and 120 point symbol font. Each digit was presented for 250ms followed by a 900ms mask of the white background. Participants used the index finger of their preferred hand for responding. The

task consisted of a practice block of 15 trials, followed by a single block of 225 trials with 25 occasions of the target stimulus. Participants were instructed to be as fast and as accurate as possible. To measure response inhibition, we calculated commission errors (i.e., keypresses during the target "3" trials). We also recorded mean reaction time and omission errors (i.e., no response on go trials).

4.3.3.4. Random Number Generation (RNG) task

To examine inhibitory control in a task involving working memory, we used the RNG task, which is considered to measure the ability to inhibit habitual and stereotyped responses (Jahanshahi, Saleem, Ho, Dirnberger, & Fuller, 2006). The RNG task involved participants generating five random lists of 20 numbers using the numbers 0-9. Participants' number generation was paced with a flashing black 'X' (18-point Bold Courier New) presented on a white background at a rate of 1 per second. Participants were instructed to synchronize their number generation with the flashing 'X'. The task involved a 20-trial practice run and then five blocks of 20 numbers with a break between each block. The RNG task was administered using E-Prime software (Version 2.0) and participants were provided with instructions based on Baddeley (1966).

To measure departures from randomness, we calculated variables for the three factors proposed to be important in describing non-randomness: repetition, seriation and cycling (Ginsburg & Karpiuk, 1994; Peters, Giesbrecht, Jelicic, & Merckelbach, 2007), as well as a commonly used index of randomness (Evans, 1978). Because some participants did not maintain the required response rate resulting in variable response size sets and because some randomness measures are influenced by variable response sizes, all participant data were trimmed to 90 trials. The following variables were used for data analysis and were predominantly calculated using the RgCalc program (Towse & Neil, 1998):

1. *Sample size deviation* (*n* – 100) indicated divergence from the requested sample size (*n*=100).
2. *Rule breaks* indicated number of responses outside the response set (0-9).
3. *Repetitions* are the sum of the number of times a participant repeats the same number on successive trials.
4. *Count Scores* are a measure of seriation and reflect an individual's tendency to count in steps of 1 or 2 (e.g., 5-4-3; *Count Score 1* or 2-4-6-8; *Count Score 2*). Count Scores are calculated by summing the squared sequence length which gives higher weight to runs of longer sequences (e.g. 8-6-4 includes two count steps thus the count score would equal 4 (2^2)) (Spatt & Goldenberg, 1993).
5. *Gap* indicates the average gap between every occurrence of a digit and is a measure of cycling through the response set (0-9).
6. *RNG Index* (Evans, 1978) is a first order redundancy measure that reflects the difference between expected and observed probabilities of pairs of consecutive digits.

4.3.4. Statistical Analysis

Missing data due to time constraints (RNG *n=3*), colour-blindness (emotional Stroop *n*=1) or refusal to perform the task (SST *n*=3) resulted in a smaller *n* for some tasks. Group demographics and clinical variables were compared using two-tailed Independent-Samples t-tests and corrected for multiple comparisons using the Bonferroni correction method. Error trials on tasks involving reaction time (SST, emotional Stroop & SART) were not included in analysis as evidence suggests that go trials and errors are associated with different patterns of neural activation (Garavan, Ross, Murphy, Roche, & Stein, 2002; Menon, Adleman, White, Glover, & Reiss, 2001; Rubia, Smith, Brammer, & Taylor, 2003). In addition, for the SART and emotional Stroop task, reaction time trials that were 3 standard deviations above or below the mean were excluded from analysis to remove any extreme outliers within participants.

We did not adjust reaction time trials in the SST as trials timed out at 1500ms. Behavioural data meeting assumptions of normality were analysed with a two-tailed analysis of variance (ANOVA). The SSRT data from the SST was analysed using a Mann Whitney U test as the assumption of normality was violated. The SST after-effects were analysed with a 2 (problem gambler vs. control) x 3 (go vs. successful inhibition vs. failed inhibition) x 2 (repetition vs. no-repetition) mixed model ANOVA with a Huynh-Feldt correction, as the assumption of sphericity was violated. The emotional Stroop blocked presentation was analysed using a repeated measures ANOVA to examine the effect of group and word list and their potential interactions on reaction time. In this ANOVA, word list (neutral, emotional and gambling) was the within subjects factor and group (problem gamblers vs. controls) was the between subjects factor. Significance for these tests were set at $p<.05$ unless otherwise stated. Pearson's correlations were performed between main outcome variables for inhibitory control tasks, trait impulsivity measures, gambling severity, and urge to gamble for the problem gambling group, with a Bonferroni correction for multiple comparisons.

4.4. Results

As seen in Table 2, problem gamblers demonstrated higher levels of trait impulsivity on all facets of the UPPS-P (Negative Urgency, Premeditation, Perseverance and Positive Urgency) except Sensation Seeking, compared to controls. In addition, problem gamblers demonstrated higher scores than controls on all three subscales of the BIS-11 (Attentional, Motor and Non-Planning Impulsiveness).

On inhibitory control measures, the overall problem gambling sample demonstrated significantly more errors during the go trials of the SST than controls, which may suggest greater difficulty on this task or inattention (see Table 2). In addition, problem gamblers demonstrated a significantly lower gap score on the RNG task than controls, indicating more

rapid cycling through the response set. Problem gamblers, however, did not differ from controls on any other variables of the SST, SART, emotional Stroop or RNG task. Despite no group differences, a significant main effect for word list was found on the emotional Stroop task ($F(2,154) = 8.24$, $p<.001$, $\eta^2 = 0.10$), with all participants' slower for gambling words ($M = 1093$) than for both neutral ($M = 1052$) and emotional words ($M = 1047$) ($F(1,77) = 8.85$, $p<.01$, $\eta^2 = 0.10$; $F(1,77) = 15.54$, $p<.001$, $\eta^2 = 0.17$). Furthermore, for SST after-effects, we found a main effect for trial type ($F(2, 143) = 63.25$, $p<.001$, $\eta^2 = 0.46$) and repetition ($F(1, 75) = 42.83$, $p<.001$, $\eta^2 = 0.36$), as well as a significant interaction between trial type and repetition ($F(2,112) = 26.60$, $p<.001$, $\eta^2 = 0.26$) (see Table 3). In this regard, reaction time was faster for go-go trials than go-successful inhibition ($F(1,75) = 36.52$, $p<.001$, $\eta^2 = 0.33$) or go-failed inhibition trials ($F(1,75) = 163.51$, $p<.001$, $\eta^2 = 0.68$), demonstrating after-effects in the SST, and repetition trials were faster than no repetition trials ($F(1,71) = 40.47$, $p<.001$, $\eta^2 = 0.36$). However, there was no main effect of group ($F(1,75) = 2.65$, $p = 0.11$), and no interaction between trial type or repetition, and group ($F(2,143) = 0.11$, $p = 0.88$; $F(1,75) = 2.38$, $p = 0.13$), and no repetition x trial type x group interaction ($F(2,111) = 0.81$, $p = 0.41$), indicating that the problem gamblers and controls did not differ across the after-effect trials.

We then conducted correlations to examine the relationship between inhibitory control tasks, trait impulsivity measures, gambling severity, and urge to gamble for the problem gambling group. This analysis revealed that problem gamblers' performance on all of the inhibitory control measures was not associated with any index of self-reported impulsivity, gambling severity or urge to gamble.

Lastly, we conducted a preliminary analysis of whether the two problem gambling subgroups differed from matched controls on self-reported impulsivity or inhibitory control (see Table 4). Strategic (n=15) and non-strategic (n=24) problem gamblers reported

significantly higher levels of impulsivity than their respective control groups on all self-reported impulsive traits except Sensation Seeking. On inhibitory control measures, non-strategic problem gamblers recorded more go errors on the SST and a lower RNG gap score than their respective control group. However, there were no differences between strategic problem gamblers and their respective matched controls on inhibitory control measures.

Table 2
Group performance on self-reported impulsivity and inhibitory control measures

	PGs M (SD)	**Controls M (SD)**	**Test statistic**
UPPS-P Impulsivity Scale			
Negative Urgency**	**2.95 (0.61)**	**2.02 (0.49)**	***t*(78) = -7.68, *p*<0.001, *r*=0.65**
Premeditation**	**2.32 (0.57)**	**1.76 (0.42)**	***t*(78) = -5.09, *p*<0.001, *r*=0.49**
Perseverance**	**2.28 (0.56)**	**1.80 (0.36)**	***t*(64) = -4.21, *p*<0.001, *r*=0.43**
Sensation Seeking	2.16 (0.60)	2.42 (0.79)	*t*(75) = 1.61, NS
Positive Urgency**	**2.53 (0.81)**	**1.50 (0.41)**	***t*(56) = -7.27, *p*<0.001, *r*=0.64**
BIS-11 Impulsivity Scale			
Attentional**	**17.97 (4.21)**	**14.22 (3.31)**	***t*(76) = -4.39, *p*<0.001, *r*=0.45**
Motor**	**24.78 (4.58)**	**20.41 (3.63)**	***t*(76) = -4.70, *p*<0.001, *r*=0.47**
Non-planning**	**27.41 (5.96)**	**20.59 (3.89)**	***t*(61) = -5.91, *p*<0.001, *r*=0.57**
SST			
Go RT	591 (160)	541 (98)	*F*(1, 75) = 2.96, NS
SSRT	226 (75)	197 (53)	*U*(77) = 612, NS
Go Errors*	**7.39 (9.31)**	**3.67 (4.19)**	***F*(1,75) = 5.35, *p* = 0.02, η^2=0.07**
Emotional Stroop Task			
Neutral RT	1093 (257)	1015 (178)	*F*(1,77) = 2.75, NS
Emotional RT	1084 (269)	1014 (174)	
Gambling RT	1146 (313)	1044 (178)	
Total Errors	3.71 (3.62)	3.32 (2.59)	*F*(1, 77) = 0.31, NS
After-effect	996 (245)	962 (198)	*F*(1, 77) = 0.46, NS
SART			
Go RT	343 (66)	331 (49)	*F*(1,78) = 0.72, NS
Omission errors	2.41 (4.95)	1.63 (3.08)	*F*(1,78) = 0.72, NS
Commission Errors	7.92 (5.66)	7.80 (4.79)	*F*(1,78) = 0.01, NS
RNG			
Sample size deviation	-0.31(3.73)	1.18 (5.02)	*F*(1, 74) = 2.09, NS
Rule breaks	0.31 (0.58)	0.30 (0.65)	*F*(1, 74) = 0.002, NS
Repetitions	2.86 (3.00)	2.15 (2.64)	*F*(1, 73) = 1.18, NS
Count Score 1	35.31 (12.53)	34.38 (15.61)	*F*(1, 73) = 0.08, NS
Count Score 2	22.80 (7.03)	21.82 (6.75)	*F*(1, 73) = 0.38, NS
Gap*	**9.05 (0.52)**	**9.28 (0.47)**	***F*(1,73) = 4.12, *p* = 0.04, η^2=0.05**
RNG Index	0.31 (0.04)	0.30 (0.04)	*F*(1, 74) = 0.87, NS

Note: Reaction time (RT) is in msec. PGs: problem gamblers; SST: Stop Signal Task; SART: Sustained Attention to Response Task. RNG: Random Number Generation; SSRT: Stop Signal Reaction Time. SST tracking algorithm was effective with no significant differences between groups (problem gamblers M = 0.55, controls M = 0.53) on stop task accuracy ($F(1,71) = 2.46$, $p = 0.12$). * $p<.05$

Table 3

Group performance on SST after-effect variables

	Repetition		No Repetition	
Trial type	PGs	Controls	PGs	Controls
Go-go	575 (161)	522 (103)	585 (158)	535 (96)
Go-Successful Inhibition	638 (153)	585 (101)	588 (171)	544 (104)
Go-Failed Inhibition	677 (196)	617 (126)	611 (147)	578 (113)

Note: All scores are M (SD). Reaction time is in msec. Go-go: go trial that follows another go trial; Go-Successful Inhibition: go trial that follows successful inhibition; Go-Failed Inhibition: Go trial that follows failed inhibition. Comparison significant at $p<.05$

Table 4

Strategic and non-strategic problem gamblers' self-reported impulsivity and performance on inhibitory control tasks compared to their respective matched control group

	Strategic			**Non-strategic**		
	PGs (*n*=15)	**Controls (*n*=17)**	**Test Statistic**	**PGs (*n*=24)**	**Controls (*n*=24)**	**Test statistic**
UPPS-P Impulsivity Scale						
Negative Urgency	**2.75 (0.71)****	**1.85 (0.38)**	***t*(21) = -4.34, *p*<0.001, *r*=0.63**	**3.11 (0.50)****	**2.15 (0.53)**	***t*(46) = -6.50, *p*<0.001, *r*=0.69**
Premeditation	**2.31 (0.60)***	**1.65 (0.41)**	***t*(30) = -3.67, *p*<0.01, *r*=0.55**	**2.33 (0.55)***	**1.84 (0.41)**	***t*(46) = -3.49, *p*<0.01, *r*=0.45**
Perseverance	**2.21 (0.47)****	**1.65 (0.27)**	***t*(30) = -4.20, *p*<0.001, *r*=0.61**	**2.29 (0.64)***	**1.91 (0.39)**	***t*(46) = -2.47, *p*<0.01, *r*=0.34**
Sensation Seeking	2.33 (0.58)	2.67 (0.80)	*t*(30) = 1.38, NS	2.06 (0.60)	2.24 (0.75)	*t*(46) = -0.88, NS
Positive Urgency	**2.40 (0.93)***	**1.55 (0.43)**	***t*(19) = -3.24, *p*<0.01, *r*=0.53**	**2.65 (0.73)****	**1.47 (0.40)**	***t*(46) = -6.95, *p*<0.001, *r*=0.72**
BIS-11 Impulsivity Scale						
Attentional	**17.86 (4.70)***	**14.18 (4.10)**	***t*(29) = -2.33, *p*<0.05, *r*=0.39**	**18.04 (3.99)****	**14.25 (2.71)**	***t*(45) = -3.83, *p*<0.001, *r*=0.49**
Motor	**23.57 (4.64)***	**19.65 (3.59)**	***t*(29) = -2.66, *p*<0.01, *r*=0.44**	**25.52 (4.48)****	**20.96 (3.63)**	***t*(45) = -3.84, *p*<0.001, *r*=0.49**
Non-Planning	**26.57 (6.05)****	**19.65 (3.69)**	***t*(21) = -3.92, *p*<0.001, *r*=0.59**	**27.91 (5.99)****	**21.25 (3.97)**	***t*(45) = -4.51, *p*<0.001, *r*=0.56**
SST						
Go RT	556 (82)	538 (82)	*F*(1,29) = 0.33, NS	615 (192)	542 (109)	*F*(1,44) = 2.56, NS
SSRT	213 (79)	199 (65)	*U* (31) = 116, NS	234 (73)	196 (45)	*U* (46) = 192, NS
Go Errors	5.14 (6.5)	3.47 (3.26)	*F*(1,29) = 0.87, NS	**8.82* (10.62)**	**3.79 (4.81)**	***F*(1,44) = 4.40, *p* =0.04, η^2=0.09**
Emotional Stroop						
Neutral RT	1160 (254)	1055 (197)	*F*(1,30) = 2.35, NS	1049 (255)	988 (162)	*F*(1,45) = 0.86, NS
Emotional RT	1147 (260)	1041 (180)		1044 (273)	994 (170)	
Gambling RT	1218 (305)	1061 (194)		1099 (316)	1031 (169)	
Total Errors	1.93 (1.33)	2.82 (2.38)	*F*(1,30) = 1.64, NS	4.87 (4.16)	3.67 (2.73)	*F*(1,45) = 1.39, NS
SART						
Go RT	363 (79)	340 (41)	*F*(1,30) = 1.06, NS	329 (56)	325 (55)	*F*(1,46) = 0.08, *NS*
Omission errors	2.20 (4.83)	1.71 (3.06)	*F*(1,30) = 0.12, NS	2.54 (5.11)	1.58 (3.16)	*F*(1,46) = 0.61, NS
Commission errors	6.07 (5.81)	7.24 (4.82)	*F*(1,30) = 0.39, NS	9.08 (5.36)	8.21 (4.83)	*F*(1,46) = 0.35, NS
RNG						
Repetitions	2.31 (2.59)	2.47 (3.00)	*F*(1,28) = 0.02, NS	3.09 (3.19)	1.91 (2.37)	*F*(1,44) = 2.01, NS
Count Score 1	33.69 (19.29)	31.82 (13.80)	*F*(1,28) = 0.10, NS	38.35 (11.67)	36.26 (16.87)	*F*(1,44) = 0.24, NS
Count Score 2	22.77 (8.03)	22.35 (7.23)	*F*(1,28) = 0.02, NS	22.13 (7.21)	21.43 (6.51)	*F*(1,44) = 0.12, NS
Gap	9.15 (0.51)	9.22 (0.51)	*F*(1,28) = 0.15, NS	**9.03* (0.54)**	**9.34 (0.45)**	***F*(1,44) = 4.39, *p* =0.04, η^2=0.09**

Note: All scores are M (SD). Reaction time (RT) is in msec. PGs: problem gamblers; SST: Stop Signal Task; SART: Sustained Attention to Response Task. RNG: Random Number Generation; SSRT: Stop Signal Reaction Time. * *p*<.05, ***p*<.001

4.5. Discussion

In this study, we found that treatment-seeking problem gamblers reported being more impulsive on self-report trait impulsivity questionnaires, and demonstrated more go errors on the SST and a lower gap score on the RNG task than matched controls. However, overall we *did not* find strong evidence that treatment-seeking problem gamblers are more impulsive on inhibitory control measures. Previous inhibitory control findings in problem gambling has been mixed, and our results add to this by having used a wider range of inhibitory control tasks than previous studies, as well as tasks (SART and RNG) that to our knowledge have not been previously used in this population. We also found that treatment-seeking problem gamblers' trait impulsivity was unrelated to inhibitory control, suggesting that these measurement tools assess disparate aspects of impulsivity in problem gamblers. Lastly, strategic and non-strategic problem gamblers did not appear to differ on measures of impulsivity or inhibitory control.

Overall, we found that treatment-seeking problem gamblers displayed more go errors on the SST and a lower gap score on the RNG task than controls. Go errors on the SST can be associated with task difficulty or inattention, whilst RNG gap scores may relate more to working memory than inhibitory control (Miyake et al., 2000). Thus, treatment-seeking problem gamblers may demonstrate poor inhibitory control as task demands and cognitive load increases. However, on all other inhibitory control variables, treatment-seeking problem gamblers *did not* differ from controls. While this is consistent with some past research (Brand et al., 2005; de Ruiter et al., 2011; Lawrence et al., 2009a; Ledgerwood et al., 2012; Ledgerwood et al., 2009), conflicting findings exist (Billieux et al., 2012; Goudriaan et al., 2006; Kertzman et al., 2008). It is possible that impaired inhibitory control may not be present in all problem gamblers. Indeed, Billieux et al. (2012) found that problem gamblers vary greatly in impulsivity levels with some showing no impairments, while others show

global impulsivity deficits across self-report and laboratory tasks. Billieux et al. (2012) suggest that in some problem gamblers impulsivity may be a core deficit; however other pathways to problem gambling are also possible. Similarly, some heterogeneity models of problem gambling include a subtype with low levels of impulsivity, i.e., Behaviourally Conditioned Problem Gamblers in Blaszczynski and Nower's (2002) pathways model and Cluster One of Lesieur's (2001) subtypes. The large variability across our problem gambling sample on inhibitory control measures may reflect this neurocognitive heterogeneity. Generally, our results support Billieux et al. (2012) findings that poor inhibitory control, one form of impulsivity, may not be a central component in *all* problem gamblers.

Another potential explanation for the conflicting findings with past literature and the variability in our sample is our larger percentage of female problem gamblers compared to previous studies (Billieux et al., 2012; Goudriaan et al., 2006; Kertzman et al., 2006). Blaszczynski and Nower's (2002) pathways model describes an Emotionally Vulnerable problem gambling subtype which is more common in women (Ledgerwood & Petry, 2006; Ledgerwood & Petry, 2010), and is characterised by elevated psychological distress and gambling for emotional escape, but not necessarily high impulsivity. Furthermore, men are generally found to be more impulsive than women (Cross, Copping, & Campbell, 2011), and male problem gamblers have displayed higher levels of self-reported impulsivity than female problem gamblers (Echeburua, Gonzalez-Ortega, de Corral, & Polo-Lopez, 2011). However, our non-strategic problem gamblers, which were predominantly women, did not appear to differ from the male strategic problem gamblers on either self-reported impulsivity or inhibitory control measures, and male and female problem gamblers have previously demonstrated similar patterns of response inhibition (Grant, Chamberlain, Schreiber, & Odlaug, 2012a), indicating that gender differences may not have influenced our results. In addition, we considered whether gambling severity was associated with the variability within

our problem gambling sample, as Brevers et al. (2012b) reported that gambling severity is associated with response inhibition. However, we did not find that problem gambling severity was associated with performance on any of the inhibitory control tasks.

In theoretical models of addiction, elevated levels of impulsivity are a key component to the development of addictive behaviours. Dual-process theories of addiction (Bechara, 2005; Wiers et al., 2007) propose two dysfunctional systems in addictive behaviours; an impulsive system associated with strengthened motivation and reactions toward addictive cues and a reflective system involving impaired control over impulses (measured as impulsivity) and poor decision making. Given that our problem gambling sample did not appear to demonstrate poor inhibitory control (a reflective system component), other aspects of these theoretical models may be more pertinent to their development of addictive behaviour. Furthermore, although our sample of treatment-seeking problem gamblers did not demonstrate poor inhibitory control, their impulsivity may instead manifest in other ways such as impulsive choices measured by delay discounting tasks. There is evidence from previous studies that problem gamblers demonstrate poor performance on delay discounting tasks (Ledgerwood et al., 2009; Michalczuk, Bowden-Jones, Verdejo-Garcia, & Clark, 2011; Petry, 2001), and that different forms of impulsivity may be associated with different underlying fronto-striatal pathways (Dalley, Everitt, & Robbins, 2011).

Our treatment-seeking problem gamblers demonstrated higher levels of the impulsive traits Negative and Positive Urgency, Perseverance and Premeditation than controls. However, consistent with past research (Billieux et al., 2012; Hammelstein, 2004; Ledgerwood et al., 2009), Sensation-Seeking was not elevated in treatment-seeking problem gamblers. Sensation-Seeking may be independent from other impulsivity traits (Hammelstein, 2004; Ledgerwood et al., 2009), and our results provide further support that gambling problems are not associated with a need to experience excitement. In contrast,

Negative and Positive Urgency were particularly high in our problem gamblers. In this regard, negative mood states are often reported as triggers for gambling (Morasco, Weinstock, Ledgerwood, & Petry, 2007), and problem gamblers report using gambling as an emotional escape or to modify arousal levels (Ricketts & Macaskill, 2003); therefore, the relationship between impulsivity and mood states appears particularly important.

Interestingly, our preliminary analysis of subgroups of problem gamblers demonstrated that non-strategic problem gamblers differed from matched controls on SST errors and RNG gap score, which may suggest that they experience greater difficulty on these tasks. However, overall, problem gamblers preferring strategic and non-strategic gambling activities reported similar levels of self-reported impulsivity, and inhibitory control performances generally did not differ from matched controls. Thus, our findings suggest similarities in problem gambling subgroups on inhibitory control measures. Similarly, Grant et al. (2012b) found that strategic and non-strategic problem gamblers perform similarly on the SST. However, this is not consistent with Goudriaan et al. (2005) findings that EGM problem gamblers perform worse than casino problem gamblers on a Go/No-Go task, although this study used a reward/loss version of a Go/No-Go task which also measured motivation and emotional processing.

Several important limitations should be considered when interpreting the results of this study. Firstly, although our sample size was comparable with previous studies (Goudriaan et al., 2006; Grant et al., 2012b; Roca et al., 2008), we may not have had enough power to detect small group differences in inhibitory control. In this regard, a retrospective power analysis for the SST revealed that the study had only a 39% probability of detecting group differences, and we particularly emphasize the small sample sizes in our preliminary subgroup comparisons. Given the variability we found between problem gamblers, future studies should adopt a larger sample size or a more homogenous sample of problem

gamblers. In addition, to increase the generalisability of the findings, our sample necessarily included problem gamblers with psychiatric comorbidities, which may also have influenced the results. However, since the most common comorbidity in our sample (depression) has been reported to be associated with poor inhibitory control (Kaiser et al., 2003), we do not believe that the presence of comorbid psychiatric disorders in our sample inappropriately influenced our results. We also acknowledge that we used a fixed order for administration of tasks and used a computerized emotional Stroop task with manual responding whereas vocal responses may result in larger interference effects (Cox et al., 2006). Finally, laboratory tasks have previously been criticised for poorly representing the real world (Burgess et al., 2006), and therefore, problem gamblers may indeed demonstrate dysinhibition in natural environments which involve gambling cues (e.g., casino/club) that may trigger emotional responses. In this regard, a further limitation of our study was that we did not examine whether emotional responses influence inhibitory control performances. However, response inhibition has been associated with self control when attempting to quit smoking (Berkman, Falk, & Lieberman, 2011), and SST performance has been associated with observable impulsivity in children with attention deficit hyperactivity disorder (Solanto et al., 2001), suggesting laboratory measures can correlate to real-world instances of self-control.

In summary, contrary to some past literature, we *did not* find strong evidence that treatment-seeking problem gamblers demonstrate impaired inhibitory control, despite heightened levels of trait impulsivity as measured by self-report questionnaires. Furthermore, treatment-seeking problem gamblers who prefer strategic and non-strategic gambling forms demonstrated comparable levels of trait impulsivity and performed similarly on inhibitory control measures, indicating that heterogeneity among problem gamblers may not extend to these constructs. These findings suggest that whilst impulsive traits may be a key feature of problem gambling, poor inhibitory control may not be central for *all* problem gamblers and

other factors may be more pertinent in the development of addictive behaviour in some problem gamblers.

4.7. References

Aichert, D. S., Wöstmann, N. M., Costa, A., Macare, C., Wenig, J. R., Möller, H.-J., Rubia, K., & Ettinger, U. (2012). Associations between trait impulsivity and prepotent response inhibition. *Journal of Clinical and Experimental Neuropsychology, 34*, 1016-1032.

Alessi, S. M., & Petry, N. M. (2003). Pathological gambling severity is associated with impulsivity in a delay discounting procedure. *Behavioural Processes, 64*, 345-354.

American Psychiatric Association (APA). (2000). *Diagnostic and statistical manual of mental disorders (DSM-IV-TR)*. Washington, DC: APA.

Baddeley, A. D. (1966). The capacity for generating information by randomization. *Quarterly Journal of Experimental Psychology, 18*, 119-129.

Balota, D. A., Yap, M. J., Cortese, M. J., Hutchison, K. A., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The english lexicon project. *Behavior Research Methods, 39*, 445-459.

Bechara, A. (2005). Decision making, impulse control and loss of willpower to resist drugs: A neurocognitive perspective. *Nature Neuroscience, 8*, 1458-1463.

Berkman, E. T., Falk, E. B., & Lieberman, M. D. (2011). In the trenches of real-world self-control: Neural correlates of breaking the link between craving and smoking. *Psychological Science, 22*, 498-506.

Billieux, J., Lagrange, G., Van der Linden, M., Lançon, C., Adida, M., & Jeanningros, R. (2012). Investigation of impulsivity in a sample of treatment-seeking pathological gamblers: A multidimensional perspective. *Psychiatry Research, 198*, 291-296.

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

Brand, M., Kalbe, E., Labudda, K., Fujiwara, E., Kessler, J., & Markowitsch, H. J. (2005). Decision-making impairments in patients with pathological gambling. *Psychiatry Research, 133*, 91-99.

Brevers, D., Cleeremans, A., Goudriaan, A. E., Bechara, A., Kornreich, C., Verbanck, P., & Noël, X. (2012a). Decision making under ambiguity but not under risk is related to problem gambling severity. *Psychiatry Research, 200*, 568-574.

Brevers, D., Cleeremans, A., Verbruggen, F., Bechara, A., Kornreich, C., Verbanck, P., & Noël, X. (2012b). Impulsive action but not impulsive choice determines problem gambling severity. *PLOS One, 7*, e50647.

Burgess, P. W., Alderman, N., Forbes, C., Costello, A., M-A.Coates, L., Dawson, D. R., Anderson, N. D., Gilbert, S. J., Dumontheil, I., & Channon, S. (2006). The case for the development and use of "ecologically valid" measures of executive function in experimental and clinical neuropsychology. *Journal of the International Neuropsychological Society, 12*, 194-209.

Chambers, C. D., Garavan, H., & Bellgrove, M. A. (2009). Insights into the neural basis of response inhibition from cognitive and clinical neuroscience. *Neuroscience & Biobehavioral Reviews, 33*, 631-646.

Cox, W. M., Fadardi, J. S., & Pothos, E. M. (2006). The addiction-stroop test: Theoretical considerations and procedural recommendations. *Psychological Bulletin, 132*, 443-476.

Cross, C. P., Copping, L. T., & Campbell, A. (2011). Sex differences in impulsivity: A meta-analysis. *Psychological Bulletin, 137*, 97-130.

Cyders, M. A., & Coskunpinar, A. (2011). Measurement of constructs using self-report and behavioral lab tasks: Is there overlap in nomothetic span and construct representation for impulsivity? *Clinical Psychology Review, 31*, 965-982.

Cyders, M. A., & Coskunpinar, A. (2012). The relationship between self-report and lab task conceptualizations of impulsivity. *Journal of Research in Personality, 46*, 121-124.

Dalley, Jeffrey W., Everitt, Barry J., & Robbins, Trevor W. (2011). Impulsivity, compulsivity, and top-down cognitive control. *Neuron, 69*, 680-694.

Dalley, J. W., Mar, A. C., Economidou, D., & Robbins, T. W. (2008). Neurobehavioral mechanisms of impulsivity: Fronto-striatal systems and functional neurochemistry. *Pharmacology Biochemistry and Behavior, 90*, 250-260.

de Ruiter, M. B., Oosterlaan, J., Veltman, D. J., van den Brink, W., & Goudriaan, A. E. (2011). Similar hyporesponsiveness of the dorsomedial prefrontal cortex in problem gamblers and heavy smokers during an inhibitory control task. *Drug and Alcohol Dependence, 121*, 81-89.

Diergaarde, L., Pattij, T., Poortvliet, I., Hogenboom, F., de Vries, W., Schoffelmeer, A. N. M., & De Vries, T. J. (2008). Impulsive choice and impulsive action predict vulnerability to distinct stages of nicotine seeking in rats. *Biological Psychiatry, 63*, 301-308.

Dowling, N. (In Press). The cognitive-behavioural treatment of female problem gambling. In D. Richard, A. Blaszczynski & L. Nower (Eds.), *Wiley-Blackwell Handbook of Disordered Gambling*: Wiley-Blackwell.

Echeburua, E., Gonzalez-Ortega, I., de Corral, P., & Polo-Lopez, R. (2011). Clinical gender differences among adult pathological gamblers seeking treatment. *Journal of Gambling Studies, 27*, 215-227.

Enticott, P. G., Bradshaw, J. L., Bellgrove, M. A., Upton, D. J., & Ogloff, J. R. P. (2009). Stop task after-effects: The extent of slowing during the preparation and execution of movement. *Experimental Psychology, 56*, 247-251.

Enticott, P. G., Ogloff, J. R. P., & Bradshaw, J. L. (2006). Associations between laboratory measures of executive inhibitory control and self-reported impulsivity. *Personality and Individual Differences, 41*, 285-294.

Evans, F. J. (1978). Monitoring attention deployment by random number generation: An index to measure subjective randomness. *Bulletin of the Psychonomic Society, 12*, 35-38.

Fassbender, C., Murphy, K., Foxe, J. J., Wylie, G. R., Javitt, D. C., Robertson, I. H., & Garavan, H. (2004). A topography of executive functions and their interactions revealed by functional magnetic resonance imaging. *Cognitive Brain Research, 20*, 132-143.

Fassbender, C., Simoes-Franklin, C., Murphy, K., Hester, R., Meaney, J., Robertson, I. H., & Garavan, H. (2006). The role of a right fronto-parietal network in cognitive control: Common activations for "cues-to-attend" and response inhibition. *Journal of Psychophysiology, 20*, 286-296.

Ferris, J., & Wynne, H. (2001). The Canadian Problem Gambling Index: Final Report: Canadian Centre on Substance Abuse (CCSA).

Forbush, k. T., Shaw, M., Graeber, M. A., Hovick, L., Meyer, V. L., Moser, D. J., Bayless, J., Watson, D., & Black, D. W. (2008). Neuropsychological characteristics and personality traits in pathological gambling. *CNS Spectrum, 13*, 306-315.

Friedman, N. P., & Miyake, A. (2004). The relations among inhibition and interference control functions: A latent-variable analysis. *Journal of Experimental Psychology: General, 133*, 101-135.

Garavan, H., Ross, T. J., Murphy, K., Roche, R. A. P., & Stein, E. A. (2002). Dissociable executive functions in the dynamic control of behavior: Inhibition, error detection, and correction. *NeuroImage, 17*, 1820-1829.

Ginsburg, N., & Karpiuk, P. (1994). Random generation: Analysis of the responses. *Perceptual and Motor Skills, 79*, 1059-1067.

Goudriaan, A. E., Oosterlaan, J., de Beurs, E., & van den Brink, W. (2005). Decision making in pathological gambling: A comparison between pathological gamblers, alcohol dependents, persons with tourette syndrome, and normal controls. *Cognitive Brain Research, 23*, 137-151.

Goudriaan, A. E., Oosterlaan, J., de Beurs, E., & van den Brink, W. (2006). Neurocognitive functions in pathological gambling: A comparison with alcohol dependence, tourette syndrome and normal controls. *Addiction, 101*, 534-547.

Grant, J. E., Chamberlain, S. R., Schreiber, L. R. N., & Odlaug, B. L. (2012a). Gender-related clinical and neurocognitive differences in individuals seeking treatment for pathological gambling. *Journal of Psychiatric Research, 46*, 1206-1211.

Grant, J. E., Odlaug, B. L., Chamberlain, S. R., & Schreiber, L. R. N. (2012b). Neurocognitive dysfunction in strategic and non-strategic gamblers. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 38*, 336-340.

Hammelstein, P. (2004). Faites vos jeux! Another look at sensation seeking and pathological gambling. *Personality and Individual Differences, 37*, 917-931.

Hester, R., & Garavan, H. (2005). Working memory and executive function: The influence of content and load on the control of attention. *Memory and Cognition, 33*, 221-233.

Jahanshahi, M., Saleem, T., Ho, A. K., Dirnberger, G., & Fuller, R. (2006). Random number generation as an index of controlled processing. *Neuropsychology, 20*, 391-399.

Kaiser, S., Unger, J., Kiefer, M., Markela, J., Mundt, C., & Weisbrod, M. (2003). Executive control deficit in depression: Event-related potentials in a go/nogo task. *Psychiatry Research: Neuroimaging, 122*, 169-184.

Kertzman, S., Lowengrub, K., Aizer, A., Nahum, Z. B., Kotler, M., & Dannon, P. N. (2006). Stroop performance in pathological gamblers. *Psychiatry Research, 142*, 1-10.

Kertzman, S., Lowengrub, K., Aizer, A., Vainder, M., Kotler, M., & Dannon, P. N. (2008). Go-no-go performance in pathological gamblers. *Psychiatry Research, 161*, 1-10.

Lawrence, A. J., Luty, J., Bogdan, N. A., Sahakian, B. J., & Clark, L. (2009a). Impulsivity and response inhibition in alcohol dependence and problem gambling. *Psychopharmacology, 207*, 163-172.

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

Leblond, J., Ladouceur, R., & Blaszczynski, A. (2003). Which pathological gamblers will complete treatment? *British Journal of Clinical Psychology, 42*, 205-209.

Ledgerwood, D., Orr, E., Kaploun, K., Milosevic, A., Frisch, G., Rupcich, N., & Lundahl, L. (2012). Executive function in pathological gamblers and healthy controls. *Journal of Gambling Studies, 28,* 89-103.

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

Ledgerwood, D. M., & Petry, N. M. (2006). Psychological experience of gambling and subtypes of pathological gamblers. *Psychiatric Research, 144*, 17-27.

Ledgerwood, D. M., & Petry, N. M. (2010). Subtyping pathological gamblers based on impulsivity, depression, and anxiety. *Psychology of Addictive Behaviors, 24*, 680-688.

Lesieur, H. R. (2001). *Cluster analysis of types of inpatient pathological gamblers (Unpublished doctoral dissertation thesis).* ProQuest Information & Learning, US.

Logan, G. D., Cowan, W. B., & Davis, K. A. (1984). On the ability to inhibit simple and choice reaction time responses: A model and a method. *Journal of Experimental Psychology: Human Perception & Performance, 10*, 276-291.

Lorains, F. K., Cowlishaw, S., & Thomas, S. A. (2011). Prevalence of comorbid disorders in problem and pathological gambling: Systematic review and meta-analysis of population surveys. *Addiction, 106*, 490-498.

Lovibond, S. H., & Lovibond, P. E. (1995). Manual for the depression anxiety stress scales (2nd ed.). Sydney, Australia: Psychology Foundation of Australia.

Lund, K., & Burgess, C. (1996). Producing high-dimensional semantic spaces from lexical co-occurrence. *Behavior Research Methods, 28*, 203-208.

MacLaren, V. V., Fugelsang, J. A., Harrigan, K. A., & Dixon, M. J. (2011). The personality of pathological gamblers: A meta-analysis. *Clinical Psychology Review, 31*, 1057-1067.

McNab, F., Leroux, G., Strand, F., Thorell, L., Bergman, S., & Klingberg, T. (2008). Common and unique components of inhibition and working memory: An fMRI, within-subjects investigation. *Neuropsychologia, 46,* 2668-2682.

Menon, V., Adleman, N. E., White, C. D., Glover, G. H., & Reiss, A. L. (2001). Error-related brain activation during a go/nogo response inhibition task. *Human Brain Mapping, 12*, 131-143.

Michalczuk, R., Bowden-Jones, H., Verdejo-Garcia, A., & Clark, L. (2011). Impulsivity and cognitive distortions in pathological gamblers attending the UK national problem gambling clinic: A preliminary report. *Psychological Medicine, 41*, 2625-2635.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*, 49-100.

Morasco, B. J., Weinstock, J., Ledgerwood, D. M., & Petry, N. M. (2007). Psychological factors that promote and inhibit pathological gambling. *Cognitive and Behavioral Practice, 14*, 208-217.

Nelson, H. E., & Willison, J. (1991). *National Adult Reading Test (NART): Test manual* (2nd ed.). Windsor, UK: NFER Nelson.

Nigg, J. T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*, 220-246.

Odlaug, B., Marsh, P., Kim, S., & Grant, J. (2011). Strategic vs nonstrategic gambling: Characteristics of pathological gamblers based on gambling preference. *Annals of Clinical Psychiatry, 23*, 105-112.

Pagani, L. S., Derevensky, J. L., & Japel, C. (2009). Predicting gambling behavior in sixth grade from kindergarten impulsivity: A tale of developmental continuity. *Archives of Pediatrics & Adolescent Medicine, 163*, 238-243.

Patton, J. H., Stanford, M. S., & Barratt, E. S. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology, 51*, 768-774.

Peters, M., Giesbrecht, T., Jelicic, M., & Merckelbach, H. (2007). The random number generation task: Psychometric properties and normative data of an executive function task in a mixed sample. *Journal of the International Neuropsychological Society, 13*, 626-634.

Petry, N. M. (2001). Pathological gamblers, with and without substance use disorders, discount delayed rewards at high rates. *Journal of Abnormal Psychology, 110*, 482-487.

Phaf, R. H., & Kan, K.-J. (2007). The automaticity of emotional stroop: A meta-analysis. *Journal of Behavior Therapy and Experimental Psychiatry, 38*, 184-199.

Potenza, M., N, Leung, H.-C., Blumberg, H., P, Peterson, B., S, Fulbright, R. K., Lacadie, C. M., Skudlarski, P., & Gore, J. C. (2003). An fMRI stroop task study of ventromedial prefrontal cortical function in pathological gamblers. *American Journal of Psychiatry, 160*, 1990.

Potenza, M. N., Steinberg, M. A., McLaughlin, S. D., Wu, R. M. S., Rounsaville, B. J., & O'Malley, S. S. (2001). Gender-related differences in the characteristics of problem gamblers using a gambling helpline. *American Journal of Psychiatry, 158*, 1500-1505.

Raylu, N., & Oei, T. P. S. (2004). The gambling urge scale: Development, confirmatory factor validation, and psychometric properties. *Psychology of Addictive Behaviors, 18*, 100-105.

Regard, M., Knoch, D., Gutling, E., & Landis, T. (2003). Brain damage and addictive behavior: A neuropsychological and electroencephalogram investigation with pathologic gamblers. *Cognitive and Behavioral Neurology, 16*, 47-53.

Ricketts, T., & Macaskill, A. (2003). Gambling as emotion management: Developing a grounded theory of problem gambling. *Addiction Research and Theory, 11*, 383-400.

Robertson, I. H., Manly, T., Andrade, J., Baddeley, B. T., & Yiend, J. (1997). Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia, 35*, 747-758.

Robinson, E. S. J., Eagle, D. M., Economidou, D., Theobald, D. E. H., Mar, A. C., Murphy, E. R., Robbins, T. W., & Dalley, J. W. (2009). Behavioural characterisation of high impulsivity on the 5-choice serial reaction time task: Specific deficits in 'waiting' versus 'stopping'. *Behavioural Brain Research, 196*, 310-316.

Roca, M., Torralva, T., Lopez, P., Cetkovich, M., Clark, L., & Manes, F. (2008). Executive functions in pathologic gamblers selected in an ecologic setting. *Cognitive and Behavioral Neurology, 21*, 1-4.

Rodriguez-Jimenez, R., Avila, C., Jimenez-Arriero, M. A., Ponce, G., Monasor, R., Jimenez, M., Aragues, M., Hoenicka, J., Rubio, G., & Palomo, T. (2006). Impulsivity and sustained attention in pathological gamblers: Influence of childhood ADHD history. *Journal of Gambling Studies, 22*, 451-461.

Rubia, K., Smith, A. B., Brammer, M. J., & Taylor, E. (2003). Right inferior prefrontal cortex mediates response inhibition while mesial prefrontal cortex is responsible for error detection. *NeuroImage, 20*, 351-358.

Sheehan, D. V., Lecrubier, Y., Sheehan, K. H., Amorim, P., Janavs, J., Weiller, E., Hergueta, T., Baker, R., & Dunbar, G. C. (1998). The Mini-International Neuropsychiatric Interview (M.I.N.I.): The development and validation of a structured diagnostic psychiatric interview for DSM-IV and ICD-10. *The Journal of Clinical Psychiatry, 59*, 22-33.

Solanto, M. V., Abikoff, H., Sonuga-Barke, E., Schachar, R., Logan, G. D., Wigal, T., Hechtman, L., Hinshaw, S., & Turkel, E. (2001). The ecological validity of delay aversion and response inhibition as measures of impulsivity in AD/HD: A supplement to the ninth multimodal treatment study of AD/HD. *Journal of Abnormal Child Psychology, 29*, 215-228.

Spatt, J., & Goldenberg, G. (1993). Components of random generation by normal subjects and patients with dysexecutive syndrome. *Brain and Cognition, 23*, 231-242.

Towse, J., & Neil, D. (1998). Analyzing human random generation behavior: A review of methods used and a computer program for describing performance. *Behavior Research Methods, 30*, 583-591.

Upton, D., Enticott, P., Croft, R., Cooper, N., & Fitzgerald, P. (2010). ERP correlates of response inhibition after-effects in the stop signal task. *Experimental Brain Research, 206*, 351-358.

Verbruggen, F., Chambers, C. D., & Logan, G. D. (2013). Fictitious inhibitory differences: How skewness and slowing distort the estimation of stopping latencies. *Psychological Science, 24*, 352-362.

Verbruggen, F., & Logan, G. D. (2008a). After-effects of goal shifting and response inhibition: A comparison of the stop-change and dual-task paradigms. *Quarterly Journal of Experimental Psychology, 61*, 1151-1159.

Verbruggen, F., & Logan, G. D. (2008b). Automatic and controlled response inhibition: Associative learning in the go/no-go and stop-signal paradigms. *Journal of Experimental Psychology: General, 137*, 649-672.

Verbruggen, F., Logan, G. D., Liefooghe, B., & Vandierendonck, A. (2008). Short-term aftereffects of response inhibition: Repetition priming or between-trial control adjustments? *Journal of Experimental Psychology: Human Perception & Performance, 34*, 413-426.

Verdejo-García, A., Lawrence, A. J., & Clark, L. (2008). Impulsivity as a vulnerability marker for substance-use disorders: Review of findings from high-risk research, problem gamblers and genetic association studies. *Neuroscience & Biobehavioral Reviews, 32*, 777-810.

Whiteside, S. P., & Lynam, D. R. (2001). The five factor model and impulsivity: Using a structural model of personality to understand impulsivity. *Personality and Individual Differences, 30*, 669-689.

Wiers, R. W., Bartholow, B. D., van den Wildenberg, E., Thush, C., Engels, R. C. M. E., Sher, K. J., Grenard, J., Ames, S. L., & Stacy, A. W. (2007). Automatic and controlled processes and the development of addictive behaviors in adolescents: A review and a model. *Pharmacology Biochemistry and Behavior, 86*, 263-283.

World Health Organization. (2001). The Alcohol Use Disorders Identification Test (AUDIT) (2nd ed.): World Health Organization.

CHAPTER 5: STRATEGIC AND NON-STRATEGIC PROBLEM GAMBLERS DIFFER ON DECISION MAKING UNDER RISK AND AMBIGUITY

Explanatory Note

According to neurocognitive models of substance-based addiction, dysfunction within the prefrontal cortex results in inhibitory control impairments and poor decision making with a preference for immediate gains over long term rewards. In the preceding Chapter we reported our study investigating impulsivity and inhibitory control in problem gamblers. In Chapter 5 we report our study investigating decision making in problem gambling. In this Chapter we used two decision making tasks, the Iowa Gambling Task (IGT) and a Loss Aversion Task, to investigate problem gamblers' decision making under conditions of risk with explicit gains and losses are available (*Loss Aversion Task*), and conditions of ambiguity in which participants must learn risk/reward outcomes over time (*IGT*). Moreover, we report the first study to use a novel cognitive modelling procedure to probe underlying cognitive processes, including learning, reward processing and motivation, associated with problem gamblers' decision making during the IGT. Consistent with Chapter 4, we examined decision making in both the overall sample of problem gamblers, and also in subtypes of problem gamblers distinguished based on preferred gambling form. This Chapter consists of a manuscript that was submitted and to the journal '*Addiction'* in June 2013.

Declaration for Thesis Chapter Five

Monash University

Declaration by candidate

In the case of Chapter [insert chapter number], the nature and extent of my contribution to the work was the following:

Nature of contribution	**Extent of contribution (%)**
Conceptualisation and design of study, data collection and analysis and manuscript preparation	80%

The following co-authors contributed to the work. If co-authors are students at Monash University, the extent of their contribution in percentage terms must be stated:

Name	**Nature of contribution**	**Extent of contribution (%) for student co-authors only**
Julie Stout	Conceptualisation of study, supervision and revision of drafts	
Peter Enticott	Conceptualisation of study, supervision and revision of drafts	
John Bradshaw	Conceptualisation of study, supervision and revision of drafts	
Nicki Dowling	Conceptualisation of study, supervision and revision of drafts	
Jennifer Trueblood	Assistance with cognitive modelling procedures, revision of drafts	

The undersigned hereby certify that the above declaration correctly reflects the nature and extent of the candidate's and co-authors' contributions to this work*.

Candidate's Signature		**Date**

Declaration by co-authors

The undersigned hereby certify that:

(1) the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.

(2) they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;

(3) they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;

(4) there are no other authors of the publication according to these criteria;

(5) potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and

(6) the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

Location(s)	Monash University, School of Psychology and Psychiatry, Clayton

Julie Stout	[redacted]	**10/10/2013**
Peter Enticott	[redacted]	**10/10/2013**
John Bradshaw	[redacted]	**10/10/2013**
Nicki Dowling	[redacted]	**10/10/2013**
Jennifer Trueblood	[redacted]	**10/10/2013**

Running head: DECISION MAKING IN PROBLEM GAMBLING

Strategic and non-strategic problem gamblers differ on decision making under risk and ambiguity

Felicity K Lorains[a], Nicki A Dowling[b], Peter G Enticott[c], John L Bradshaw[a], Jennifer S Trueblood[d] & Julie C Stout[a]

[a] School of Psychology and Psychiatry, Monash University, Clayton, Victoria, 3800, Australia.

[b] Problem Gambling Research and Treatment Centre, The University of Melbourne, Victoria, 3010, Australia

[c] Monash Alfred Psychiatry Research Centre, The Alfred and Central Clinical School, Monash University, Melbourne, Victoria, 3004, Australia

[d]Department of Cognitive Sciences, University of California, Irvine, 92697, United States of America.

* Corresponding author at: Building 17, School of Psychology and Psychiatry, Monash University, Clayton, Victoria, 3800, Australia. Tel.: +61 3 9905 3987; fax: +61 3 9905 3948. E-mail address: Julie.Stout@monash.edu.au (J. Stout).

5.1. Abstract

Aims We analysed problem gamblers' decision making under risk and ambiguity, and investigated underlying psychological factors associated with their choice behaviour. We also examined whether decision making differed in strategic (e.g., sports betting) and non-strategic (e.g., electronic gaming machine) problem gamblers. **Design** Cross-sectional study. **Setting** Out-patient treatment centres and university testing facilities. **Participants** 39 problem gamblers and 41 age-, gender- and estimated-IQ-matched controls. **Measurements** Decision making tasks included the Iowa Gambling Task (IGT) and a Loss Aversion Task. The Prospect Valence Learning (PVL) model was used to provide an explanation of cognitive, motivational and response style factors involved in IGT performance. **Findings** Overall, problem gamblers performed more poorly than controls on both the IGT ($p = 0.03$) and the Loss Aversion Task ($p = 0.02$), and their IGT decisions were associated with heightened attention to gains ($p = 0.006$) and less consistency ($p = 0.0001$). Strategic problem gamblers did not differ from matched controls on either decision making task, whereas, non-strategic problem gamblers performed worse on both the IGT ($p = 0.03$) and the Loss Aversion task ($p = 0.01$). Furthermore, we found differences in the PVL model parameters underlying strategic and non-strategic problem gamblers choices on the IGT. **Conclusions** Problem gamblers demonstrated poor decision making under risk and ambiguity, moreover, strategic and non-strategic problem gamblers differed in decision making and the underlying psychological processes associated with their decisions. These findings underscore the necessity of disentangling heterogeneity amongst problem gamblers.

5.2. Introduction

Problem gambling is increasingly being viewed as a behavioural addiction and has now been reclassified as an addictive disorder in the Diagnostic and Statistical Manual of Mental Disorders (version 5) (1). Decision making is a critical cognitive process involved in addictive disorders (2), and both substance abusers and problem gamblers demonstrate decision making impairments. Like substance abuse, problem gambling may be, in part, a decision making disorder (3), and laboratory-based decision making studies are providing useful insights into problem gambling.

Decision making studies have shown that problem gamblers perform more poorly than controls under risk and ambiguity. For example, on the Iowa Gambling Task (IGT), a commonly used decision making task, problem gamblers make significantly more disadvantageous choices and are slower to learn from feedback than controls (4-6). On other decision making tasks, problem gamblers are more impulsive (7, 8), overconfident (9) and take less time to deliberate (4), and even when explicit risk information is available, they chose risky and disadvantageous options (10-12). Evidence also indicates that decision making under ambiguity, but not under risk, is associated with increased problem gambling severity (11).

Advances in decision making research have allowed for more precise and mechanistic investigations into cognitive processes driving decision making. For example, our group has developed cognitive models (the Expectance Valence Learning Model (13) and the Prospect Valence Learning (PVL) Model (14)) that allow IGT performance to be decomposed into constituent psychological processes. These models have demonstrated different combinations of cognitive, motivational and response style factors in the decision making of cocaine and

polysubstance abusers, Huntington's disease, and individuals with orbitofrontal brain lesions (15). Cognitive modelling has not previously been applied to problem gamblers.

Another key factor involved in decision making that may be relevant to problem gambling is loss aversion. Loss aversion refers to a phenomenon in which people demonstrate greater sensitivity to losses than gains during decision making (16), and may result from an asymmetry in affective responses in which negative and positive stimuli are not equally weighted (17). Loss aversion is associated with emotional processing (18, 19), and the absence of loss aversion could reflect an inability to integrate, or differentially process affective information (20). Problem gamblers demonstrate altered neural representations of losses (21, 22) and deficits in emotional signalling during decision making according to the 'somatic marker hypothesis' (23). Therefore, investigating problem gamblers' loss aversion may provide key insights into their decision making.

Decision making alterations may differentially relate to gambling type. Problem gambling is a heterogeneous disorder (24-26) and many problem gamblers report a specific gambling form as most problematic (27). Compared to problem gamblers who prefer strategic gambling (e.g., sports betting, casino games), problem gamblers who prefer non-strategic gambling (e.g., electronic gaming machines; EGMs) are more likely to be older and female (28), demonstrate greater gambling severity (29) and have a faster onset of problem gambling (30). Furthermore, EGM problem gamblers have displayed poorer IGT performance and a more conservative approach on the Card Playing task than casino problem gamblers (4). Importantly, gender needs to be carefully considered when subgrouping problem gamblers based on preferred gambling form as gamblers preferring non-strategic activities tend to be women while gamblers preferring strategic activities tend to be men (28, 31).

In this study, we investigated factors associated with problem gamblers' decision making under conditions of risk and ambiguity, and examined differences in decision making between problem gambling subtypes. Specifically, we applied a cognitive modelling procedure to examine the cognitive, motivational and response style processes underlying problem gamblers' IGT performances, and investigated problem gamblers' sensitivity to losses on a loss aversion task. Additionally, we examined whether preferring strategic or non-strategic gambling activities was differentially associated with decision making using gender-matched controls.

5.3. Method

5.3.1. Participants and procedures

Thirty-nine problem gamblers were recruited through advertising placed in Gamblers Help, an outpatient counselling service, located in Victoria, Australia. Problem gamblers met diagnostic criteria for problem gambling (≥8) on the Problem Gambling Severity Index (PGSI) from the Canadian Problem Gambling Index (32). In addition, 41 age-, gender- and estimated-IQ- (measured by the National Adult Reading Test; (33)) matched controls were recruited by community advertising. Exclusion criteria included age over 65 years, previous head injury, neurological disorders, psychosis/psychotic disorders and recent alcohol or illicit drug use (prior 12 hours). Additional exclusion criteria for controls included current or lifetime mental health disorders (measured by the Mini-International Neuropsychiatric Interview (MINI) (34)), score of above three on the PGSI and gambling more than once a month. The groups did not differ on age or estimated-IQ; however, controls reported higher total years of education (see Table 1). Problem gamblers scored higher on psychological distress as measured by the Depression Anxiety and Stress Scale (DASS) (35), however, we

found no difference in alcohol use and related problems as measured by the Alcohol Use Disorders Identification Test (36). Due to the high prevalence of comorbid mental health disorders in problem gambling (37), problem gamblers with comorbidities were included in our sample (see Table 2).

Participants were allocated into strategic and non-strategic gambling forms based on Grant and colleagues (29) criteria for most problematic gambling form. Strategic gambling included games where skill or knowledge may have some impact on the outcome (e.g., poker, sports betting, horse/dog races), whilst non-strategic gambling included games that involve little or no skill (e.g., EGMs, bingo) (29). None of the problem gamblers reported equal preference for both forms. Due to gender differences between the gambling subgroups, with only men in the strategic gambling group (n=15) and more women than men in the non-strategic gambling group (n=24), age-, gender- and estimated-IQ-matched control groups were used to compare the two gambling subtypes performance on the decision making tasks. Strategic and non-strategic problem gamblers did not differ on age, education, estimated-IQ, psychological distress or alcohol use (see Table 3). However, non-strategic problem gamblers reported greater gambling severity and less years of problem gambling than strategic problem gamblers.

Participants provided signed informed consent and the study protocol was approved by the Monash University Human Research Ethics Committee and the Department of Justice (Victoria) Research Ethics Committee. Participants were tested individually in a quiet room as part of a larger study with the order of tasks fixed. Participants were reimbursed with a gift voucher to a local department store.

Table 1 Means and standard deviations (in parentheses) for demographic and clinical data

	PGs n=39	**Control n=41**	**Test Statistic**
Gender (M/F)	19/20	21/20	
Age	46.64 (9.46)	44.34 (11.43)	t(77) = -0.98, NS
Years of education	12.88 (2.09)	14.76 (2.28)	t(78) = 3.82, p <0.001
Estimated IQ (NART)	103.54 (6.99)	106.87 (9.44)	t(78) = 1.81, NS
Gambling Severity (PGSI)	18.31 (4.79)	0.27 (0.71)	t(40) = -23.27, p<0.001
Self-Reported Years of PG	14.92 (9.61)		
DASS –Depression	15.59 (12.42)	3.41 (3.56)	t(44) = -5.90, p<0.001
DASS –Anxiety	11.85 (11.35)	1.37 (1.86)	t(40) = -5.83, p<0.001
DASS – Stress	17.90 (11.71)	5.66 (4.19)	t(47) = -6.16, p<0.001
DASS – Total	45.95 (33.91)	10.44 (7.73)	t(42) = -6.39, p<0.001
AUDIT Total	5.32 (6.16)	4.56 (4.21)	t(65) = -0.63, NS

Note: All scores are mean (SD) unless otherwise indicated. Group demographics and clinical variables were compared using two-tailed independent t-tests and corrected for multiple comparisons using Bonferroni correction method. PGs: problem gamblers; M:male, F:female; NART: National Adult Reading Test; PGSI: Problem Gambling Severity Index; DASS: Depression, Anxiety and Stress Scale; AUDIT; Alcohol Use Disorders Identification Test.

Table 2 Frequency of comorbid mental health issues in the problem gambling sample

DSM-IV Comorbid Disorder	**Total PGs (%)**	**Strategic PGs (%)**	**Non-Strategic PGs (%)**
Major Depressive Episode	8 (20.5%)	4 (26.7%)	4 (16.7%)
Major Depressive Disorder	10 (25.6%)	3 (20.0%)	7 (29.2%)
Dysthymia	7 (17.9%)	0	7 (29.2%)
Hypomanic Episode – Past	3 (7.7%)	1 (6.7%)	2 (8.3%)
Manic Episode – Past	5 12.8%)	1 (6.7%)	4 (16.7%)
Panic Disorder	3 (7.7%)	1 (6.7%)	2 (8.3%)
Panic Disorder Lifetime	10 (25.6%)	4 (26.7%)	6 (25.0%)
Agoraphobia	3 (7.7%)	1 (6.7%0	2 (8.7%)
Social Phobia	1 (2.6%)	1 (6.7%)	0
Post-Traumatic Stress Disorder	1 (2.6%)	0	1 (4.3%)
Alcohol Dependence	2 (5.1%)	0	2 (8.3%)
Alcohol Abuse	1 (2.6%)	1 (6.7%)	0
Substance Dependence	3 (7.7%)	1 (6.7%)	2 (8.3%)
Substance Abuse	1 (2.6%)	1 (6.7%)	0
Generalised Anxiety Disorder	2 (5.1%)	0	2 (8.7%)
Antisocial Personality Disorder - Lifetime	4 (10.3%)	1 (6.7%)	3 (13%)
Any Comorbid Disorder	30 (76.9%)	9 (60.0%)	21 (87.5%)

Note: All disorders are current unless otherwise stated.

Table 3 Demographic and clinical data for problem gamblers based on preferred gambling form

	Strategic PGs n=15	**Non-Strategic PGs n=24**	**Test Statistic**
Gender (M/F)	15/0	4/19	
Age	44.33 (8.12)	48.08 (10.10)	t(37) = -1.21, NS
Years of education	12.67 (2.61)	13.02 (1.75)	t(37) = -0.51, NS
Estimated IQ (NART)	102.13 (8.68)	104.42 (5.72)	t(22) = -0.99, NS
Gambling Severity (PGSI)	15.40 (4.75)	20.13 (3.90)	t(37) = -3.38, p<0.01
Self-Reported Years of PG	20.73 (11.95)	11.29 (5.48)	t(18) = 2.88, p<0.01
DASS - Depression	12.93 (12.98)	17.25 (12.04)	t(37) = -1.06, NS
DASS - Anxiety	10.53 (11.48)	12.67 (11.43)	t(37) = -0.57, NS
DASS - Stress	14.67 (12.46)	19.92 (10.99)	t(37) = -1.38, NS
DASS- Total	38.13 (34.61)	51.22 (33.94)	t(37) = -1.14, NS
AUDIT Total	5.67 (6.51)	5.09 (6.06)	t(37) = 0.28, NS

Note: All scores are mean (SD) unless otherwise indicated. Group demographics and clinical variables were compared using two-tailed independent t-tests and corrected for multiple comparisons using Bonferroni correction method. PGs: problem gamblers; Strategic PGs: Sports-betting (n=12) & casino games (n=3); Non-strategic: EGMs (n=24); M:male, F:female; NART: National Adult Reading Test; PGSI: Problem Gambling Severity Index; DASS: Depression, Anxiety and Stress Scale; AUDIT; Alcohol Use Disorders Identification Test

5.3.2. Measures

5.3.2.1. Iowa Gambling Task (IGT)

We used a computerised version of the IGT based on Bechara *et al.* (38). Participants were presented with four card decks and instructed to accumulate as much (play) money as possible by choosing cards from the decks. Decks differed in payoffs and penalties. Selections from decks A and B yielded $100, and selections from decks C and D yielded $50, with winnings often paired with a loss. Decks A and B were disadvantageous because the occasional losses ($150-$1250) resulted in losing $250 per 10 cards. Decks C and D were advantageous because the occasional losses ($25-$250) resulted in a net gain of $250 per 10 cards. The position of decks A-D was randomly assigned and all participants began with a $2000 loan. The task consisted of 150 trials in 6 blocks of 25 trials, with feedback on net win/loss given after each block. Instructions were based on Bechara *et al.* (39). Task

performance was measured by the net score (number of advantageous choices [C+D] minus number of disadvantageous choices [A+B]) in each block.

5.3.2.2. PVL Model for decomposing IGT performance (14)

The PVL model was used to disentangle underlying psychological processes involved in IGT performance (see supporting information). The PVL model yields four free parameters; Utility Shape, Loss Aversion, Recency/Learning, and Consistency. The Utility Shape parameter measures the attention given to the magnitude of gains. The Loss Aversion parameter indicates sensitivity to losses. The Recency/Learning parameter indicates attention given to past experiences with a deck versus attention given to the most recent deck selection. Lastly, the Consistency parameter measures how consistent the decision makers' selections are with their expected value.

5.3.2.3. Loss Aversion task

The Loss Aversion task was based on the De Martino *et al*. (40) task and administered using E-Prime software (Version 2.0). Participants were instructed to accept or reject a series of mixed gambles with an equal probability (50%) of winning or losing a variable amount of money (e.g., win $25 or lose $5). Gambles were presented as a coin toss, and responses made by a key press. A five trial practice-run was conducted first, then a single block of 49 trials. Wins ranged from $15 to $45 and losses ranged from $5 to $35 both in $5 increments. Because previous research suggested that people are twice as sensitive to losses as wins (17), the wins and losses were chosen to attempt to elicit a wide range of responses. The win/loss combination of each trial was randomly determined with all gambles presented. Participants did not receive any financial rewards or incur any financial losses based on performance; however they were instructed to evaluate each gamble as if they would win or lose the presented monetary amounts.

Gamble decision (yes or no) and response time were recorded. Using the methods from Tom *et al.* (41), we computed an estimate of loss aversion (λ) for each participant by fitting a logistic regression to each participant's gamble decisions with the gain and loss as independent variables (see supporting information). This value indicates how heavily participants weighed losses compared to gains when deciding whether to accept a gamble.

5.3.3. Data analysis

The IGT was examined as 6 blocks of 25 trials. Past research suggests that choices made during the first two blocks involve trial and error while participants attempt to learn the task (42). Task performance then improves significantly between the first and third blocks (43) and the later portion of the task better indicates performance. As such, we analysed the first two blocks separately (*learning trials*) from the last four blocks (*performance trials*). To determine group and block effects, a repeated measures ANOVA was conducted with group as between factor, block as within factor and net score as the dependent measure. Mahalanobis distance indicated one multivariate outlier, which was excluded from analysis. Group differences in the PVL model parameters were analysed using Independent-Samples t-tests.

For the Loss Aversion task, we were unable to calculate loss aversion (λ) for 8 participants (5 problem gamblers and 3 controls) because they did not accept any gambles during the task; thus these participants were excluded from analyses. However, according to Fisher's Exact test, the ratio of non-responders did not differ between groups ($p = 0.47$). The remaining participants' loss aversion (λ) and response times were compared using an Independent-Samples t-test or Mann Whitney U test if the assumption of normality was violated.

5.4. Results

5.4.1. Performance on the IGT

Across the learning trials, there was no difference between problem gamblers and controls with no group ($F(1,77) = 0.49$, $p = 0.49$) or block effect ($F(1,77) = 1.49$, $p = 0.23$), and no interaction ($F(1,77) = 0.41$, $p = 0.53$). However, on the performance trials, we found that problem gamblers performed significantly worse than controls (group effect, $F(1,77) = 5.13$, $p = 0.03$, $\eta^2 = 0.06$), whilst there was no block effect ($F(3,77) = 1.56$, $p = 0.20$) or interaction ($F(3,77) = 0.726$, $p = 0.54$). Both problem gamblers and controls demonstrated learning across the task with more advantageous choices on the performance trials compared to the learning trials ($F(1,77) = 14.08$, $p = 0.0003$, $\eta^2 = 0.15$; see Figure 1).

Using the PVL model we found that, compared to controls, problem gamblers were more influenced by the magnitude of the potential gain (higher Utility Shape, $p = 0.006$), and their choices tended to be more random or erratic (lower Consistency, $p = 0.0001$). The groups did not differ on either the Recency/Learning or Loss Aversion parameters (see Table 4).

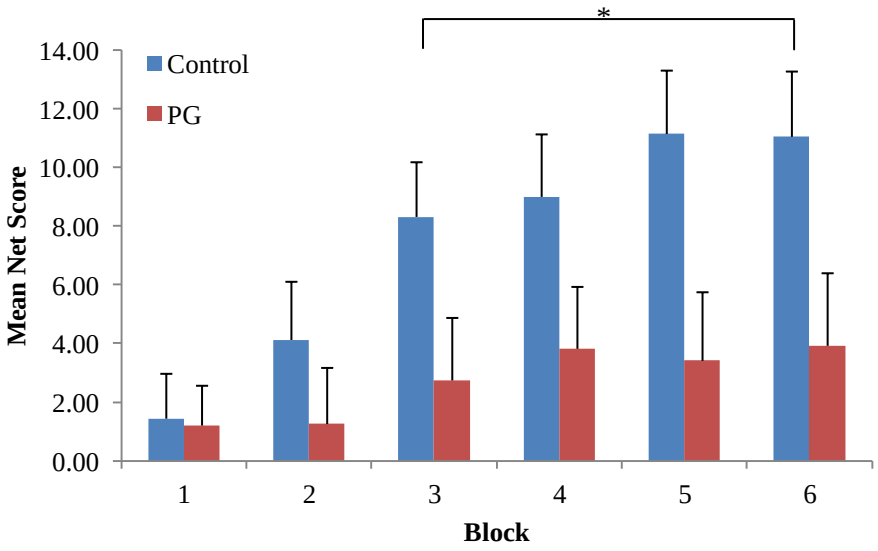

Figure 1. Overall group performances on the IGT represented as mean net score per block. Error bars represent standard error of the mean.*$p<0.05$

Table 4 Mean and standard deviations (in parentheses) of the model parameters for the PVL model and the Bayesian Information Criterion (BIC) scores

	PGs M (SD)	**Control M (SD)**	**Test Statistic**
Overall sample			
Utility Shape*	0.32 (0.13)	0.25 (0.12)	$t(78) = -2.85$, $p = 0.006$, $r = 0.31$
Loss Aversion	0.86 (0.68)	0.75 (0.51)	$t(70) = -.83$, NS
Recency/Learning	0.65 (0.24)	0.66 (0.24)	$t(78) = 0.28$, NS
Consistency**	0.18 (0.07)	0.29 (0.16)	$t(58) = 4.17$, $p = 0.0001$, $r = 0.48$
BIC	17.02 (24.21)	22.67 (27.90)	-
Strategic groups			
Utility Shape**	0.45 (0.17)	0.23 (0.14)	$t(30) = -3.96$, $p = 0.0004$, $r = 0.58$
Loss Aversion**	1.01 (0.54)	0.37 (0.15)	$t(30) = -4.74$, $p = 0.00003$, $r = 0.65$
Recency/Learning	0.75 (0.27)	0.71 (0.18)	$t(30) = -0.60$, NS
Consistency**	0.13 (0.05)	0.32 (0.16)	$t(30) = 4.51$, $p = 0.00001$, $r=0.64$
BIC	14.01 (22.76)	20.58 (33.36)	-
Non-Strategic groups			
Utility Shape	0.23 (0.04)	0.23 (0.08)	$t(46) = 0.14$, NS
Loss Aversion**	0.20 (0.17)	1.01 (0.72)	$t(46) = 5.33$, $p = 0.00002$, $r = 0.64$
Recency/Learning	0.55 (0.22)	0.63 (0.28)	$t(46) = 1.16$, NS
Consistency	0.27 (0.16)	0.30 (0.17)	$t(46) = 0.56$, NS
BIC	16.29 (27.53)	18.35 (24.40)	-

Note: Bayesian Information Criterion (BIC) scores were used to compare the PVL model to baseline statistical model with positive values indicating the PVL is a better model. For the PVL model parameters, groups were compared using an Independent Samples t-test. Overall sample: PG (n=39) and age-, gender and estimated-IQ matched controls (n=41); Strategic groups: Strategic PG (n=15) and age-, gender- and estimated-IQ matched controls (n=17); Non-strategic groups: Non-strategic PGs (n=24) and age-, gender- and estimated-IQ matched controls (n=24). * $p < 0.01$; ** $p < 0.001$

Strategic problem gamblers did not differ from controls on either the learning *or* performance trials of the IGT (see Figure 2). Specifically, on the learning trials, there was no group ($F(1,30) = 0.44$, $p = 0.51$) or block effect ($F(1,30) = 0.56$, $p = 0.46$), and no interaction ($F(1,30) = 0.42$, $p = 0.53$). On the performance trials, there was no group effect ($F(1,30) = 1.89$, $p = 0.18$) or interaction ($F(3,30) = 0.24$, $p = 0.87$). However, a significant block effect ($F(3,30) = 2.81$, $p = 0.04$, $\eta^2 = 0.09$) indicated that performance improved with task

progression and both groups performed better on the performance trials than the learning trials ($F(1,30) = 41.15$, $p = 0.0001$, $\eta^2 = 0.61$). Despite no group differences between strategic problem gamblers and controls, the PVL model indicated differences in underlying decision making processes (see Table 4). Strategic problem gamblers exhibited greater sensitivity to the magnitude of gains (higher Utility Shape, $p = 0.0004$), more sensitivity to losses (higher Loss Aversion, $p = 0.00003$), and more erratic or random choices than controls (lower Consistency, $p = 0.00001$) than controls. There was no group effect on the Recency/Learning parameter.

Non-strategic problem gamblers performed similarly to controls on the learning trials of the IGT (no group effect, $F(1,46) = 2.95$, $p = 0.09$, block effect $F(1,46) = 0.42$, $p = 0.52$), and no interaction ($F(1,46) = 2.70$, $p = 0.11$; see Figure 2). However, non-strategic problem gamblers performed worse than controls on the performance trials (group effect, $F(1,45) = 5.08$, $p = 0.03$, $\eta^2 = 0.10$). There was no block effect ($F(3,45) = 0.27$, $p = 0.85$) or interaction ($F(3,45) = 0.58$, $p = 0.63$) on the performance trials. In addition, non-strategic problem gamblers and controls did not improve from the learning to performance trials ($F(1,46) = 1.21$, $p = 0.28$) indicating that, unlike the strategic groups (discussed above), neither non-strategic group demonstrated learning across the task. The PVL model indicated that non-strategic problem gamblers demonstrated less sensitivity to losses than controls (lower Loss Aversion, $p = 0.00002$, see Table 4). Groups did not differ on the Recency/Learning, Consistency or Utility Shape parameters.

For all group analyses, the PVL model demonstrated a positive Bayesian Information Criterion indicating that the PVL model provided a better fit than a baseline statistical model even after model complexity was considered (see Table 4). It is also important to note that by using gender-matched control groups, we effectively created two very different control

groups which displayed performances that were quite different from the overall control group. In effect, the non-strategic groups were mostly women, whereas the strategic groups were all men. In this regard, we found a gender difference in the controls' IGT performance with men performing better overall than women ($t(39) = 4.42$, $p = 0.0007$, $r = 0.58$). Thus, in part, the differences we observed between the problem gambling subtypes are conflated with the gender makeup of these groups, and therefore, the results must be considered within the combined context of gender and gambler subtype. Lastly, we used regression analyses to determine whether the most prevalent comorbid condition in the problem gamblers (depression) was associated with IGT performance, and found that the self-reported depressive symptoms (measured by the DASS) did not predict IGT performance ($R^2 = .03$, $F(1,77) = 2.55$, $p = 0.12$).

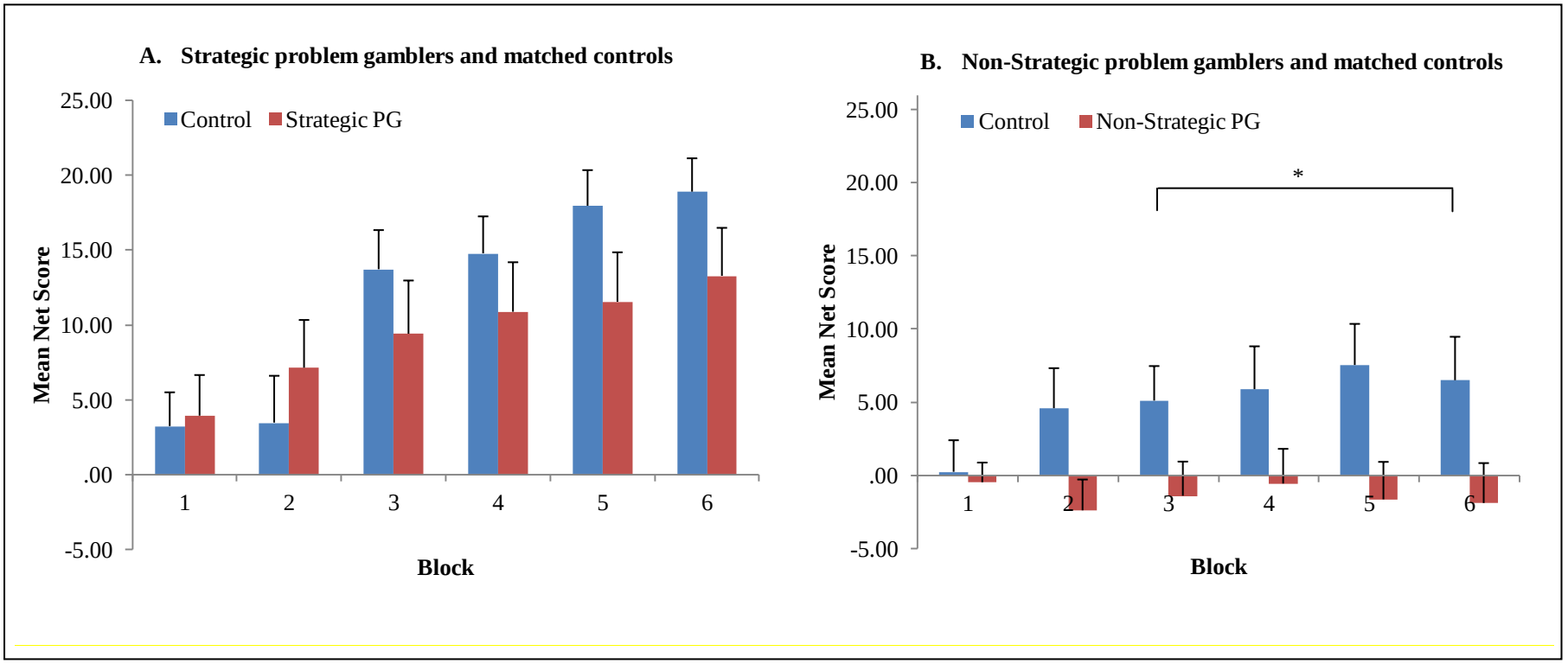

Figure 2. Strategic and non-strategic problem gamblers and their respective matched control groups performance on the IGT represented as mean net score per block. Error bars represent standard error of the mean. A) Strategic problem gamblers did not differ from matched controls on the IGT. B) Non-Strategic problem gamblers performed more poorly than their respective controls on the performance trials (blocks 3-6) with a significant group effect. *$p<0.05$.

5.4.2. Performance on the Loss Aversion task

Overall, problem gamblers (*M* = 1.66) demonstrated less loss aversion than controls (*M* = 2.25), *t*(69) = 2.34, *p* = 0.02, *r* = 0.27, but did not differ from controls on response time (problem gamblers *M* = 1934, controls *M* = 1625, *t*(69) = -1.78, *p* = 0.10; see Figure 3). With regard to the gambler subgroups, strategic problem gamblers (*M* = 1.47) did not differ from controls (*M* = 1.63), *t*(28) = 0.49, *p* = 0.63. In contrast, non-strategic problem gamblers (*M* = 2.02) were less loss averse than controls (*M* = 2.76), Mann Whitney U_c = 111.5, *p* = 0.01, *r* = 0.40.

Interestingly, the non-strategic control group, which was mostly women, displayed higher loss aversion than the strategic control group, which were all men, and we found that female controls (*M* = 3.02) demonstrated higher loss aversion than male controls (*M* = 1.79), *t*(35) = -2.84, *p* = 0.008, *r* = 0.43, again highlighting gender effects within the subgroups, which are a key consideration for understanding the different subtypes of problem gamblers. Self-reported depressive symptoms (measured by the DASS) did not predict loss aversion on this task (R^2 = .0007, *F*(1,69) = 0.005, *p* = 0.94).

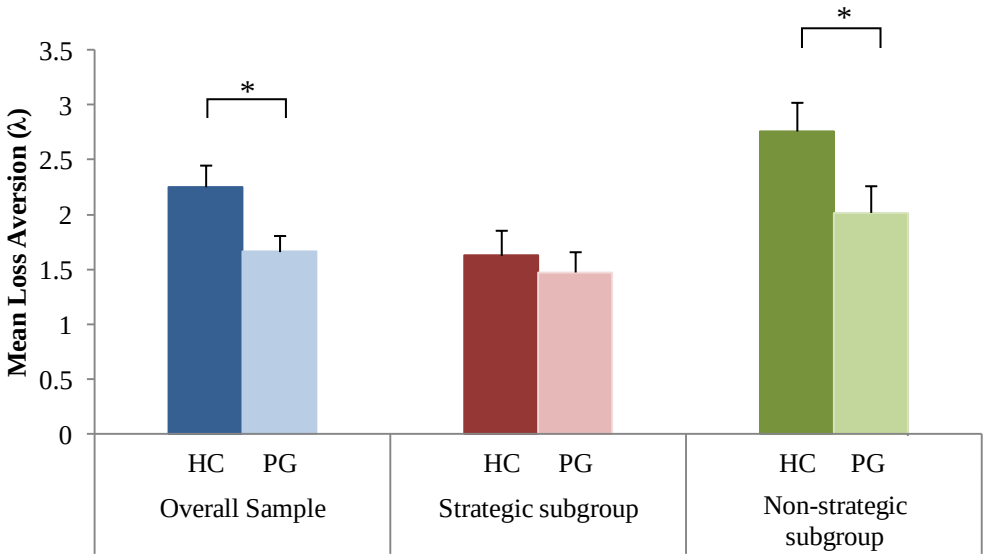

Figure 3. Mean loss aversion (λ) for problem gamblers compared to representive matched control groups. Error bars represent standard error of the mean. *p<0.05

5.5. Discussion

Overall, problem gamblers made more disadvantageous choices on the IGT and displayed less sensitivity to losses during the Loss Aversion task. Using cognitive modelling for the first time with problem gamblers, we also showed that problem gamblers IGT performance was underpinned by greater attention to the magnitude of gains and less choice consistency than controls. Our findings that problem gamblers performed poorly on both decision making tasks is consistent with past research using the IGT (4, 6, 44) and other risky decision making tasks (10-12), and highlights that particular decision making styles may underlie problem gambling. Furthermore, substance abusers perform similarly (45, 46), and display similar IGT cognitive modelling parameters (46-48) to problem gamblers, further supporting the concept of problem gambling as an addictive disorder.

A key feature of our study was the inclusion of separate groups of strategic and non-strategic problem gamblers, which yielded novel insights into how problem gambling subgroups differ in decision processes. Strategic problem gamblers *performed as well as their controls* on the IGT, but they showed greater attention to gains, *more* sensitivity to losses, and less choice consistency. In contrast, non-strategic problem gamblers *performed worse than their controls*, and showed *less* sensitivity to losses. Further differences were observed in the Loss Aversion task. Strategic problem gamblers and their controls performed similarly, whereas, consistent with less sensitivity to losses on the IGT, non-strategic problem gamblers were less loss averse than their controls on the Loss Aversion task. These results indicate differing underlying decision styles in strategic and non-strategic problem gamblers. Heterogeneity amongst problem gamblers' decision making has also been shown in EGM and casino problem gamblers (4). Strategic gambling activities may include more analytical decision making processes (28), which may enable strategic problem gamblers to learn the IGT better than non-strategic problem gamblers.

As the strategic problem gamblers were all men and the non-strategic problem gamblers were mostly women, we took gender makeup into account by using gender-matched controls, making it possible highlight differences in these gambling subtypes. However, considering our data from the gender point of view, rather than gambling subtype, we found gender differences in decision making with men performing better on the IGT and women demonstrating higher loss aversion. These findings are consistent with past research showing women require longer to learn the IGT (49, 50) and are more loss averse during risky gambles than men (51). This highlights the importance of considering gender in decision making research.

Our cognitive modelling results showed that problem gamblers demonstrated altered reward processing during decision making. This is consistent with neuroimaging data showing that problem gamblers have reduced activation in reward regions (ventral striatum and ventromedial prefrontal cortex) during monetary gains (52) and while processing rewards and losses (22). Our results provide further evidence that aberrant reward processing may be a key factor in problem gamblers' decision making, and go beyond these findings by adding that reward processing appears to be altered differentially for gambling subgroups. That is, strategic problem gamblers showed altered gain *and* loss processing, whilst non-strategic problem gamblers demonstrated less sensitivity *only to losses*. Whether this cognitive evidence would bear out in neuroimaging studies as different brain activation patterns is not yet known.

Furthermore, our finding that problem gamblers (regardless of subtype) and controls demonstrated similar Recency/Learning parameters indicates that IGT performance may not be due to poor learning or memory. This is consistent with findings that problem gamblers do demonstrate memory impairments (53) and working memory is unrelated to their IGT performance (11). We also found that the overall problem gambling sample, and strategic but

not non-strategic problem gamblers, demonstrated lower choice consistency on the IGT. This parameter may relate to impulsivity (48), and high self-reported impulsivity is common in problem gamblers (54, 55), which may be a greater issue for strategic problem gamblers.

We note that our sample were treatment-seeking, which limits generalisation to problem gamblers who do not seek treatment, many of whom recover without treatment (56). Moreover, to enhance generalisability, we retained comorbid disorders in our study because they are exceedingly common in problem gamblers. However, we note that depression, our most common comorbidity, was not associated with IGT or Loss Aversion task performance. Furthermore, as our controls were in essence non-gamblers, our study did not compare non-problem gamblers to problem gamblers to isolate specific decision making styles associated with gambling problems themselves.

In summary, our study is the first to use cognitive modelling to understand problem gamblers' decision making, and our findings provide a novel insight into differences between subtypes of problem gamblers. Strategic problem gamblers decisions are influenced by *both gains and losses*, and they tend to have an *inconsistent*, possibly impulsive, choice style. In contrast, non-strategic problem gamblers are *less sensitive to losses* and show *poor learning* during decision making. Our findings highlight the presence of important cognitive differences between subtypes of problem gamblers which require further investigation.

5.6. Supplementary Methods

5.6.1. PVL Model for decomposing IGT performance

The PVL model is an extension of the Expectance Valence Learning model (13) and was used to disentangle underlying processes involved in IGT performance. The PVL model has three basic assumptions; 1) a utility function represents an individual's affective reaction

for integrated gains and losses on each trial, 2) a learning rule represents how the decision maker develops expectancies for each deck and how these are updated, and 3) a probabilistic function which represents that the choice made on each trial is based on the expectancies associated with each deck. The three general assumptions of the PVL model create four free parameters; Utility Shape, Loss Aversion, Recency/Learning, and Consistency. The equations used in the PVL model illustrating the four free parameters are shown in Table S1.

The first concept of 'valuing a card' involves two parameters, Utility Shape and Loss Aversion. During each card selection, the decision maker assesses the value of a card according to the amount of attention given to gains versus losses. In the PVL model, a non-linear prospect utility function is used to describe how decision makers value cards. The Utility Shape parameter depicts the curvature of the utility function, and can range between 0 and 1. Values closer to 1 indicate that subjective value increases in direct proportion with the outcome value and reflects higher sensitivity to gains, whilst values closer to 0 indicate that subjective utility increases in a stepwise fashion so all gains are subjectively equal and all losses are subjectively equal. The Loss Aversion parameter indicates an individual's sensitivity to losses compared to gains, and values range between 0 and 10. Values close to 0 indicate losses are experienced as neutral events, values closer to 1 indicate losses and gains are experienced as equal, and values greater than 1 indicate that losses have a greater impact than gains on subjective utility of an outcome.

The second concept of 'creating a deck expectancy' is measured by the Recency/Learning parameter. This parameter indicates how much attention is given to past experiences with a deck versus how much attention is given to the most recent selection from that deck. This parameter ranges from 0 to 1. Smaller values indicating greater learning over time and that the value of the most recent outcome has a smaller influence on deck selection.

Larger values indicate that the most recent card selection has a large influence on the expected value of that deck.

The third concept of 'probability of choosing a deck' is derived from the decision makers' expectancies associated with each deck and the consistency in their choices. The Consistency parameter is a measure of how consistent the decision makers' selections are with their expected value. Higher values for the Consistency parameter indicate that the decision maker's choosing is in keeping with his/her expected values for each deck, whilst lower values indicate a more random and erratic response style, possibly reflective of impulsivity.

The PVL model was evaluated using the Bayesian Information Criterions (BIC, (57)) as in Ahn *et al*. (14). Specifically, the model was compared to a Bernoulli baseline model. The baseline model selects a deck using a Bernoulli process where the probability of a deck is equal to an individual's overall proportion of choices for that deck. Using this method the BIC is given by:

$$BIC = G^2 - \Delta k \times \ln(N)$$

where N is the number of trials and Δ k is the difference in the number of parameters for the PVL model and baseline model. The quantity G^2 is the difference in the log likelihood for the PVL model the baseline model defined as:

$$G^2 = 2 \times [LL_{PVL} - LL_{baseline}].$$

A positive BIC indicates that the PVL model is preferred over the baseline model even after model complexity is considered.

Loss Aversion task analysis

To determine participant's loss aversion on the Loss Aversion task, we used the methods from Tom *et al.* (41). We computed an estimate of loss aversion (λ) which indicates how heavily participants weighed losses compared to gains when deciding whether or not to accept a gamble. Participants' utility function (U) for monetary values (X) was expressed as:

$$U(X) = \begin{cases} x & x \geq 0 \\ \lambda x & x < 0 \end{cases}$$

This parameter is similar to the λ parameter used in Prospect Theory (16), however, it makes the assumption of a linear rather than curvilinear value function (a commonly employed alteration (41, 58, 59)), and it uses identical decision weights with a 0.5 probability to gain or lose money (whereas in Prospect Theory, gains and losses are not handled symmetrically, allowing for gains and losses to differently influence decision outcomes). Furthermore, it is these assumptions that differ between the behavioural loss aversion coefficient (λ) calculated from the Loss Aversion task and the Loss Aversion parameter of the PVL model.

In this formula, λ represents the relative weighting of losses to gains with λ>1 indicating that losses have a greater influence than gains on choices. The log-odds for accepting a gamble are given by a standard logistic regression:

$$ln\left\{\frac{P(G,L)}{1-P(G,L)}\right\} = \alpha + \beta_{gain}G + \beta_{loss}L,$$

This is equivalent to:

$$P(G,L) = \frac{\exp\left(\alpha + \beta_{gain}G + \beta_{loss}L\right)}{1 + \exp\left(\alpha + \beta_{gain}G + \beta_{loss}L\right)}.$$

The gain and loss of each presented gamble was entered into a logistic regression analysis as an independent variable, whilst participants' choices (yes or no) were the dependent variable. Behavioural loss aversion (λ) was computed for each individual participant as:

$\lambda = -\beta loss / \beta gain$

βloss and βgain are the unstandardised regression coefficients for the loss and gain variables, respectively

Table S1. PVL model equations for estimating parameters

Concept	Model Equation	Free parameter
Valuing a card	$u(t) = \begin{cases} x(t)^{\alpha} \\ -\lambda \lvert x(t)^{\alpha} \rvert \end{cases}$	λ = Loss aversion α = Utility shape
Creating a deck expectancy	$E_j = E_j(t-1) + A \cdot \delta_j(t) \cdot [u(t) - E_j(t-1)]$	A = Recency
Probability of choosing deck *j*	$\Pr[D(t+1) = j] = \frac{e^{0(t) \cdot E_j(t)}}{\sum_{j=1}^{4} e^{0(t) \cdot E_j(t)}}$	
Consistency between choices and expectancies	$\theta(t) = 3^c - 1$	c = Consistency

Note: *j* refers to deck A, B, C or D. $\delta_j(t)$ is a dummy variable equal to 1 if deck *j* was chosen on trial *t*, otherwise 0.

5.7. References

1. American Psychiatric Association (APA). Diagnostic and Statistical Manual of Mental Disorders (DSM-5): American Psychiatric Publishing; 2013.
2. Bechara A. Decision making, impulse control and loss of willpower to resist drugs: a neurocognitive perspective. *Nat Neurosci*. 2005;**8**:1458-63.
3. Coventry KR. Gambling and decision-making: A dual process perspective. *Behav Brain Sci*. 2008;**31**:444-5.
4. Goudriaan AE, Oosterlaan J, de Beurs E, van den Brink W. Decision making in pathological gambling: A comparison between pathological gamblers, alcohol dependents, persons with Tourette syndrome, and normal controls. *Cogn Brain Res*. 2005;**23**:137-51.
5. Cavedini P, Riboldi G, Keller R, D'Annucci A, Bellodi L. Frontal lobe dysfunction in pathological gambling patients. *Biol Psychiatry*. 2002;**51**:334-41.
6. Ledgerwood D, Orr E, Kaploun K, Milosevic A, Frisch G, Rupcich N, et al. Executive function in pathological gamblers and healthy controls. *J Gamb Stud*. 2012;**28**:89-103.
7. Petry NM. Pathological gamblers, with and without substance use disorders, discount delayed rewards at high rates. *J Abnorm Psychol*. 2001;**110**:482-7.
8. Dixon MR, Marley J, Jacobs EA. Delay discounting by pathological gamblers. *J Appl Behav Anal*. 2003;**36**:449-58.
9. Lakey CE, Goodie AS, Campbell W. Frequent card playing and pathological gambling: The utility of the Georgia Gambling Task and Iowa Gambling Task for predicting pathology. *J Gamb Stud*. 2007;**23**:285-97.
10. Labudda K, Wolf OT, Markowitsch HJ, Brand M. Decision-making and neuroendocrine responses in pathological gamblers. *Psychiatry Res*. 2007;**153**:233-43.
11. Brevers D, Cleeremans A, Goudriaan AE, Bechara A, Kornreich C, Verbanck P, et al. Decision making under ambiguity but not under risk is related to problem gambling severity. *Psychiatry Res*. 2012;**200**:568-74.
12. Brand M, Kalbe E, Labudda K, Fujiwara E, Kessler J, Markowitsch HJ. Decision-making impairments in patients with pathological gambling. *Psychiatry Res*. 2005;**133**:91-9.

13. Busemeyer JR, Stout JC. A contribution of cognitive decision models to clinical assessment: Decomposing performance on the Bechara gambling task. *Psychol Assessment*. 2002;**14**:253-62.
14. Ahn W-Y, Busemeyer JR, Wagenmakers E-J, Stout JC. Comparison of decision learning models uing the generalization criterion method. *Cognitive Sci*. 2008;**32**:1376-402.
15. Yechiam E, Busemeyer JR, Stout JC, Bechara A. Using cognitive models to map relations between neuropsychological disorders and human decision-making deficits. *Psychol Sci*. 2005;**16**:973-8.
16. Tversky A, Kahneman D. Advances in prospect theory: Cumulative representation of uncertainty. *J Risk Uncertainty*. 1992;**5**:297-323.
17. Tversky A, Kahneman D. Loss aversion in riskless choice: A reference-dependent model. *Q J Econ*. 1991;**106**:1039-61.
18. Bibby PA, Ferguson E. The ability to process emotional information predicts loss aversion. *Pers Individ Dif*. 2011;**51**:263-6.
19. Sokol-Hessner P, Camerer CF, Phelps EA. Emotion regulation reduces loss aversion and decreases amygdala responses to losses. *Soc Cogn Affec Neurosci*. 2013;**8**:341-50.
20. Tremeau F, Brady M, Saccente E, Moreno A, Epstein H, Citrome L, et al. Loss aversion in schizophrenia. *Schizophr Res*. 2008;**103**:121-8.
21. de Ruiter MB, Veltman DJ, Goudriaan AE, Oosterlaan J, Sjoerds Z, Van Den Brink W. Response perseveration and ventral prefrontal sensitivity to reward and punishment in male problem gamblers and smokers. *Neuropsychopharmacol*. 2009;**34**:1027-38.
22. Balodis IM, Kober H, Worhunsky PD, Stevens MC, Pearlson GD, Potenza MN. Diminished frontostriatal activity during processing of monetary rewards and losses in pathological gambling. *Biol Psychiatry*. 2012;**71**:749-57.
23. Goudriaan AE, Oosterlaan J, de Beurs E, van den Brink W. Psychophysiological determinants and concomitants of deficient decision making in pathological gamblers. *Drug Alcohol Depend*. 2006;**84**:231-9.
24. Milosevic A, Ledgerwood DM. The subtyping of pathological gambling: A comprehensive review. *Clin Psychol Rev*. 2010;**30**:988-98.

25. Nower L, Martins SS, Lin K-H, Blanco C. Subtypes of disordered gamblers: Results from the National Epidemiologic Survey on Alcohol and Related Conditions (NESARC). *Addiction*. 2013;**108**:789-98.
26. Blaszczynski A, Nower L. A pathways model of problem and pathological gambling. *Addiction*. 2002;**97**:487-99.
27. Petry NM. A comparison of treatment-seeking pathological gamblers based on preferred gambling activity. *Addiction*. 2003;**98**:645-55.
28. Odlaug B, Marsh P, Kim S, Grant J. Strategic vs nonstrategic gambling: characteristics of pathological gamblers based on gambling preference. *Ann Clin Psychiatry*. 2011;**23**:105-12.
29. Grant JE, Odlaug BL, Chamberlain SR, Schreiber LRN. Neurocognitive dysfunction in strategic and non-strategic gamblers. *Prog Neuropsychopharmacol Biol Psychiatry*. 2012;**38**:336-40.
30. Breen R, Zimmerman M. Rapid onset of pathological gambling in machine gamblers. *J Gamb Stud*. 2002;**18**:31-43.
31. Potenza MN, Steinberg MA, McLaughlin SD, Wu RMS, Rounsaville BJ, O'Malley SS. Gender-related differences in the characteristics of problem gamblers using a gambling helpline. *Am J Psychiatry*. 2001;**158**:1500-5.
32. Ferris J, Wynne H. The Canadian Problem Gambling Index: Final Report. Canadian Centre on Substance Abuse (CCSA), 2001.
33. Nelson HE, Willison J. National Adult Reading Test (NART): Test Manual. 2nd ed. Windsor, UK: NFER Nelson; 1991.
34. Sheehan DV, Lecrubier Y. MINI International Neuropsychiatric Interview. 2006.
35. Lovibond SH, Lovibond PE. Manual for the Depression Anxiety Stress Scales. Sydney, Australia: Psychology Foundation of Australia, 1995.
36. World Health Organization. The Alcohol Use Disorders Identification Test (AUDIT). World Health Organization, 2001.
37. Lorains FK, Cowlishaw S, Thomas SA. Prevalence of comorbid disorders in problem and pathological gambling: systematic review and meta-analysis of population surveys. *Addiction*. 2011;**106**:490-8.
38. Bechara A, Damasio AR, Damasio H, Anderson SW. Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition*. 1994;**50**:7-15.

39. Bechara A, Damasio H, Damasio AR, Lee GP. Different contributions of the human amygdala and ventromedial prefrontal cortex to decision-making. *J Neurosci*. 1999;**19**:5473-81.
40. De Martino B, Camerer CF, Adolphs R. Amygdala damage eliminates monetary loss aversion. *Proc Natl Acad Sci U S A*. 2010;**107**:3788-92.
41. Tom SM, Fox CR, Trepel C, Poldrack RA. The neural basis of loss aversion in decision-making under risk. *Science*. 2007;**315**:515-8.
42. Brand M, Recknor EC, Grabenhorst F, Bechara A. Decisions under ambiguity and decisions under risk: Correlations with executive functions and comparisons of two different gambling tasks with implicit and explicit rules. *J Clin Exp Neuropsychol*. 2007;**29**:86-99.
43. Preston SD, Buchanan TW, Stansfield RB, Bechara A. Effects of anticipatory stress on decision making in a gambling task. *Behav Neurosci*. 2007;**121**:257-63.
44. Kertzman S, Lidogoster H, Aizer A, Kotler M, Dannon PN. Risk-taking decisions in pathological gamblers is not a result of their impaired inhibition ability. *Psychiatry Res*. 2011;**188**:71-7.
45. Verdejo-García AJ, Perales JC, Pérez-García M. Cognitive impulsivity in cocaine and heroin polysubstance abusers. *Addict Behav*. 2007;**32**:950-66.
46. Stout JC, Rock SL, Campbell MC, Busemeyer JR, Finn PR. Psychological processes underlying risky decisions in drug abusers. *Psychol Addict Behav*. 2005;**19**:148-57.
47. Stout JC, Busemeyer JR, Lin A, Grant SJ, Bonson KR. Cognitive modeling analysis of decision-making processes in cocaine abusers. *Psychon B Rev*. 2004;**11**:742-7.
48. Fridberg DJ, Queller S, Ahn W-Y, Kim W, Bishara AJ, Busemeyer JR, et al. Cognitive mechanisms underlying risky decision-making in chronic cannabis users. *J Math Psychol*. 2010;**54**:28-38.
49. van den Bos R, Homberg J, de Visser L. A critical review of sex differences in decision-making tasks: Focus on the Iowa Gambling Task. *Behav Brain Res*. 2013;**238**:95-108.
50. van den Bos R, Jolles J, van der Knaap L, Baars A, de Visser L. Male and female Wistar rats differ in decision-making performance in a rodent version of the Iowa Gambling Task. *Behav Brain Res*. 2012;**234**:375-9.
51. Brooks P, Zank H. Loss averse behavior. *J Risk Uncertainty*. 2005;**31**:301-25.

52. Reuter J, Raedler T, Rose M, Hand I, Glascher J, Buchel C. Pathological gambling is linked to reduced activation of the mesolimbic reward system. *Nat Neurosci*. 2005;**8**:147-8.
53. Goudriaan AE, Oosterlaan J, de Beurs E, van den Brink W. Neurocognitive functions in pathological gambling: A comparison with alcohol dependence, Tourette syndrome and normal controls. *Addiction*. 2006;**101**:534-47.
54. Ledgerwood DM, Alessi SM, Phoenix N, Petry NM. Behavioral assessment of impulsivity in pathological gamblers with and without substance use disorder histories versus healthy controls. *Drug Alcohol Depend*. 2009;**105**:89-96.
55. Maccallum F, Blaszczynski A, Ladouceur R, Nower L. Functional and dysfunctional impulsivity in pathological gambling. *Pers Individ Dif*. 2007;**43**:1829-38.
56. Slutske WS. Natural recovery and treatment-seeking in pathological gambling: Results of two U.S. national surveys. *Am J Psychiatry*. 2006;**163**:297-302.
57. Schwarz G. Estimating the dimension of a model. *Ann Stat*. 1978;**6**:461-4.
58. Gachter S, Johnson EJ, Herrman A. Individual-level loss aversion in riskless and risky choices. IZA discussion paper no 2961, 2007.
59. Chib Vikram S, De Martino B, Shimojo S, O'Doherty John P. Neural mechanisms underlying paradoxical performance for monetary incentives are driven by loss aversion. *Neuron*. 2012;**74**:582-94.

CHAPTER 6: INTEGRATED DISCUSSION

6.1. Overview of Main Findings and Contribution to the Literature

Gambling is a form of entertainment for most people. However, for some people gambling leads to a serious psychiatric disorder. Problem gambling is associated with a large societal cost, and despite growing awareness of this issue, the aetiology of problem gambling is not well known. My thesis aimed to further our understanding of this complex psychiatric disorder, with our findings ultimately being able to inform the development of more targeted treatments.

As outlined in Chapter 2, problem gambling is now considered a behavioural addiction and the substance-based addiction models may be a useful and applicable framework for investigating this disorder. Neurocognitive theories of substance-based addictions highlight the key involvement of the fronto-striatal networks in drug user's inability to control their addictive behaviour (Bechara, 2005; Jentsch & Taylor, 1999; Lubman, Yücel, & Pantelis, 2004). In particular, cognitive dysfunction in the prefrontal cortex results in a heightened ability of addictive cues to control behaviour, and poor inhibitory control and decision making. In my thesis, we have focused on *inhibitory control* and *decision making*.

In Chapters 4 and 5, I described our studies which investigated *inhibitory control* and *decision making* in problem gamblers. Whilst inhibitory control and decision making have been investigated previously in problem gambling, we have added new evidence to the body of literature by 1) examining the multi-faceted construct of impulsivity using a range of self-report scales and laboratory tasks, 2) examining decision making under conditions of both risk and ambiguity, and 3) investigating the underlying processes involved in choice behaviour using a cognitive modelling technique. Moreover, our studies have provided a unique contribution to the field by highlighting the striking cognitive differences in problem

gamblers subtyped according to preferred gambling form. Below I discuss our main findings and the contributions to the literature that have arisen from my thesis.

Chapter 4 described a study examining impulsivity and inhibitory control in problem gamblers. Impulsivity is considered a key feature of problem gambling and can be measured through various self-report questionnaires and laboratory inhibitory control tasks. Self-report impulsivity questionnaires measure stable personality characteristics of impulsivity (trait impulsivity). In contrast, inhibitory control tasks assess more momentary impulsive behaviour and are proposed to reflect the neural mechanisms underlying impulsivity. In this study, we used a multi-method approach combining a range of self-report impulsivity scales and laboratory inhibitory control tasks to examine the multi-faceted construct of impulsivity in problem gamblers. In addition, there is preliminary evidence that strategic problem gamblers have higher impulsivity levels than non-strategic problem gamblers. As such, we also examined whether self-reported impulsivity and inhibitory control differed between strategic and non-strategic problem gamblers.

As described in Chapter 4, we found that problem gamblers report high levels of trait impulsivity, however, contrary to some past literature, we *did not* find strong evidence for poor inhibitory control across any of the laboratory measures. Nevertheless, we did find large variability within our problem gambling sample on inhibitory control tasks, indicating heterogeneity in the impulsivity levels of problem gamblers. Furthermore, we found that problem gamblers' self-reported impulsivity was unrelated to their inhibitory control performances. This indicates that self-reported impulsivity questionnaires and laboratory inhibitory control tasks are tapping disparate aspects of impulsive behaviour in our problem gamblers. With regard to gambling subtypes, despite some reports that strategic problem gamblers have higher impulsivity levels than non-strategic problem gamblers, we found no differences between strategic and non-strategic problem gamblers on either impulsivity or

inhibitory control measures. Overall, our findings suggest that while impulsive traits are central to problem gambling, poor inhibitory control is not present in *all* problem gamblers. The unique contribution of this study is the multiple and varied impulsivity and inhibitory control measurement tools that we have used to examine different aspects of impulsivity in problem gambling. These included paradigms that, to our knowledge, have not been used in previous problem gambling studies and thereby enabled us to study different facets of impulsivity in this population.

Chapter 5 described a study of decision making in problem gamblers using the IGT and a loss aversion task, as well as a cognitive modelling procedure to explain IGT performance. Previous research indicates that problem gamblers make poor decisions. We, therefore, utilised two experimental paradigms and a cognitive model to uncover underlying factors involved in problem gamblers' poor decision making. In this study, we examined decision making in problem gamblers under conditions of both risk where explicit information is available (*Loss Aversion task)* and ambiguity where risk and reward information must be learnt over time (*IGT).*

As described in Chapter 5, we found that our overall problem gambling sample performed more poorly on both the IGT and the Loss Aversion task than controls. Moreover, in general, problem gamblers' IGT choices were associated with *greater* attention to the magnitude of gains and *less* choice consistency, according to our cognitive model. These findings indicate that problem gamblers have an inconsistent decision making style, however, during each choice they are paying more attention to the magnitude of gains. In addition to these overall group differences, our principal findings were the key decision making differences between subtypes of problem gamblers based on preferred gambling form. Strategic problem gamblers performed *comparably* to their controls on both the Loss Aversion task and the IGT, and demonstrated some learning during the IGT. Additionally,

strategic problem gamblers' IGT choices were associated with *greater* attention to gains, *more* sensitivity to losses and *less* consistency than their matched control group. In contrast, non-strategic problem gamblers performed *more poorly* than their matched controls on both the Loss Aversion task and the IGT, and demonstrated minimal learning across the IGT. Furthermore, non-strategic problem gamblers' IGT choices were associated with *less* sensitivity to losses than their matched control group. Together, these findings indicate that the decision making styles of strategic and non-strategic problem gamblers are underpinned by key differences in reward processing, ability to learn from feedback and risk-taking. This is the first reported study to employ cognitive modelling techniques to understand decision making in problem gamblers. Our findings have provided a unique contribution to the field by highlighting salient differences in decision making performances of problem gambling subtypes.

In summary, we found that problem gamblers demonstrate elevated trait impulsivity, but not inhibitory control impairments (Chapter 4). Moreover, we found disparity between aspects of impulsivity and measurement tools in problem gamblers, highlighting the multi-faceted construct of impulsivity, and heterogeneity in problem gamblers' impulsivity levels (Chapter 4). Using a cognitive modelling procedure for the first time in this population, we demonstrated that altered reward processing and choice inconsistency underlie poor decision making in problem gambling (Chapter 5). However, our key findings were that strategic and non-strategic problem gamblers demonstrate striking differences in decision making styles and processes, despite not differing in self-reported impulsivity or in tasks reflecting inhibitory control. Thus, our findings provide a novel contribution to the literature by highlighting the presence of heterogeneity in problem gamblers' cognitive functioning, and demonstrating important cognitive differences associated with subtypes of problem gambling based on preferred gambling form.

6.2. General Discussion and Implications

6.2.1. Implications for heterogeneity in problem gambling

Heterogeneity is now considered a key aspect of problem gambling with theoretical models incorporating different subtypes of problem gamblers (Blaszczynski & Nower, 2002; Sharpe, 2002). We used the criteria reported by Grant et al. (2012a) to subtype problem gamblers, based on their preferred gambling form, into strategic and non-strategic groups. Our findings have advanced our understanding of heterogeneity in problem gambling by demonstrating that different problem gambling subtypes are associated with distinct decision making differences, as well as potential similarities in impulsivity. However, there was also variability within these subtypes, indicating diversity in neurocognitive functioning. Using a cognitive modelling technique, we have provided rich, detailed information on the underlying cognitive and motivational processes involved in problem gamblers' decision making. Our findings have also highlighted how gender differences are intrinsically important to understanding problem gambling subtypes and their decision making patterns. Given the stark differences we found in decision making between strategic and non-strategic problem gamblers, our findings further support the categorisation of problem gambling subtypes based on preferred gambling form. These findings should be incorporated into theoretical models of problem gambling to provide a more detailed understanding of this heterogeneous disorder.

The decision making differences we found between strategic and non-strategic problem gamblers have implications for treatment. Very little research has examined whether subtypes of problem gamblers preferentially respond to certain treatments, although preliminary evidence suggests that preferred gambling form is not associated with treatment dropout from cognitive therapies (Milton, Crino, Hunt, & Prosser, 2002; Sylvain, Ladouceur, & Boisvert, 1997). In my thesis, we found that non-strategic problem gamblers demonstrated poor learning and less sensitivity to losses during decision making. This may indicate that

non-strategic problem gamblers difficulty in reducing their gambling behaviour is fuelled by an inability to recognise appropriate risk/reward information and poor ability to integrate past knowledge during new choices. Novel therapeutic techniques aimed at improving decision making may, therefore, be beneficial for non-strategic problem gamblers (see Treatment Implications and Future Directions section below). In contrast, strategic problem gamblers demonstrated altered reward processing and tendencies towards impulsive choices. Consequently, pharmacological agents that target reward processing networks (i.e., opioid antagonists) may be beneficial for strategic problem gamblers. One retrospective follow-up study has, however, reported that preferred gambling activity was *not* associated with problem gamblers response to the opioid antagonists naltrexone and nalmefene (Grant, Kim, Hollander, & Potenza, 2008), indicating the need for further research.

6.2.2. Implications for problem gambling as an addiction

Our findings that problem gamblers failed to demonstrate poor inhibitory control raises theoretical implications for understanding this disorder as a behavioural addiction. The presence of inhibitory control impairments in substance-based addictions is a key construct of the neurocognitive models of addiction (Bechara, 2005; Jentsch & Taylor, 1999; Lubman et al., 2004), and inhibitory control impairments are commonly reported in substance abuse (Feil et al., 2010; Verdejo-García, Perales, & Pérez-García, 2007). However, not all substance-based disorders have been associated with poor inhibitory control. Evidence is equivocal as to whether cannabis and ecstasy abusers demonstrate impaired inhibitory control (Griffith-Lendering, Huijbregts, Vollebergh, & Swaab, 2012; Hoshi et al., 2007; Lamers, Bechara, Rizzo, & Ramaekers, 2006; Murphy, Wareing, Fisk, & Montgomery, 2009; Quednow et al., 2007), suggesting that inhibitory control impairments may not *always* be a feature of substance-use disorders.

As discussed in Chapter 4, although we failed to find strong evidence of poor inhibitory control in our problem gamblers, this does not rule out the presence of inhibitory control impairments in *all* problem gamblers. Indeed, our problem gamblers demonstrated large variability on inhibitory control tasks suggesting that inhibitory control may be important for some problem gamblers. Additionally, subtypes of problem gamblers have been proposed in which impulsivity is not a key aspect, for example, the Behaviourally Conditioned Problem Gamblers in Blaszczynski and Nower's (2002) pathways model, and Cluster One Problem Gamblers in Lesieur's (2001) subtypes. The presence of some of these subtypes in our sample may have contributed to the variability in inhibitory control performances. Furthermore, Billieux and colleagues (2012) recently demonstrated vast individual variability in problem gamblers on self-report and laboratory impulsivity tasks. They found that some problem gamblers performed normally on impulsivity measures, some demonstrated specific deficits, and others demonstrated global impulsivity deficits (Billieux et al., 2012). Our findings, as well as past research, support the idea that impulsivity may not be a central feature for *all* problem gamblers and there may be subtypes of problem gamblers with no inhibitory control deficits.

6.2.3. Implications for the neural mechanisms associated with problem gambling

Our findings imply that the neural networks associated with decision making, but not necessarily those associated with inhibitory control, may be dysfunctional in problem gamblers. In healthy populations, decision making during the IGT has been associated with fMRI activation in the VMPFC (Lawrence, Jollant, O'Daly, Zelaya, & Phillips, 2009), ventral striatum, insula, posterior cingulate cortex, anterior cingulate and supplementary motor area (Li, Lu, D'Argembeau, Ng, & Bechara, 2010; Lin, Chiu, Cheng, & Hsieh, 2008). Similarly, during a loss aversion task, increasing gains are associated with increased activation in the dorsal and ventral striatum, VMPFC, VLPFC, ACC, and dopaminergic midbrain regions

(Tom, Fox, Trepel, & Poldrack, 2007). Conversely, increasing losses are associated with decreased activation in the ventral striatum, VMPFC, ventral ACC and medial OFC (Tom et al., 2007). Our findings indirectly suggest that poor decision making in problem gamblers may be associated with alterations in the prefrontal cortex and/or subcortical regions. Indeed, problem gamblers have displayed reduced VMPFC activation during rewards and risky decision making (Balodis et al., 2012; Reuter et al., 2005; Tanabe et al., 2007). In contrast, problem gamblers have demonstrated enhanced neural activation in subcortical regions including the ventral striatum, and substantia nigra/ventral tegmental area during impulsive decision making (Miedl, Peters, & Büchel, 2012). Given our findings that problem gamblers' decision making is generally associated with altered reward processing and less consistency, future research on the neural mechanisms of gains and losses processing and consistency during different decision making conditions in problem gamblers is warranted.

Interestingly, it is as yet unknown whether strategic and non-strategic problem gamblers differ in patterns of neural activation during decision making. We found that non-strategic problem gamblers performed more poorly on the Loss Aversion task than their matched controls. The amygdala, which is involved in emotional processing, has been reported to be crucial for accurately experiencing loss aversion during a similar loss aversion task (De Martino et al., 2010). Furthermore, evidence suggests that non-strategic problem gamblers may gamble as an emotional escape from feelings of worry or depression (Holdsworth et al., 2012; Stewart & Zack, 2008). Together, these findings suggest that non-strategic problem gamblers may demonstrate alterations in brain regions involved in decision making and emotional processing. Past research has demonstrated heightened amygdala activation in problem gamblers whilst viewing gambling pictures, which are a type of emotional stimulus, but differences between problem gambling subtypes were not examined (Goudriaan, de Ruiter, van den Brink, Oosterlaan, & Veltman, 2010). We suggest that the

amygdala may be a region of interest for future research into understanding poor decision making in non-strategic problem gamblers. Furthermore, our finding that strategic and non-strategic problem gamblers demonstrate different decision making styles highlights the importance of using problem gambler subtypes to explore the neural mechanisms associated with decision making in this disorder.

6.3. Treatment Implications and Future Directions

In Australia, primarily psychological treatment options are available for problem gambling. Although several treatments demonstrate efficacy over the short term (Cowlishaw et al., 2012), relapse rates are high (Hodgins & el-Guebaly, 2004; Ledgerwood & Petry, 2006) and long-term effectiveness is not well known (Cowlishaw et al., 2012). Our findings, along with past research, support the view that altered cognitive processes are a key aspect of problem gambling. New therapeutic techniques that target cognitive functioning, therefore, may be viable and effective treatment options. In this section, I discuss potential novel treatments for problem gambling associated with the main findings from my thesis.

Non-invasive brain stimulation techniques including transcranial magnetic stimulation (TMS) and transcranial direct current stimulation (tDCS) are promising methods for altering cognitive functioning including decision making and risk-taking behaviour. In healthy individuals, repetitive TMS over the right DLPFC is associated with longer reaction times during a strategic decision making task (van 't Wout, Kahn, Sanfey, & Aleman, 2005), and riskier choices on a risky decision making task (Knoch et al., 2006). In contrast, Fecteau et al. (2007) found that bilateral tDCS over the DLPFC resulted in a risk-averse response style during the Balloon Analogue Risk Task. Similarly, Hecht, Walsh, and Lavidor (2010) found that anodal tDCS (positive stimulation) to left DLPFC and cathodal tDCS (negative stimulation) to right DLPFC were associated with faster optimal responses on a probabilistic

decision making task. These findings provide preliminary evidence that TMS and tDCS may alter decision making and therefore could be a therapeutic option for improving problem gamblers' decision making. However, the DLPFC was targeted in these studies rather than the VMPFC which is more strongly associated with decision making, and evidence for TMS altering decision making in clinical populations is lacking. Furthermore, the effects of TMS may only be short-lived and therefore may not be able to produce long lasting changes in problem gamblers' poor decision making. However, repetitive TMS over the DLPFC has reduced craving in cigarette (Amiaz, Levy, Vainiger, Grunhaus, & Zangen, 2009), cocaine (Camprodon, Martínez-Raga, Alonso-Alonso, Shih, & Pascual-Leone, 2007), and alcohol dependence (Mishra, Nizamie, Das, & Praharaj, 2010). These findings suggest that TMS may also be able to reduce gambling craving which is a symptom strongly associated with relapse in problem gamblers (Hodgins & el-Guebaly, 2004; Ledgerwood & Petry, 2006).

Cognitive training techniques are another therapeutic option for improving decision making in problem gamblers. In healthy populations, greater metacognitive awareness (i.e., awareness of cognitive and thinking processes) is associated with improved decision making performance, and learning metacognitive strategies is beneficial for poor decision makers but not average or above-average decision makers (Batha & Carroll, 2007). In problem gamblers, metacognitive strategies may improve insight into poor decision making, as there is evidence that training in metacognitive awareness has increased insight in other disorders such as schizophrenia (Favrod, Maire, Bardy, Pernier, & Bonsack, 2011). Additionally, McCaig, Dixon, Keramatian, Liu, and Christoff (2011) demonstrated that healthy individuals are able to control fMRI activation levels in the rostrolateral prefrontal cortex using metacognitive awareness strategies. These findings suggest that problem gamblers may be able to use meta-cognitive training to potentially alter neural activations in regions associated with decision making which may lead to improved decision making.

Computerised cognitive training programs are another approach to improving decision making and other executive functions. The Goal Management Training program, which targets planning and organisation, has been associated with executive functioning improvements in older adults (Levine et al., 2007), people with frontal lobe damage (Levine et al., 2011) and people with spina bifida (Stubberud, Langenbahn, Levine, Stanghelle, & Schanke, 2013). Of particular relevance to our findings is evidence that the Goal Management Training program, in combination with mindfulness meditation, improved performances on the IGT and the Stroop task in polysubstance abusers (Alfonso, Caracuel, Delgado-Pastor, & Verdejo-García, 2011). Nevertheless, improvements on computerised cognitive training programs may not generalise to everyday situations (Grant, Ponsford, & Bennett, 2012c), and therefore is an area that needs further development.

Similar to computerised training programs, training on a particular cognitive task may be able to influence performance on a different cognitive skill. For example, Bickel, Yi, Landes, Hill, and Baxter (2011) reported that performing a working memory task decreases impulsive decision making among stimulant addicts. Similarly, Verbruggen, Adams, and Chambers (2012) found that training on a response inhibition task reduced risk taking during decision making for up to two hours. Following response inhibition training, participants took longer to select choices and chose lower monetary amounts with higher probabilities of winning. However, in a subsequent study, this effect disappeared when the delay between response inhibition training and decision making was extended to 24 hours, despite increased training (Verbruggen et al., 2013). Taken together, these different approaches to cognitive training provide preliminary evidence that problem gamblers' poor decision making could be altered or ameliorated; however, further research is required.

Finally, several pharmacotherapies have improved cognitive skills (e.g., sustained attention, working memory and response inhibition) in substance users (see Sofuoglu,

DeVito, Waters, & Carroll, 2013 for a review), and therefore may modify decision making in problem gamblers. In problem gamblers with high self-reported impulsivity, modafinil, an atypical stimulant, has been found to reduce motivation to gamble, decrease salience of gambling words, reduce risky decision making on the IGT and improve inhibitory control on the SST (Zack & Poulos, 2009). Conversely, the opposite effects were seen in problem gamblers with low self-reported impulsivity. These findings further highlight the heterogeneity in impulsivity levels of problem gamblers, and support our findings that impulsivity may not be central for *all* problem gamblers. Furthermore, naltrexone, which is an opioid antagonist, has demonstrated efficacy in reducing problem gambling symptoms (Crockford & El-Guebaly, 1998; Grant, Kim, & Hartman, 2008; Kim, Grant, Adson, & Shin, 2001). Naltrexone may also alter decision making given evidence that during an impulsive decision making task acute naltrexone administration in alcoholics increases activation in the OFC, which is an area strongly associated with decision making (Boettiger, Kelley, Mitchell, D'Esposito, & Fields, 2009). In addition, alcoholics with a low locus of control demonstrate more impulsive choices following naltrexone administration, whereas alcoholics with a high locus of control make fewer impulsive choices (Mitchell, Tavares, Fields, D'Esposito, & Boettiger, 2007). These findings suggest that naltrexone has a bi-directional effect based on individual characteristics. Collectively, pharmacological agents are promising treatments for altering cognitive functioning in problem gambling. However, given the evidence that the effectiveness of pharmacotherapies appear to be altered by individual factors, pharmacological agents may need to be targeted individually.

6.4. Limitations

Our findings must be considered in light of several limitations. Firstly, although we chose our sample size to be comparable to past research (Goudriaan, Oosterlaan, de Beurs, &

van den Brink, 2006; Grant et al., 2012a; Ledgerwood et al., 2012; Roca et al., 2008), our sample size was relatively small (n =39) and may have limited the statistical power available to detect significant differences between key group comparisons. As discussed in Chapter 4, our sample size may have been associated with our non-significant findings between problem gamblers and controls on the inhibitory control tasks. In this regard, we acknowledge that retrospective power analysis for this study demonstrated only a 39% chance of detecting a significant difference for the SST. Given that we also found large variability in inhibitory control performances within the problem gambling sample, future studies may require larger sample sizes to detect any possible group differences.

An additional limitation was the inclusion of problem gamblers with comorbid mental health issues. As problem gambling is a highly comorbid disorder (see Lorains et al., 2011 for a review), the inclusion of problem gamblers with comorbid disorders suggests our findings are more readily generalised to the wider problem gambling population. However, the presence of comorbid disorders in our problem gambling sample may have influenced our results. Commonly present comorbid disorders in problem gambling (e.g., depression and substance-use disorders) have been associated with poor decision making and inhibitory control (Bechara & Damasio, 2002; Feil et al., 2010; Grant, Contoreggi, & London, 2000; Kaiser et al., 2003; Stout, Rock, Campbell, Busemeyer, & Finn, 2005). Nonetheless, when we directly examined the relationship of comorbid disorders in our problem gambling sample by conducting additional analysis examining depression, the most common comorbid condition in our sample (see Chapter 5), we did not find that it was associated with problem gamblers' decision making. This suggested that the presence of comorbid disorders in our problem gambling sample may not have contributed to our main findings in this study. We also acknowledge that our control group reported more total years of education than the problem

gamblers which may have influenced our results; however, importantly the groups did not differ on estimated-IQ.

Lastly, the method we adopted to subtype problem gamblers could also be a limitation. We used Grant and colleagues' (2012a) criteria to categorise problem gamblers into subtypes based on preferred gambling form. Although we found prominent decision making differences in subgroups determined using this method, Grant and colleagues' (2012a) criteria are not yet empirically validated and other approaches to subtyping may be at least as useful. In particular, emerging evidence supports Blaszczynski and Nower's (2002) three pathways to problem gambling (Ledgerwood & Petry, 2010; Milosevic & Ledgerwood, 2010). Blaszczynski and Nower's (2002) pathways model differentiates problem gamblers based on personality traits, coping strategies, biological vulnerabilities and environmental factors. This method may provide a more rich and detailed description of characteristics associated with the problem gambling subtypes (Blaszczynski & Nower, 2002). Whilst there is not yet strong evidence for the clinical variables associated with strategic and non-strategic problem gamblers categorised according to Grant and colleagues' (2012a) criteria. One challenge, however, in using Blaszczynski and Nower's three subtypes, is that they may not be mutually exclusive and thus lead to difficulties in categorising participants (Ledgerwood & Petry, 2010; Milosevic & Ledgerwood, 2010). Moreover, to date there is no reliable assessment tool available to categorise problem gamblers into subtypes, and further research is required to empirically validate subtypes. Despite these limitations, the studies in my thesis have several important strengths, including the use of carefully matched groups, well validated self-reported and neuropsychological measures, and a novel combination of experimental tasks and data analysis procedures.

6.5. Conclusion

The overall aim of the research presented in my thesis was to examine *inhibitory control* and *decision making* in a sample of treatment-seeking problem gamblers, and to investigate whether these cognitive skills differed between strategic and non-strategic problem gamblers. Our findings provide evidence that problem gamblers may not demonstrate poor inhibitory control, despite elevated self-reported impulsivity levels. Furthermore, using a cognitive modelling approach, we demonstrated that problem gamblers' choices on the IGT are associated with altered reward processing through *greater* attention to gains and *less* choice consistency. However, our most novel findings were the key differences between strategic and non-strategic problem gamblers in decision making styles, and the cognitive, motivational and response style factors associated with their choice behaviour. The findings from my thesis provide a unique contribution to the body of literature by outlining the presence of heterogeneity in the problem gambling population, as well as providing further evidence of distinct subtypes of problem gamblers. These findings will ultimately inform the development of targeted treatments for problem gambling that are specific to the variable patterns of clinical characteristics occurring in this complex heterogeneous disorder.

REFERENCES

ABS. (2009). *Australian National Accounts: National Income, Expenditure and Product*. Canberra: Australian Government.

Ahn, W.-Y., Busemeyer, J.R., Wagenmakers, E.-J., & Stout, J.C. (2008). Comparison of decision learning models uing the generalization criterion method. *Cognitive Science, 32*(8), 1376-1402.

Alfonso, J.P., Caracuel, A., Delgado-Pastor, L.C., & Verdejo-García, A. (2011). Combined goal management training and mindfulness meditation improve executive functions and decision-making performance in abstinent polysubstance abusers. *Drug and Alcohol Dependence, 117*(1), 78-81.

Algom, D., Chajut, E., & Lev, S. (2004). A rational look at the emotional stroop phenomenon: A generic slowdown, not a stroop effect. *Journal of Experimental Psychology: General, 133*(3), 323-338.

American Psychiatric Association (APA). (1980). *Diagnostic and Statistical Manual of Mental Disorders (DSM-III)*. Washington: American Psychiatric Association.

American Psychiatric Association (APA). (2000). *Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR)*. Washington, DC: APA.

American Psychiatric Association (APA). (2013). *Diagnostic and Statistical Manual of Mental Disorders (DSM-5)*: American Psychiatric Publishing.

Amiaz, R., Levy, D., Vainiger, D., Grunhaus, L., & Zangen, A. (2009). Repeated high-frequency transcranial magnetic stimulation over the dorsolateral prefrontal cortex reduces cigarette craving and consumption. *Addiction, 104*(4), 653-660.

Antony, M.M., Bieling, P.J., Cox, B.J., Enns, M.W., & Swinson, R.P. (1998). Psychometric properties of the 42-item and 21-item versions of the Depression Anxiety Stress Scales in clinical groups and a community sample. *Psychological Assessment, 10*(2), 176-181.

Aron, A.R., Behrens, T.E., Smith, S., Frank, M.J., & Poldrack, R.A. (2007a). Triangulating a cognitive control network using diffusion-weighted magnetic resonance imaging (MRI) and functional MRI. *Journal of Neuroscience, 27*(14), 3743-3752.

Aron, A.R., Durston, S., Eagle, D.M., Logan, G.D., Stinear, C.M., & Stuphorn, V. (2007b). Converging evidence for a fronto-basal-ganglia network for inhibitory control of action and cognition. *The Journal of Neuroscience, 27*(44), 11860-11864.

Aron, A.R., Fletcher, P.C., Bullmore, E.T., Sahakian, B.J., & Robbins, T.W. (2003). Stop-signal inhibition disrupted by damage to right inferior frontal gyrus in humans. *Nature Neuroscience, 6*(2), 115-116.

Aron, A.R., Robbins, T.W., & Poldrack, R.A. (2004). Inhibition and the right inferior frontal cortex. *Trends in Cognitive Sciences, 8*(4), 170-177.

Australian Productivity Commission. (1999). *Australia's Gambling Industries*. AusInfo, Canberra.

Bagby, R.M., Vachon, D.D., Bulmash, E., & Quilty, L.C. (2008). Personality disorders and pathological gambling: A review and re-examination of prevalence rates. *Journal of Personality Disorders, 22*(2), 191-207.

Balodis, I.M., Kober, H., Worhunsky, P.D., Stevens, M.C., Pearlson, G.D., & Potenza, M.N. (2012). Diminished frontostriatal activity during processing of monetary rewards and losses in pathological gambling. *Biological Psychiatry, 71*(8), 749-757.

Balota, D.A., Yap, M.J., Cortese, M.J., Hutchison, K.A., Kessler, B., Loftis, B., Neely, J.H., Nelson, D.L., Simpson, G.B., & Treiman, R. (2007). The english lexicon project. *Behavior Research Methods, 39*, 445-459.

Batha, K., & Carroll, M. (2007). Metacognitive training aids decision making. *Australian Journal of Psychology, 59*(2), 64-69.

Battersby, M., Tolchard, B., Scurrah, M., & Thomas, L. (2006). Suicide ideation and behaviour in people with pathological gambling attending a treatment service. *International Journal of Mental Health and Addiction, 4*(3), 233-246.

Bechara, A. (2005). Decision making, impulse control and loss of willpower to resist drugs: A neurocognitive perspective. *Nature Neuroscience, 8*(11), 1458-1463.

Bechara, A., Damasio, A.R., Damasio, H., & Anderson, S.W. (1994). Insensitivity to future consequences following damage to human prefrontal cortex. *Cognition, 50*(1-3), 7-15.

Bechara, A., & Damasio, H. (2002). Decision-making and addiction (part I): Impaired activation of somatic states in substance dependent individuals when pondering decisions with negative future consequences. *Neuropsychologia, 40*(10), 1675-1689.

Bickel, W.K., Yi, R., Landes, R.D., Hill, P.F., & Baxter, C. (2011). Remember the future: Working memory training decreases delay discounting among stimulant addicts. *Biological Psychiatry, 69*(3), 260-265.

Billieux, J., Lagrange, G., Van der Linden, M., Lançon, C., Adida, M., & Jeanningros, R. (2012). Investigation of impulsivity in a sample of treatment-seeking pathological gamblers: A multidimensional perspective. *Psychiatry Research, 198*(2), 291-296.

Black, D.W., Monahan, P.O., Temkit, M.H., & Shaw, M. (2006). A family study of pathological gambling. *Psychiatry Research, 141*(3), 295-303.

Blanco, C., Hasin, D.S., Petry, N., Stinson, F.S., & Grant, B.F. (2006). Sex differences in subclinical and DSM-IV pathological gambling: Results from the National Epidemiologic Survey on Alcohol and Related Conditions. *Psychological Medicine, 36*(7), 943-953.

Blasi, G., Goldberg, T.E., Weickert, T., Das, S., Kohn, P., Zoltick, B., Bertolino, A., Callicott, J.H., Weinberger, D.R., & Mattay, V.S. (2006). Brain regions underlying response inhibition and interference monitoring and suppression. *European Journal of Neuroscience, 23*(6), 1658-1664.

Blaszczynski, A., & Nower, L. (2002). A pathways model of problem and pathological gambling. *Addiction, 97*(5), 487-499.

Blaszczynski, A., Walker, M., Sharpe, L., & Nower, L. (2008). Withdrawal and tolerance phenomenon in problem gambling. *International Gambling Studies, 8*(2), 179-192.

Boettiger, C.A., Kelley, E.A., Mitchell, J.M., D'Esposito, M., & Fields, H.L. (2009). Now or later? An fMRI study of the effects of endogenous opioid blockade on a decision-making network. *Pharmacology, Biochemistry and Behavior, 93*(3), 291-299.

Bohn, M.J., Krahn, D.D., & Staehler, B.A. (1995). Development and initial validation of a measure of drinking urges in abstinent alcoholics. *Alcoholism: Clinical and Experimental Research, 19*(3), 600-606.

Breen, R.B., & Zuckerman, M. (1999). 'Chasing' in gambling behavior: Personality and cognitive determinants. *Personality and Individual Differences, 27*(6), 1097-1111.

Brewer, J.A., & Potenza, M.N. (2008). The neurobiology and genetics of impulse control disorders: Relationships to drug addictions. *Biochemical Pharmacology, 75*(1), 63-75.

Brown, T.A., Chorpita, B.F., Korotitsch, W., & Barlow, D.H. (1997). Psychometric properties of the Depression Anxiety Stress Scales (DASS) in clinical samples. *Behaviour Research and Therapy, 35*(1), 79-89.

Camprodon, J.A., Martínez-Raga, J., Alonso-Alonso, M., Shih, M.-C., & Pascual-Leone, A. (2007). One session of high frequency repetitive transcranial magnetic stimulation (rTMS) to the right prefrontal cortex transiently reduces cocaine craving. *Drug and Alcohol Dependence, 86*(1), 91-94.

Chambers, C.D., Bellgrove, M.A., Gould, I.C., English, T., Garavan, H., McNaught, E., Kamke, M., & Mattingley, J.B. (2007). Dissociable mechanisms of cognitive control in prefrontal and premotor cortex. *Journal of Neurophysiology, 98*(6), 3638-3647.

Chambers, C.D., Bellgrove, M.A., Stokes, M.G., Henderson, T.R., Garavan, H., Robertson, I.H., Morris, A.P., & Mattingley, J.B. (2006). Executive "brake failure" following deactivation of human frontal lobe. *Journal of Cognitive Neuroscience, 18*(3), 444-455.

Chambers, C.D., Garavan, H., & Bellgrove, M.A. (2009). Insights into the neural basis of response inhibition from cognitive and clinical neuroscience. *Neuroscience and Biobehavioral Reviews, 33*(5), 631-646.

Compton, R.J., Banich, M.T., Mohanty, A., Milham, M.P., Herrington, J., Miller, G.A., Scalf, P.E., Webb, A., & Heller, W. (2003). Paying attention to emotion: An fMRI investigation of cognitive and emotional stroop tasks. *Cognitive, Affective, & Behavioral Neuroscience, 3*(2), 81-96.

Cowlishaw, S., Merkouris, S., Dowling, N., Anderson, C., Jackson, A., & Thomas, S. (2012). Psychological therapies for pathological and problem gambling. *Cochrane Database of Systetmatic Reviews, 11*, CD008937.

Cox, W.M., Fadardi, J.S., & Pothos, E.M. (2006). The addiction-stroop test: Theoretical considerations and procedural recommendations. *Psychological Bulletin, 132*(3), 443-476.

Crockford, D.N., & El-Guebaly, N. (1998). Naltrexone in the treatment of pathological gambling and alcohol dependence. *Canadian Journal of Psychiatry. Revue Canadienne de Psychiatrie, 43*(1), 86.

Cunningham-Williams, R.M., Gattis, M.N., Dore, P.M., Shi, P., & Spitznagel, E.L. (2009). Towards DSM-V: Considering other withdrawal-like symptoms of pathological gambling disorder. *International Journal of Methods in Psychiatric Research, 18*(1), 13-22.

Dannon, P.N., Lowengrub, K., Shalgi, B., Sasson, M., Tuson, L., Saphir, Y., & Kotler, M. (2006). Dual psychiatric diagnosis and substance abuse in pathological gamblers. *Journal of Addictive Diseases, 25*(3), 49-54.

De Castella, A., Bolding, P., Lee, A., Cosic, S., & Kulkarni, J. (2011). *Problem Gambling in People Presenting to a Public Mental Health Service*. Victoria, Australia: Office of Gaming and Racing, Department of Justice.

De Martino, B., Camerer, C.F., & Adolphs, R. (2010). Amygdala damage eliminates monetary loss aversion. *Proceedings of the National Academy of Sciences of the United States of America, 107*(8), 3788-3792.

Delfabbro, P. (2000). Gender differences in Australian gambling: A critical summary of sociological and psychological research. *Australian Journal of Social Issues, 35,* 145-158

Delfabbro, P. (2011). Australasian Gambling Review (1992-2011) (5th ed.): Independent Gambling Authority of South Australia.

Delfabbro, P., & King, D. (2012). Gambling in Australia: Experiences, problems, research and policy. *Addiction, 107*(9), 1556-1561.

Desai, R.A., & Potenza, M.N. (2008). Gender differences in the associations between past-year gambling problems and psychiatric disorders. *Social Psychiatry and Psychiatric Epidemiology, 43*(3), 173-183.

Dickerson, M., Baron, E., Hong, S.-M., & Cottrell, D. (1996). Estimating the extent and degree of gambling related problems in the australian population: A national survey. *Journal of Gambling Studies, 12*(2), 161-178.

Dillon, D.G., & Pizzagalli, D.A. (2007). Inhibition of action, thought, and emotion: A selective neurobiological review. *Applied and Preventive Psychology, 12*(3), 99-114.

Echeburua, E., Gonzalez-Ortega, I., de Corral, P., & Polo-Lopez, R. (2011). Clinical gender differences among adult pathological gamblers seeking treatment. *Journal of Gambling Studies, 27*(2), 215-227.

Enticott, P.G., Bradshaw, J.L., Bellgrove, M.A., Upton, D.J., & Ogloff, J.R.P. (2009). Stop task after-effects: The extent of slowing during the preparation and execution of movement. *Experimental Psychology, 56*(4), 247-251.

Fassbender, C., Murphy, K., Foxe, J.J., Wylie, G.R., Javitt, D.C., Robertson, I.H., & Garavan, H. (2004). A topography of executive functions and their interactions revealed by functional magnetic resonance imaging. *Cognitive Brain Research, 20*(2), 132-143.

Fassbender, C., Simoes-Franklin, C., Murphy, K., Hester, R., Meaney, J., Robertson, I.H., & Garavan, H. (2006). The role of a right fronto-parietal network in cognitive control: Common activations for "cues-to-attend" and response inhibition. *Journal of Psychophysiology, 20*(4), 286-296.

Favrod, J., Maire, A., Bardy, S., Pernier, S., & Bonsack, C. (2011). Improving insight into delusions: A pilot study of metacognitive training for patients with schizophrenia. *Journal of Advanced Nursing, 67*(2), 401-407.

Fecteau, S., Pascual-Leone, A., Zald, D.H., Liguori, P., Théoret, H., Boggio, P.S., & Fregni, F. (2007). Activation of prefrontal cortex by transcranial direct current stimulation

reduces appetite for risk during ambiguous decision making. *The Journal of Neuroscience, 27*(23), 6212-6218.

Feil, J., Sheppard, D., Fitzgerald, P.B., Yücel, M., Lubman, D.I., & Bradshaw, J.L. (2010). Addiction, compulsive drug seeking, and the role of frontostriatal mechanisms in regulating inhibitory control. *Neuroscience and Biobehavioral Reviews, 35*(2), 248-275.

Ferris, J., & Wynne, H. (2001). The Canadian Problem Gambling Index: Final Report: Canadian Centre on Substance Abuse (CCSA).

Field, M., & Cox, W.M. (2008). Attentional bias in addictive behaviors: A review of its development, causes, and consequences. *Drug and Alcohol Dependence, 97*(1-2), 1-20.

Fuentes, D., Tavares, H., Artes, R., & Gorenstein, C. (2006). Self-reported and neuropsychological measures of impulsivity in pathological gambling. *Journal of the International Neuropsychological Society, 12*(6), 907-912.

Garavan, H., Hester, R., Murphy, K., Fassbender, C., & Kelly, C. (2006). Individual differences in the functional neuroanatomy of inhibitory control. *Brain Research, 1105*(1), 130-142.

Garavan, H., Ross, T.J., Murphy, K., Roche, R.A.P., & Stein, E.A. (2002). Dissociable executive functions in the dynamic control of behavior: Inhibition, error detection, and correction. *Neuroimage, 17*(4), 1820-1829.

Gerstein, D., Hoffmann, J., Larison, C., Laszlo, E., Murphy, S., Palmer, A., Chuchro, L., Toce, M., Johnson, R., Buie, T., Hill, M.A., Volberg, R.A., Harwood, H., Tucker, A., Christiansen, E., Cummings, W., & Sinclair, S. (1999). Gambling Impact and Behavior Study: Report to the National Gambling Impact Study Commission. Chicago: National Opinion Research Center at the University of Chicago.

Goldstein, R.Z., & Volkow, N.D. (2011). Dysfunction of the prefrontal cortex in addiction: Neuroimaging findings and clinical implications. *Nature Reviews Neuroscience, 12*(11), 652-669.

Goudriaan, A.E., de Ruiter, M.B., van den Brink, W., Oosterlaan, J., & Veltman, D.J. (2010). Brain activation patterns associated with cue reactivity and craving in abstinent problem gamblers, heavy smokers and healthy controls: An fMRI study. *Addiction Biology, 15*(4), 491-503.

Goudriaan, A.E., Oosterlaan, J., de Beurs, E., & van den Brink, W. (2006). Neurocognitive functions in pathological gambling: A comparison with alcohol dependence, tourette syndrome and normal controls. *Addiction, 101*(4), 534-547.

Grant, J.E., & Kim, S.W. (2002). Gender differences in pathological gamblers seeking medication treatment. *Comprehensive Psychiatry, 43*(1), 56-62.

Grant, J.E., & Kim, S.W. (2005). Quality of life in kleptomania and pathological gambling. *Comprehensive Psychiatry, 46*(1), 34-37.

Grant, J.E., Kim, S.W., & Hartman, B.K. (2008). A double-blind, placebo-controlled study of the opiate antagonist naltrexone in the treatment of pathological gambling urges. *Journal of Clinical Psychiatry, 69*(5), 783-789.

Grant, J.E., Kim, S.W., Hollander, E., & Potenza, M.N. (2008). Predicting response to opiate antagonists and placebo in the treatment of pathological gambling. *Psychopharmacology, 200*(4), 521-527.

Grant, J.E., Odlaug, B.L., Chamberlain, S.R., & Schreiber, L.R.N. (2012a). Neurocognitive dysfunction in strategic and non-strategic gamblers. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 38*(2), 336-340.

Grant, J.E., Odlaug, B.L., & Mooney, M.E. (2012b). Telescoping phenomenon in pathological gambling: Association with gender and comorbidities. *The Journal of Nervous and Mental Disease, 200*(11), 996-998.

Grant, M., Ponsford, J., & Bennett, P.C. (2012c). The application of goal management training to aspects of financial management in individuals with traumatic brain injury. *Neuropsychological Rehabilitation, 22*(6), 852-873.

Grant, S., Contoreggi, C., & London, E.D. (2000). Drug abusers show impaired performance in a laboratory test of decision making. *Neuropsychologia, 38*(8), 1180-1187.

Griffith-Lendering, M.F., Huijbregts, S.C., Vollebergh, W.A., & Swaab, H. (2012). Motivational and cognitive inhibitory control in recreational cannabis users. *Journal of Clinical and Experimental Neuropsychology, 34*(7), 688-697.

Gupta, R., & Derevensky, J. (1998). Adolescent gambling behavior: A prevalence study and examination of the correlates associated with problem gambling. *Journal of Gambling Studies, 14*(4), 319-345.

Hare, S. (2009). A Study of Gambling in Victoria: Problem gambling from a Public Health Perspective. Victoria, Australia: Department of Justice.

Hecht, D., Walsh, V., & Lavidor, M. (2010). Transcranial direct current stimulation facilitates decision making in a probabilistic guessing task. *The Journal of Neuroscience, 30*(12), 4241-4245.

Heinrichs, R.W., & Zakzanis, K.K. (1998). Neurocognitive deficit in schizophrenia: A quantitative review of the evidence. *Neuropsychology, 12*(3), 426-445.

Henry, J.D., & Crawford, J.R. (2005). The short-form version of the Depression Anxiety Stress Scales (DASS-21): Construct validity and normative data in a large non-clinical sample. *British Journal of Clinical Psychology, 44*(2), 227-239.

Hester, R., & Garavan, H. (2005). Working memory and executive function: The influence of content and load on the control of attention. *Memory and Cognition, 33*(2), 221-233.

Hodgins, D.C., & El-Guebaly, N. (2000). Natural and treatment-assisted recovery from gambling problems: A comparison of resolved and active gamblers. *Addiction, 95*(5), 777-789.

Hodgins, D.C., & el-Guebaly, N. (2004). Retrospective and prospective reports of precipitants to relapse in pathological gambling. *Journal of Consulting and Clinical Psychology, 72*(1), 72-80.

Hodgins, D.C., Shead, N.W., & Makarchuk, K. (2007). Relationship satisfaction and psychological distress among concerned significant others of pathological gamblers. *The Journal of Nervous and Mental Disease, 195*(1), 65-71.

Holdsworth, L., Hing, N., & Breen, H. (2012). Exploring women's problem gambling: A review of the literature. *International Gambling Studies, 12*(2), 199-213.

Holtgraves, T. (2009). Evaluating the Problem Gambling Severity Index. *Journal of Gambling Studies, 25*(1), 105-120.

Hoshi, R., Mullins, K., Boundy, C., Brignell, C., Piccini, P., & Curran, H.V. (2007). Neurocognitive function in current and ex-users of ecstasy in comparison to both matched polydrug-using controls and drug-naïve controls. *Psychopharmacology, 194*(3), 371-379.

Ibanez, A., Blanco, C., Donahue, E., Lesieur, H.R., Perez de Castro, I., Fernandez-Piqueras, J., & Saiz-Ruiz, J. (2001). Psychiatric comorbidity in pathological gamblers seeking treatment. *American Journal of Psychiatry, 158*(10), 1733-1735.

Ibáñez, A., Blanco, C., Moreryra, P., & Sáiz-Ruiz, J. (2003). Gender differences in pathological gambling. *The Journal of clinical psychiatry, 64*(3), 295-301.

Jahanshahi, M., & Dirnberger, G. (1998). The left dorsolateral prefrontal cortex and random generation of responses: Studies with transcranial magnetic stimulation. *Neuropsychologia, 37*(2), 181-190.

Jentsch, J.D., & Taylor, J.R. (1999). Impulsivity resulting from frontostriatal dysfunction in drug abuse: Implications for the control of behavior by reward-related stimuli. *Psychopharmacology, 146*(4), 373-390.

Joppich, G., Däuper, J., Dengler, R., Johannes, S., Rodriguez-Fornells, A., & Münte, T.F. (2004). Brain potentials index executive functions during random number generation. *Neuroscience Research, 49*(2), 157-164.

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

Kaiser, S., Unger, J., Kiefer, M., Markela, J., Mundt, C., & Weisbrod, M. (2003). Executive control deficit in depression: Event-related potentials in a go/nogo task. *Psychiatry Research: Neuroimaging, 122*(3), 169-184.

Kalischuk, R.G., Nowatzki, N., Cardwell, K., Klein, K., & Solowoniuk, J. (2006). Problem gambling and its impact on families: A literature review. *International Gambling Studies, 6*(1), 31-60.

Kessler, R.C., Berglund, P., Demler, O., Jin, R., Merikangas, K.R., & Walters, E.E. (2005). Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the national comorbidity survey replication. *Archives of General Psychiatry, 62*(6), 593-602.

Kessler, R.C., Hwang, I., LaBrie, R., Petukhova, M., Sampson, N.A., Winters, K.C., & Shaffer, H.J. (2008). DSM-IV pathological gambling in the national comorbidity survey replication. *Psychological Medicine, 38*(9), 1351-1360.

Kim, S.W., Grant, J.E., Adson, D.E., & Shin, Y.C. (2001). Double-blind naltrexone and placebo comparison study in the treatment of pathological gambling. *Biological Psychiatry, 49*, 914-921.

Kim, S.W., Grant, J.E., Eckert, E.D., Faris, P.L., & Hartman, B.K. (2006). Pathological gambling and mood disorders: Clinical associations and treatment implications. *Journal of Affective Disorders, 92*(1), 109-116.

Knoch, D., Brugger, P., & Regard, M. (2005). Suppressing versus releasing a habit: Frequency-dependent effects of prefrontal transcranial magnetic stimulation. *Cerebral Cortex, 15*(7), 885-887.

Knoch, D., Gianotti, L.R.R., Pascual-Leone, A., Treyer, V., Regard, M., Hohmann, M., & Brugger, P. (2006). Disruption of right prefrontal cortex by low-frequency repetitive transcranial magnetic stimulation induces risk-taking behavior. *The Journal of Neuroscience, 26*(24), 6469-6472.

Korman, L.M., Collins, J., Dutton, D., Dhayananthan, B., Littman-Sharp, N., & Skinner, W. (2008). Problem gambling and intimate partner violence. *Journal of Gambling Studies, 24*(1), 13-23.

Ladouceur, R. (2004). Perceptions among pathological and nonpathological gamblers. *Addictive Behaviors, 29*(3), 555-565.

Lamers, C.T.J., Bechara, A., Rizzo, M., & Ramaekers, J.G. (2006). Cognitive function and mood in MDMA/THC users, THC users and non-drug using controls. *Journal of Psychopharmacology, 20*(2), 302-311.

LaPlante, D.A., Nelson, S.E., LaBrie, R.A., & Shaffer, H.J. (2006). Men & women playing games: Gender and the gambling preferences of Iowa gambling treatment program participants. *Journal of Gambling Studies, 22*(1), 65-80.

Larsen, R.J., Mercer, K.A., & Balota, D.A. (2006). Lexical characteristics of words used in emotional stroop experiments. *Emotion, 6*(1), 62-72.

Lawrence, A.J., Luty, J., Bogdan, N.A., Sahakian, B.J., & Clark, L. (2009). Impulsivity and response inhibition in alcohol dependence and problem gambling. *Psychopharmacology, 207*(1), 163-172.

Lawrence, N.S., Jollant, F., O'Daly, O., Zelaya, F., & Phillips, M.L. (2009). Distinct roles of prefrontal cortical subregions in the Iowa Gambling Task. *Cerebral Cortex, 19*(5), 1134-1143.

Lecrubier, Y., Sheehan, D.V., Weiller, E., Amorim, P., Bonora, I., Harnett Sheehan, K., Janavs, J., & Dunbar, G.C. (1997). The MINI International Neuropsychiatric Interview (MINI). A short diagnostic structured interview: Reliability and validity according to the CIDI. *European Psychiatry, 12*(5), 224-231.

Ledgerwood, D., Orr, E., Kaploun, K., Milosevic, A., Frisch, G., Rupcich, N., & Lundahl, L. (2012). Executive function in pathological gamblers and healthy controls. *Journal of Gambling Studies, 28*(1), 89-103.

Ledgerwood, D.M., Alessi, S.M., Phoenix, N., & Petry, N.M. (2009). Behavioral assessment of impulsivity in pathological gamblers with and without substance use disorder histories versus healthy controls. *Drug and Alcohol Dependence, 105*(1-2), 89-96.

Ledgerwood, D.M., & Petry, N.M. (2006). What do we know about relapse in pathological gambling? *Clinical Psychology Review, 26*(2), 216-228.

Ledgerwood, D.M., & Petry, N.M. (2010). Subtyping pathological gamblers based on impulsivity, depression, and anxiety. *Psychology of Addictive Behaviors, 24*(4), 680-688.

Ledgerwood, D.M., Weinstock, J., Morasco, B.J., & Petry, N.M. (2007). Clinical features and treatment prognosis of pathological gamblers with and without recent gambling-related illegal behavior. *Journal of the American Academy of Psychiatry and the Law Online, 35*(3), 294-301.

Leeman, R.F., & Potenza, M.N. (2012). Similarities and differences between pathological gambling and substance use disorders: A focus on impulsivity and compulsivity. *Psychopharmacology, 219*(2), 469-490.

Lesieur, H., & Rosenthal, R. (1991). Pathological gambling: A review of the literature (prepared for the american psychiatric association task force on DSM-IV committee on disorders of impulse control not elsewhere classified). *Journal of Gambling Studies, 7*(1), 5-39.

Lesieur, H.R. (2001). *Cluster Analysis of Types of Inpatient PathologicalGgamblers.* (62), ProQuest Information & Learning, US.

Lesieur, H.R., & Blume, S.B. (1987). The South Oaks Gambling Screen (SOGS)—a new instrument for the identification of pathological gamblers. *American Journal of Psychiatry, 144*, 1184-1188.

Levine, B, Stuss, D.T., Wincur, G., Binns, M.A., Fahy, L., Mandic, M., Bridges, K., & Robertson, I.H. (2007). Cognitive rehabilitation in the elderly: Effects on strategic behavior in relation to goal management. *Journal of the International Neuropsychological Society, 13*(01), 143-152.

Levine, B., Schweizer, T.A., O'Connor, C., Turner, G., Gillingham, S., Stuss, D.T., Manly, T., & Robertson, I.H. (2011). Rehabilitation of executive functioning in patients with frontal lobe brain damage with goal management training. *Frontiers in Human Neuroscience, 5*, 9.

Li, X., Lu, Z.L., D'Argembeau, A., Ng, M., & Bechara, A. (2010). The Iowa Gambling Task in fMRI images. *Human Brain Mapping, 31*(3), 410-423.

Lin, C.-H., Chiu, Y.-C., Cheng, C.-M., & Hsieh, J.-C. (2008). Brain maps of Iowa Gambling Task. *BMC Neuroscience, 9*, 72.

Lobo, D.S.S., & Kennedy, J.L. (2009). Genetic aspects of pathological gambling: A complex disorder with shared genetic vulnerabilities. *Addiction, 104*(9), 1454-1465.

Logan, G.D., Cowan, W.B., & Davis, K.A. (1984). On the ability to inhibit simple and choice reaction time responses: A model and a method. *Journal of Experimental Psychology: Human Perception and Performance, 10*(2), 276-291.

Lorains, F.K., Cowlishaw, S., & Thomas, S.A. (2011). Prevalence of comorbid disorders in problem and pathological gambling: Systematic review and meta-analysis of population surveys. *Addiction, 106*(3), 490-498.

Lovibond, S.H., & Lovibond, P.E. (1995). Manual for the Depression Anxiety Stress Scales (2nd ed.). Sydney, Australia: Psychology Foundation of Australia.

Lubman, D.I., Yücel, M., & Pantelis, C. (2004). Addiction, a condition of compulsive behaviour? Neuroimaging and neuropsychological evidence of inhibitory dysregulation. *Addiction, 99*(12), 1491-1502.

Lund, K., & Burgess, C. (1996). Producing high-dimensional semantic spaces from lexical co-occurrence. *Behavior Research Methods, 28*(2), 203-208.

McCaig, R.G., Dixon, M., Keramatian, K., Liu, I., & Christoff, K. (2011). Improved modulation of rostrolateral prefrontal cortex using real-time fMRI training and meta-cognitive awareness. *Neuroimage, 55*(3), 1298-1305.

McCusker, C.G., & Gettings, B. (1997). Automaticity of cognitive biases in addictive behaviours: Further evidence with gamblers. *British Journal of Clinical Psychology, 36*, 543-554.

McKenna, F.P., & Sharma, D. (2004). Reversing the emotional stroop effect reveals that it is not what it seems: The role of fast and slow components. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(2), 382-392.

McNab, F., Leroux, G., Strand, F., Thorell, L., Bergman, S., & Klingberg, T. (2008). Common and unique components of inhibition and working memory: An fMRI, within-subjects investigation. *Neuropsychologia, 46*(11), 2668-2682.

Menon, V., Adleman, N.E., White, C.D., Glover, G.H., & Reiss, A.L. (2001). Error-related brain activation during a go/nogo response inhibition task. *Human Brain Mapping, 12*(3), 131-143.

Miedl, S.F., Peters, J., & Büchel, C. (2012). Altered neural reward representations in pathological gamblers revealed by delay and probability discounting. *Archives of General Psychiatry, 69*(2), 177-186.

Milosevic, A., & Ledgerwood, D.M. (2010). The subtyping of pathological gambling: A comprehensive review. *Clinical Psychology Review, 30*(8), 988-998.

Milton, S., Crino, R., Hunt, C., & Prosser, E. (2002). The effect of compliance-improving interventions on the cognitive-behavioural treatment of pathological gambling. *Journal of Gambling Studies, 18*(2), 207-229.

Mishra, B.R., Nizamie, S.H., Das, B., & Praharaj, S.K. (2010). Efficacy of repetitive transcranial magnetic stimulation in alcohol dependence: A sham-controlled study. *Addiction, 105*(1), 49-55.

Mishra, S., Lalumière, M., Morgan, M., & Williams, R. (2011). An examination of the relationship between gambling and antisocial behavior. *Journal of Gambling Studies, 27*(3), 409-426.

Mitchell, J.M., Tavares, V.C., Fields, H.L., D'Esposito, M., & Boettiger, C.A. (2007). Endogenous opioid blockade and impulsive responding in alcoholics and healthy controls. *Neuropsychopharmacology, 32*(2), 439-449.

Mitterschiffthaler, M.T., Williams, S.C.R., Walsh, N.D., Cleare, A.J., Donaldson, C., Scott, J., & Fu, C.H.Y. (2008). Neural basis of the emotional stroop interference effect in major depression. *Psychological Medicine, 38*(02), 247-256.

Miyake, A., Friedman, N.P., Emerson, M.J., Witzki, A.H., Howerter, A., & Wager, T.D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100.

Molenberghs, P., Gillebert, C.R., Schoofs, H., Dupont, P., Peeters, R., & Vandenberghe, R. (2009). Lesion neuroanatomy of the sustained attention to response task. *Neuropsychologia, 47*(13), 2866-2875.

Moran, E. (1970). Varieties of pathological gambling. *The British Journal of Psychiatry, 116*, 593-597.

Morasco, B.J., Weinstock, J., Ledgerwood, D.M., & Petry, N.M. (2007). Psychological factors that promote and inhibit pathological gambling. *Cognitive and Behavioral Practice, 14*(2), 208-217.

Murphy, P.N., Wareing, M., Fisk, J.E., & Montgomery, C. (2009). Executive working memory deficits in abstinent ecstasy/MDMA users: A critical review. *Neuropsychobiology, 60*(3-4), 159-175.

Myrseth, H., Brunborg, G., & Eidem, M. (2010). Differences in cognitive distortions between pathological and non-pathological gamblers with preferences for chance or skill games. *Journal of Gambling Studies, 26*(4), 561-569.

Neal, P., Delfrabbo, P., & O'Neil, M. (2005). Problem gambling and harm: Towards a national definition. Melbourne, Victoria: Gambling Research Australia,.

Nelson, H.E., & Willison, J. (1991). *National Adult Reading Test (NART): Test Manual* (2nd ed.). Windsor, UK: NFER Nelson.

Nigg, J.T. (2000). On inhibition/disinhibition in developmental psychopathology: Views from cognitive and personality psychology and a working inhibition taxonomy. *Psychological Bulletin, 126*(2), 220-246.

Nower, L., Martins, S.S., Lin, K.-H., & Blanco, C. (2013). Subtypes of disordered gamblers: Results from the National Epidemiologic Survey on Alcohol and Related Conditions (NESARC). *Addiction, 108*(4), 789-798.

Odlaug, B., Marsh, P., Kim, S., & Grant, J. (2011). Strategic vs nonstrategic gambling: Characteristics of pathological gamblers based on gambling preference. *Annals of Clinical Psychiatry, 23*(2), 105-112.

Odlaug, B.L., Chamberlain, S.R., Kim, S.W., Schreiber, L.R.N., & Grant, J.E. (2011). A neurocognitive comparison of cognitive flexibility and response inhibition in gamblers with varying degrees of clinical severity. *Psychological Medicine, 41*(10), 2111-2119.

Odlaug, B.L., Schreiber, L.R., & Grant, J.E. (2013). Personality dimensions and disorders in pathological gambling. *Current Opinion in Psychiatry, 26*(1), 107-112.

Orford, J., Wardle, H., Griffiths, M., Sproston, K., & Erens, B. (2010). PGSI and DSM-IV in the 2007 British Gambling Prevalence Survey: Reliability, item response, factor structure and inter-scale agreement. *International Gambling Studies, 10*(1), 31-44.

Oscar-Berman, M., & Marinković, K. (2007). Alcohol: Effects on neurobehavioral functions and the brain. *Neuropsychology Review, 17*(3), 239-257.

Park, S., Cho, M., Jeon, H., Lee, H., Bae, J., Park, J., Sohn, J., Lee, Y., Lee, J., & Hong, J. (2010). Prevalence, clinical correlations, comorbidities, and suicidal tendencies in pathological korean gamblers: Results from the Korean Epidemiologic Catchment Area Study. *Social Psychiatry and Psychiatric Epidemiology, 45*(6), 621-629.

Patton, J.H., Stanford, M.S., & Barratt, E.S. (1995). Factor structure of the Barratt Impulsiveness Scale. *Journal of Clinical Psychology, 51*(6), 768-774.

Petry, N.M. (2001). Substance abuse, pathological gambling, and impulsiveness. *Drug and Alcohol Dependence, 63*(1), 29-38.

Petry, N.M. (2003). A comparison of treatment-seeking pathological gamblers based on preferred gambling activity. *Addiction, 98*(5), 645-655.

Petry, N.M., Stinson, F.S., & Grant, B.F. (2005). Comorbidity of DSM-IV pathological gambling and other psychiatric disorders: Results from the National Epidemiologic Survey on Alcohol and Related Conditions. *Journal of Clinical Psychiatry, 66*(5), 564-574.

Potenza, M., Steinberg, M., McLaughlin, S., Rounsaville, B., & O'Malley, S. (2000). Illegal behaviors in problem gambling: Analysis of data from a gambling helpline. *Journal of the American Academy of Psychiatry and the Law Online, 28*(4), 389-403.

Potenza, M.N. (2008). The neurobiology of pathological gambling and drug addiction: An overview and new findings. *Philosophical Transactions of the Royal Society of London - Series B: Biological Sciences, 363*(1507), 3181-3189.

Potenza, M.N., Steinberg, M.A., McLaughlin, S.D., Wu, R.M.S., Rounsaville, B.J., & O'Malley, S.S. (2001). Gender-related differences in the characteristics of problem gamblers using a gambling helpline. *American Journal of Psychiatry, 158*(9), 1500-1505.

Productivity Commission. (2010). *Gambling*. Canberra: Australian Productivity Commission.

Quednow, B., Kühn, K.-U., Hoppe, C., Westheide, J., Maier, W., Daum, I., & Wagner, M. (2007). Elevated impulsivity and impaired decision-making cognition in heavy users of MDMA ("ecstasy"). *Psychopharmacology, 189*(4), 517-530.

Raylu, N., & Oei, T.P.S. (2002). Pathological gambling: A comprehensive review. *Clinical Psychology Review, 22*(7), 1009-1061.

Raylu, N., & Oei, T.P.S. (2004). The Gambling Urge Scale: Development, confirmatory factor validation, and psychometric properties. *Psychology of Addictive Behaviors, 18*(2), 100-105.

Reinert, D.F., & Allen, J.P. (2002). The Alcohol Use Disorders Identification Test (AUDIT): A review of recent research. *Alcoholism: Clinical and Experimental Research, 26*(2), 272-279.

Reuter, J., Raedler, T., Rose, M., Hand, I., Glascher, J., & Buchel, C. (2005). Pathological gambling is linked to reduced activation of the mesolimbic reward system. *Nature Neuroscience, 8*(2), 147-148.

Robertson, I.H., Manly, T., Andrade, J., Baddeley, B.T., & Yiend, J. (1997). Oops!': Performance correlates of everyday attentional failures in traumatic brain injured and normal subjects. *Neuropsychologia, 35*(6), 747-758.

Roca, M., Torralva, T., Lopez, P., Cetkovich, M., Clark, L., & Manes, F. (2008). Executive functions in pathologic gamblers selected in an ecologic setting. *Cognitive and Behavioral Neurology, 21*(1), 1-4.

Rodriguez-Jimenez, R., Avila, C., Jimenez-Arriero, M.A., Ponce, G., Monasor, R., Jimenez, M., Aragues, M., Hoenicka, J., Rubio, G., & Palomo, T. (2006). Impulsivity and sustained attention in pathological gamblers: Influence of childhood adhd history. *Journal of Gambling Studies, 22*(4), 451-461.

Rubia, K., Smith, A.B., Brammer, M.J., & Taylor, E. (2003). Right inferior prefrontal cortex mediates response inhibition while mesial prefrontal cortex is responsible for error detection. *Neuroimage, 20*(1), 351-358.

Rush, B.R., Moxam, R., S, & Urbanoski, K.A. (2002). Characteristics of people seeking help from specialized programs for the treatment of problem gambling in ontario. *Journal of Gambling Issues*.

Selin, K.H. (2003). Test-retest reliability of the alcohol use disorder identification test in a general population sample. *Alcoholism: Clinical and Experimental Research, 27*(9), 1428-1435.

Shaffer, H.J., & Hall, M.N. (1996). Estimating the prevalence of adolescent gambling disorders: A quantitative synthesis and guide toward standard gambling nomenclature. *Journal of Gambling Studies, 12*(2), 193-214.

Sharpe, L. (2002). A reformulated cognitive-behavioral model of problem gambling: A biopsychosocial perspective. *Clinical Psychology Review, 22*(1), 1-25.

Shaw, M.C., Forbush, K.T., Schlinder, J., Rosenman, E., & Black, D.W. (2007). The effect of pathological gambling on families, marriages, and children. *CNS spectrums, 12*(8), 615-622.

Sheehan, D.V., Lecrubier, Y., Harnett Sheehan, K., Janavs, J., Weiller, E., Keskiner, A., Schinka, J., Knapp, E., Sheehan, M.F., & Dunbar, G.C. (1997). The validity of the MINI International Neuropsychiatric Interview (MINI) according to the SCID-P and its reliability. *European Psychiatry, 12*(5), 232-241.

Sheehan, D.V., Lecrubier, Y., Sheehan, K.H., Amorim, P., Janavs, J., Weiller, E., Hergueta, T., Baker, R., & Dunbar, G.C. (1998). The MINI-International Neuropsychiatric Interview (M.I.N.I.): The development and validation of a structured diagnostic

psychiatric interview for DSM-IV and ICD-10. *The Journal of clinical psychiatry, 59 Suppl 20*, 34-57.

Slutske, W.S. (2006). Natural recovery and treatment-seeking in pathological gambling: Results of two U.S. National surveys. *American Journal of Psychiatry, 163*(2), 297-302.

Smith, D.P., Pols, R.G., Battersby, M.W., & Harvey, P.W. (2013). The Gambling Urge Scale: Reliability and validity in a clinical population. *Addiction Research & Theory, 21*(2), 113-122.

Soberay, A., Faragher, J.M., Barbash, M., Brookover, A., & Grimsley, P. (2013). Pathological gambling, co-occurring disorders, clinical presentation, and treatment outcomes at a university-based counseling clinic. *Journal of Gambling Studies*, 1-9.

Sofuoglu, M., DeVito, E.E., Waters, A.J., & Carroll, K.M. (2013). Cognitive enhancement as a treatment for drug addictions. *Neuropharmacology, 64*, 452-463.

Stewart, S.H., & Zack, M. (2008). Development and psychometric evaluation of a three-dimensional gambling motives questionnaire. *Addiction, 103*(7), 1110-1117.

Stout, J.C., Rock, S.L., Campbell, M.C., Busemeyer, J.R., & Finn, P.R. (2005). Psychological processes underlying risky decisions in drug abusers. *Psychology of Addictive Behaviors, 19*(2), 148-157.

Stubberud, J., Langenbahn, D., Levine, B., Stanghelle, J., & Schanke, A.-K. (2013). Goal management training of executive functions in patients with spina bifida: A randomized controlled trial. *Journal of the International Neuropsychological Society, 19*(6), 672-685.

Sylvain, C., Ladouceur, R., & Boisvert, J.-M. (1997). Cognitive and behavioral treatment of pathological gambling: A controlled study. *Journal of Consulting and Clinical Psychology, 65*(5), 727-732.

Tanabe, J., Thompson, L., Claus, E., Dalwani, M., Hutchison, K., & Banish, M.T. (2007). Prefrontal cortex activity is reduced in gambling and nongambling substance users during decision-making. *Human Brain Mapping, 28*, 1276-1286.

Tavares, H., Martins, S.S., Lobo, D.S., Silveira, C.M., Gentil, V., & Hodgins, D.C. (2003). Factors at play in faster progression for female pathological gamblers: An exploratory analysis. *Journal of Clinical Psychiatry, 64*(4), 433-438.

Tavares, H., Zilberman, M.L., Hodgins, D.C., & el-Guebaly, N. (2005). Comparison of craving between pathological gamblers and alcoholics. *Alcoholism: Clinical and Experimental Research, 29*(8), 1427-1431.

The Economist Online (Producer). (2011, May 16th). The biggest losers. *The Economist Online*. Retrieved from http://www.economist.com/blogs/dailychart/2011/05/gambling

Tom, S.M., Fox, C.R., Trepel, C., & Poldrack, R.A. (2007). The neural basis of loss aversion in decision-making under risk. *Science, 315*(5811), 515-518.

Toneatto, T. (1999). Cognitive psychopathology of problem gambling. *Substance Use and Misuse, 34*(11), 1593-1604.

Toneatto, T., Blitz-Miller, T., Calderwood, K., Dragonetti, R., & Tsanos, A. (1997). Cognitive distortions in heavy gambling. *Journal of Gambling Studies, 13*(3), 253-266.

Toneatto, T., & Brennan, J. (2002). Pathological gambling in treatment-seeking substance abusers. *Addictive Behaviors, 27*(3), 465-469.

Towse, J., & Neil, D. (1998). Analyzing human random generation behavior: A review of methods used and a computer program for describing performance. *Behavior Research Methods, 30*(4), 583-591.

Tversky, A., & Kahneman, D. (1991). Loss aversion in riskless choice: A reference-dependent model. *The Quarterly Journal of Economics, 106*(4), 1039-1061.

Upton, D., Enticott, P., Croft, R., Cooper, N., & Fitzgerald, P. (2010). ERP correlates of response inhibition after-effects in the stop signal task. *Experimental Brain Research, 206*(4), 351-358.

van 't Wout, M., Kahn, R.S., Sanfey, A.G., & Aleman, A. (2005). Repetitive transcranial magnetic stimulation over the right dorsolateral prefrontal cortex affects strategic decision-making. *Neuroreport, 16*(16), 1849-1852.

van Holst, R.J., van den Brink, W., Veltman, D.J., & Goudriaan, A.E. (2010). Why gamblers fail to win: A review of cognitive and neuroimaging findings in pathological gambling. *Neuroscience and Biobehavioral Reviews, 34*(1), 87-107.

Verbruggen, F., Adams, R., & Chambers, C.D. (2012). Proactive motor control reduces monetary risk taking in gambling. *Psychological Science, 23*(7), 805-815.

Verbruggen, F., Adams, R.C., van ‘t Wout, F., Stevens, T., McLaren, I.P.L., & Chambers, C.D. (2013). Are the effects of response inhibition on gambling long-lasting? *Plos One, 8*(7), e70155.

Verbruggen, F., Logan, G.D., Liefooghe, B., & Vandierendonck, A. (2008). Short-term aftereffects of response inhibition: Repetition priming or between-trial control

adjustments? *Journal of Experimental Psychology: Human Perception and Performance, 34*(2), 413-426.

Verdejo-García, A.J., Perales, J.C., & Pérez-García, M. (2007). Cognitive impulsivity in cocaine and heroin polysubstance abusers. *Addictive Behaviors, 32*(5), 950-966.

Volberg, R.A. (2003). Has there been a "feminization" of gambling and problem gambling in the united states? *eGambling: The Electronic Journal of Gambling Issues*, p. 8.

Welte, J., Barnes, G., Tidwell, M.-C., & Hoffman, J. (2008). The prevalence of problem gambling among U.S. Adolescents and young adults: Results from a national survey. *Journal of Gambling Studies, 24*(2), 119-133.

Welte, J.W., Barnes, G.M., Wieczorek, W.F., Tidwell, M.-C., & Parker, J. (2002). Gambling participation in the U.S.—results from a national survey. *Journal of Gambling Studies, 18*(4), 313-337.

Whiteside, S.P., & Lynam, D.R. (2001). The five factor model and impulsivity: Using a structural model of personality to understand impulsivity. *Personality and Individual Differences, 30*(4), 669-689.

Williams, J.M.G., Mathews, A., & MacLeod, C. (1996). The emotional stroop task and psychopathology. *Psychological Bulletin, 120*(1), 3-24.

Williams, R.J., Royston, J., & Hagen, B.F. (2005). Gambling and problem gambling within forensic populations: A review of the literature. *Criminal Justice and Behavior, 32*(6), 665-689.

Williams, R.J., Volberg, R., & stevens, R.M.G. (2012). *The Population Prevalence of Problem Gambling: Methodological Influences, Standardized Rates, Jurisdictional Differences, and Worldwide Trends*. Report prepared for the Ontario Problem Gambling Research Centre and the Ontario Ministry of Health and Long Term Care.

Winters, K.C., Specker, S., & Stinchfield, R.S. (2002). Measuring pathological gambling with the Diagnostic Interview for Gambling Severity (DIGS). In J. J. Marotta, J. A. Cornelius & W. R. Eadington (Eds.), *The Downside: Problem and Pathological Gambling* (pp. 143-148). Reno, NV: University of Nevada.

World Health Organisation. (1979). *International Classification of Diseases, 9th edition* (9th ed.). Geneva: World Health Organization.

World Health Organization. (2001). The Alcohol Use Disorders Identification Test (AUDIT) (2nd ed.): World Health Organization.

Young, M., & Wohl, M.A. (2011). The Canadian Problem Gambling Index: An evaluation of the scale and its accompanying profiler software in a clinical setting. *Journal of Gambling Studies, 27*(3), 467-485.

Zack, M., & Poulos, C. (2009). Effects of the atypical stimulant modafinil on a brief gambling episode in pathological gamblers with high vs. Low impulsivity. *Journal of Psychopharmacology, 23*(6), 660-671.

Ziolowski, S. (2012). The world count of gaming machines 2011: Gaming Technologies Association.

APPENDIX A: PREVALENCE OF COMORBID DISORDERS IN PROBLEM AND PATHOLOGICAL GAMBLING: SYSTEMATIC REVIEW AND META-ANALYSIS OF POPULATION SURVEYS

Addiction

REVIEW

doi:10.1111/j.1360-0443.2010.03300.x

Prevalence of comorbid disorders in problem and pathological gambling: systematic review and meta-analysis of population surveys

Felicity K. Lorains, Sean Cowlishaw & Shane A. Thomas

Problem Gambling Research and Treatment Centre, School of Primary Health Care, Monash University, Notting Hill, Victoria, Australia

ABSTRACT

Aims This paper reviews evidence pertaining to the prevalence of common comorbid disorders, including alcohol use disorder, depression, substance use disorders, nicotine dependence, anxiety disorders and antisocial personality disorder, in population-representative samples of problem and pathological gamblers. **Methods** A systematic search was conducted for peer-reviewed and unpublished articles reported between 1 January 1998 and 20 September 2010. Only studies which examined the prevalence of comorbid conditions in problem and/or pathological gamblers from a general population sample using randomized sampling methods and standardized measurement tools were included. Meta-analysis techniques were then performed to synthesize the included studies and estimate the weighted mean effect size and heterogeneity across studies. **Results** Eleven eligible studies were identified from the literature. Results from across the studies indicated that problem and pathological gamblers had high rates of other comorbid disorders. The highest mean prevalence was for nicotine dependence (60.1%), followed by a substance use disorder (57.5%), any type of mood disorder (37.9%) and any type of anxiety disorder (37.4%). However, there was evidence of moderate heterogeneity across studies, suggesting that rate estimates do not necessarily converge around a single population figure, and that weighted means should be interpreted with caution. **Conclusions** Problem and pathological gamblers experience high levels of other comorbid mental health disorders and screening for comorbid disorders upon entering treatment for gambling problems is recommended. Further research is required to explore the underlying causes of variability observed in the prevalence estimates.

Keywords Comorbidities, meta-analysis, pathological gambling, systematic review.

Correspondence to: Felicity K. Lorains, School of Primary Health Care, Monash University, Building 1, 270 Ferntree Gully Road, Notting Hill, Victoria 3168, Australia. E-m[redacted]

Submitted 23 August 2010; initial review completed 19 September 2010; final version accepted 4 November 2010

INTRODUCTION

Epidemiological studies estimate that the prevalence of past-year adult pathological gambling is between 1.1 and 3.5% [1–3], with variation across studies due probably, in part, to sampling and measurement artefacts [4]. Although usage of the terms 'problem' and 'pathological gambling' varies, problem gambling is often used to describe an intermediate or subclinical form of the disorder 'pathological gambling'. Both problem and pathological gambling are serious public and mental health concerns, with implications for individuals, families and communities [3]. Problem and pathological gambling are associated with impaired psychological functioning, reduced quality of life, legal problems and high rates of bankruptcy, divorce and incarceration [5,6]. Gambling problems are also associated with other mental health disorders including depression, anxiety disorders, bipolar disorder, personality disorders, alcohol, substance and nicotine use [7,8]. The presence of comorbid disorders in problem and pathological gambling has been associated with increased gambling problems and severity of associated consequences [9,10]. Comorbid disorders are also suggested to partly determine access and compliance to gambling treatment [11], and may influence the efficacy of pharmacological [12] and psychological [11] interventions. Furthermore, different treatments may be more appropriate for gamblers with certain comorbid

disorders. For example, Blaszczynski & Nower's pathway model of problem gambling [13] suggests counselling or minimal intervention for gamblers with secondary depression and intensive psychological and pharmacological therapy for gamblers with comorbid antisocial personality disorder. The upcoming revision to the Diagnostic and Statistical Manual of Mental Disorders (DSM-V; [14]) is proposing to re-classify pathological gambling as a 'behavioural addiction', thus the presence of psychiatric disorders in problem and pathological gambling requires further attention.

Although it is generally accepted that many psychological disorders are likely to co-occur with gambling problems [15], conclusions drawn about psychiatric comorbidity in problem and pathological gambling often rely heavily on evidence from treatment-seeking samples. Ibanez *et al*. [16] reported that 42% of gamblers presenting to an out-patient treatment programme had a comorbid personality disorder, 33.3% had comorbid alcohol abuse/dependence and 17.4% had an adjustment disorder. Black & Moyer [17] found that 60% of treatment-seeking pathological gamblers had a comorbid mood disorder, 64% had a comorbid substance use disorder, 40% had an anxiety disorder and 87% had a personality disorder. Petry [7] reviewed such studies of treatment-seeking samples and found evidence for pathological gambling co-occurring frequently with substance use, alcohol use, affective and anxiety disorders, with mixed findings regarding co-occurring personality disorders. These findings are of relevance in an applied clinical context, as they are likely to reflect gamblers presenting for treatment.

Studies of treatment-seeking gamblers are less useful for drawing conclusions about psychiatric comorbidity in the general problem and pathological gambling population. Many gamblers never seek professional treatment, with a recent survey reporting that only 7–12% of pathological gamblers have ever sought treatment [18]. Treatment-seeking pathological gamblers may also differ systematically from gamblers in the general population. Evidence suggests that treatment-seeking samples comprise mainly pathological gamblers who are white, male and middle-aged [19], generally display more severe gambling symptoms [18] and may be more likely to present with comorbid conditions. This is consistent with the general selection bias, 'Berkson's bias', and the observation that co-occurrence of disorders increases the likelihood of treatment-seeking [20]. Paradoxically, it may be the case that problem and pathological gamblers seeking treatment are *more* likely to seek treatment for their comorbid disorders rather than their gambling problems [11], with gambling problems going undetected.

As there is considerable reason to suggest that treatment-seeking gamblers will differ systematically from gamblers who do not seek treatment, studies of clinical samples should not be used to infer characteristics of the wider problem and pathological gambling population. In contrast, general population surveys using random sampling methods are appropriate for generalizing conclusions to the population. Petry [7] provided a narrative review of some representative studies, and concluded that the general pathological gambling population also demonstrated high levels of co-occurring substance use, alcohol use, mood, anxiety and personality disorders. However, variation exists in the reported prevalence of comorbid conditions. One potential reason for such variability is that problem and pathological gambling has a low base-rate and studies of the general population often obtain small numbers of gamblers, despite large overall samples. Where samples are small, variation can be attributable to sampling error, rather than any true differences between study effects [21]. Meta-analytical techniques synthesize results across studies and provide more precise estimates based on the combined sample, indicating whether differences can be attributed to sampling error or systematic factors. As far as can be ascertained, no studies have reviewed and synthesized general population surveys systematically to estimate the prevalence of comorbid disorders in the problem and pathological gambling population. Accordingly, the aim of the current study was to review results from all population studies indicating the prevalence of common comorbid disorders in problem and pathological gambling.

METHOD

Search strategy

The systematic search conducted for this paper was a component of a general search conducted for multiple purposes, including a proposed Cochrane review evaluating the efficacy of treatments for pathological gambling. The databases used for this systematic search were: Medline, CINAHL, the Cochrane Library database, EMBASE, EBM reviews, PsycInfo and ProQuest. In addition, reference lists of all included studies were handsearched, while relevant known websites were searched for unpublished articles. To ensure recency of articles, the search was restricted to 1 January 1998 until 20 September 2010. The search terms used were a combination of MESH terms and keywords with wildcards and were: exp Gambling or gambl$ or betting or wager or gaming. A detailed description of the search strategy can be found in the online supporting information (see details at the end). After removal of duplicate articles, the search retrieved 7187 unique citations. As several different terms are used to describe gambling problems, this paper will use the

term 'pathological gambling' to refer to the most severe form of the disorder and 'problem gambling' to refer to an intermediate form of the disorder. Studies which included samples of problem and pathological gamblers will be noted.

Inclusion criteria

The following inclusion criteria were used: (i) participants were pathological and/or problem gamblers as assessed by a validated screening tool; (ii) the study used a community-based general population adult sample and a random sampling methodology; (iii) the study provided a prevalence estimate of problem or pathological gambling and one or more conditions including major depression, anxiety disorders, bipolar disorder, nicotine dependence, alcohol and substance use disorders and antisocial personality disorder, using a validated screening tool; and (iv) the study was in the English language.

Articles were excluded if they were review articles, used treatment-seeking populations, combined prevalence estimates for multiple comorbid disorders or did not use standardized measurement tools. Where duplicate articles using the same data set were identified, multiple articles were included if unique information was available from each article or the article containing the most comprehensive information was retained. The title and abstract of the retrieved articles were scanned for inclusion by the first author. Seventy-seven articles were deemed eligible for inclusion based on title and abstract. Full texts were obtained for the 77 articles and 11 studies met the inclusion criteria.

Data extraction

Information was extracted from each included study on: (i) broad study characteristics including country of origin and sample size; (ii) study methodology, including the measurement instruments used; and (iii) relevant quantitative data, including the prevalence of problem and pathological gambling in the study sample and prevalence of a comorbid condition in the problem and pathological gambling sample. The strict inclusion criteria required that standardized measurement tools and randomized sampling methods were employed; therefore, methodological quality of studies was noted during data extraction but not analysed formally. In many cases, the prevalence estimate was available from the primary study. In other instances it was necessary to derive the estimate from information reported in the article. Sufficient information for calculating a prevalence estimate was the total number of problem and pathological gamblers and the number of problem and pathological gamblers with a comorbid disorder. To ensure accuracy of the data extraction, a random selection of articles ($n = 4$) was coded independently by a second reviewer. The inter-rater agreement between the two coders was 96.4%.

Data analysis

Meta-analysis is a technique for synthesizing results from independent studies [22]. A separate meta-analysis was conducted for each comorbid disorder, using Meta-Analyst software [23] and a random-effects model to account for heterogeneity across studies [22]. This model assumes different true effect sizes (e.g. due to variations in study design [24]) and estimates the average effect from a distribution with a mean and variance [22]. Random-effects analysis partitions the observed variance into two parts: (i) chance variation attributed plausibly to sampling error; and (ii) additional differences reflecting true heterogeneity. Although many statistical indices that quantify heterogeneity are limited when the number of studies is small [24], the I^2 statistic is suitable and indicates the amount of total variation across studies due to true differences (i.e. heterogeneity) rather than sampling error. The I^2 is expressed as a proportion of the total variance and ranges from 0 to 100%, with values of 25%, 50% and 75% suggested to represent low, moderate and high levels of heterogeneity, respectively [25]. When there is evidence of heterogeneity across studies, meta-analysis considers study characteristics potentially explaining this variability [26]. In the current instance, this was limited by the small number of primary studies available [24]. When fewer than five studies were available, a summary effect and a statistical index of heterogeneity were reported, while no further analyses were conducted. Where studies numbered five or greater, limited exploratory subgroup analyses were conducted to examine potential sources of heterogeneity. Several potentially relevant factors were identified a priori, and were given emphasis in the subgroup analysis. These included: (i) the inclusion of pathological gamblers or combined samples of problem and pathological gamblers; (ii) use of clinician-administered interviews or self-report questionnaires; and (iii) focus on past-year or life-time diagnosis of problem and pathological gambling.

RESULTS

Study characteristics

Characteristics of the 11 included studies are presented in Table 1. The overall sample sizes of each study ranged from 2417 to 43 093, with the sample size of problem and pathological gamblers ranging from 21 to 265. All included studies used sampling weights to adjust their data to match certain population demographic characteristics, with most studies adjusting for age, sex and race/ethnicity. Two studies [27,28] reported both weighted and

Table 1 Characteristics of included studies.

Study	*Country*	*Sample size (n)*	*Problem/pathological gambling diagnostic tool*	*Comorbidity diagnostic tool*	*No. of problem/pathological gamblers in sample*	*Problem/pathological gambling prevalence rate*	
						Past-year	*Life-time*
Affi *et al.* 2010[c] [40]	Canada	10 056	PGSI	CIDI (DSM-IV)	320[ab]	2.7%*	
Bondolfi *et al.* 2000 [38]	Switzerland	2526	SOGS	CAGE	75[a]		0.8%*
Bondolfi *et al.* 2008 [37]	Switzerland	2803	SOGS	CAGE	93[a]	0.5%	1.1%*
Cunningham *et al.* 1998 [27]	United States	3004	DSM-III	DIS (DSM-III)	161[a]		0.9%*
Feigelman *et al.* 1998 [36]	United States	6308	SOGS	Inventory of substance use patterns (DSM-III-R)	265		4.2%*
Gerstein *et al.* 1999 [32]	United States	2417	NODS	DSM-IV	21	0.1%	0.8%*
Kessler *et al.* 2008 [34]	United States	9282	DSM-IV	CIDI (DSM-IV)	56	0.3%	0.6%*
Marshall & Wynne, 2004[c] [39]	Canada	34 770	PGSI	CIDI (DSM-IV)	174	0.5%*	
Park *et al.* 2010 [35]	Korea	5333	DSM-IV	K-CIDI (DSM-IV)	43		0.8%*
Petry *et al.* 2005 [33]	United States	43 093	DSM-IV	AUDADIS	195		0.4%*
Welte *et al.* 2001 [28]	United States	2638	DSM-IV	DIS (DSM-IV)	50	1.3%*	2.0%

South Oaks Gambling Screen (SOGS) [30], Problem Gambling Severity Index of the Canadian Problem Gambling Index (PGSI) [31], Diagnostic and Statistical Manual of Mental Health Disorder (DSM) [29], NORC DSM Criteria for Gambling Problems (NODS) [32]. DIS: Diagnostic Interview Schedule; AUDADIS: NIAAA Alcohol Use Disorder and Associated Disabilities Interview Schedule-DSM-IV Version; CIDI: Composite International Diagnostic Interview based on DSM-IV; K-CIDI: Korean version of the Composite International Diagnostic interview; CAGE: four-item screen for alcoholism: cut-down, annoyed, guilt, eye-opener. [a]Combined problem and pathological gamblers. [b]Refers only to women. [c]Same data set. *Prevalence rate used for comorbidity analysis.

unweighted statistics with small differences between the two. All prevalence rates, displayed in the Results section and used in the analysis, are weighted statistics.

Characteristics of the problem and pathological gambler samples

The prevalence estimates of past-year and life-time problem and pathological gambling ranged from 0.1 to 2.7% and 0.4 to 4.2%, respectively. The most commonly used screening tools for problem and pathological gambling diagnosis were the DSM criteria [29] and the South Oaks Gambling Screen (SOGS) [30]. Studies using the DSM involved structured interviews, while the Problem Gambling Severity Index of the Canadian Problem Gambling Index (PGSI) [31], SOGS [30] and the NORC DSM Screen for Gambling Problems (NODS) [32] were administered as self-report questionnaires. Of the five studies which used the DSM criteria, four [28,33–35] used the DSM-IV pathological gambling criteria (more than five of 10 criteria met), and one [27] combined the DSM-III problem and pathological gambling criteria (more than one of nine criteria met). All three studies [36–38] using the SOGS used the problem gambling category (more than three or four of 20). Two studies used the PGSI, with one [39] using the pathological gambling category (more than eight of 27 criteria met) and the other [40] using a combined problem and pathological gambling classification (more than three of 27 criteria met). The only study [32] using the NODS used the pathological gambling criteria (more than five of 10 criteria met).

Meta-analysis

Table 2 illustrates the prevalence rates of comorbid disorders in problem and pathological gambling, along with the average effect size (summary effect) and heterogeneity estimate (I^2). For substance use disorders, the weighted mean effect size was 57.5% for any substance use disorder, 28.1% for alcohol use disorder, 17.2% for illicit drug abuse/dependence and 60.1% for nicotine dependence. For mood disorders, the average effect size was 37.9% for any mood disorder, 23.1% for major depression and 9.8% for bipolar disorder/manic episodes. The average estimate of any anxiety disorder in problem and pathological gambling was 37.4% and the mean effect size for generalized anxiety disorder was 11.1%. The prevalence of antisocial personality disorder (ASPD) in problem and pathological gambling was 28.8%. All comorbid disorders, except generalized anxiety disorder, had a moderate level of heterogeneity in their combined prevalence estimates.

Subgroup analysis

Sensitivity analysis was performed for the three comorbid disorders that had sufficient primary studies (alcohol use

Table 2 Prevalence of comorbid mental health disorders in problem and pathological gambling.

Study	*Alcohol use disorder*	*Major depression*	*Bipolar disorder/manic episodes*	*Substance use disorders*[a]	*Illicit drug abuse/dependence*	*Nicotine dependence*	*Any anxiety disorder*[b]	*Generalized anxiety disorder*	*Any mood disorder*[c]	*Antisocial personality disorder*
Afifi *et al.* 2010 [40]			4.0%[d]		1.6%[d]					
Bondolfi *et al.* 2000 [38]	36.0%									
Bondolfi *et al.* 2008 [37]	13.5%									
Cunningham *et al.* 1998 [27]	44.5%	8.8%	3.1%		39.9%	76.3%		7.7%		35.0%
Fiegelman *et al.* 1998 [36]				26.0%						
Gerstein *et al.* 1999 [32]	9.9%	29.1%[e]	32.5%							
Kessler *et al.* 2008 [34]		38.6%	17.0%	76.3%		63.0%	60.3%[f]	16.6%	55.6%	
Marshall & Wynne, 2004 [39]	15.0%	24.0%[g]								
Park *et al.* 2010 [35]	30.2%[h]	11.6%	0.0%	69.8%		34.9%	14.0%		11.6%	
Petry *et al.* 2005 [33]	73.2%	37.0%	22.8%		38.1%	60.4%	41.3%	11.2%	49.7%	23.3%
Welte *et al.* 2001 [28]	18.0%									
Summary effect	28.1	23.1	9.8	57.5	17.2	60.1	37.4	11.1	37.9	28.8
I^2 (%)	48.9	46.9	47.7	49.1	49.2	46.9	47.2	29.8	47.1	45.3

[a]Includes alcohol abuse/dependence and/or drug abuse/dependence and/or nicotine dependence. [b]Includes panic disorder (with and without agoraphobia), phobia (social and specific) and generalized anxiety disorder. [c]Includes major depressive disorder, dysthymia and bipolar disorder/manic episodes. [d]Refers to only women. [e]Refers to depressive episode. [f]Also includes post-traumatic stress disorder. [g]Authors suggest to use with caution. [h]Refers to alcohol dependence only.

disorder, major depression and bipolar disorder/manic episodes). For alcohol use disorder, studies were grouped initially according to their inclusion of pathological gamblers only (five studies) or combined samples of problem and pathological gamblers (three studies) which yielded similar weighted mean estimates (pathological gamblers only = 26.6%; combined problem and pathological gamblers = 29.8%), with both groups still demonstrating moderate heterogeneity ($I^2 > 45\%$). Secondly, studies were grouped according to whether problem and pathological gambling was diagnosed by clinician-administered interview (four studies) or self-report questionnaire (four studies). Results indicated that the weighted mean estimate was larger in studies using clinician-administered interviews (prevalence = 41.2%) than in studies using self-reports (prevalence = 18.2%), although heterogeneity was still evident within groups ($I^2 > 45\%$). Finally, studies were grouped according to life-time (six studies) or past-year (two studies) problem and pathological gambling diagnosis, with a larger weighted mean estimate in life-time problem and pathological gambling (prevalence = 33.4%) than in past-year (prevalence = 15.7%). There was evidence of heterogeneity for the studies referring to life-time ($I^2 = 48.7\%$) but not for studies referring to past-year problem and pathological gambling ($I^2 = 0\%$).

Initially, for comorbid major depression in problem and pathological gambling, one study [27] that combined samples of problem and pathological gamblers was excluded. Removing this study did not alter considerably the prevalence estimate with a weighted mean estimate of 28.5% and moderate heterogeneity remaining ($I^2 = 42.5\%$). Studies were then grouped according to whether problem and pathological gambling was diagnosed by clinician-administered interview (four studies; prevalence = 21.4%; $I^2 = 48.1\%$) or self-report questionnaire (two studies; prevalence = 24.6%; $I^2 = 0.0\%$). Finally, analysis was limited to five studies which referenced life-time, rather than past-year problem and pathological gambling diagnosis, which produced a weighted mean prevalence estimate of 22.7%, with moderate heterogeneity remaining ($I^2 = 47.4\%$).

For comorbid bipolar disorder/manic episodes in problem and pathological gambling, studies were first grouped according to their inclusion of pathological gamblers only (four studies) or combined samples of problem and pathological gamblers (two studies), with a larger weighted mean estimate observed in studies of pathological gamblers (prevalence = 20.4%; $I^2 = 37.0\%$) than in studies of problem and pathological gamblers (prevalence = 3.7%; $I^2 = 0.0\%$). Studies were then grouped according to whether problem and pathological gambling was diagnosed by a clinician-administered interview (four studies; prevalence = 9.1%; $I^2 = 46.8\%$)

or a self-report questionnaire (two studies; prevalence = 12.1%; I^2 = 48.7%), with similar results found. Finally, analysis was limited to five studies which referenced life-time rather than past-year conditions. This comparison did not change substantially the prevalence for comorbid bipolar disorder in problem and pathological gambling, with a weighted mean prevalence estimate of 12.6% and moderate heterogeneity remaining (I^2 = 46.2%).

DISCUSSION

Previous conclusions about psychiatric comorbidity in problem and pathological gambling are based predominantly on narrative reviews drawing heavily on treatment-seeking gamblers. The current study comprised a systematic review and synthesis of population studies, and thus provided unique evidence indicating levels of comorbidity in problem and pathological gambling in the community. Results generally found high prevalence rates for many comorbid conditions in representative samples of problem and pathological gamblers. The condition with the highest mean prevalence rate was nicotine dependence, followed by a substance use disorder, any mood disorder and any anxiety disorder. To compare with studies of treatment-seeking pathological gamblers, Petry (2005) found high life-time prevalence estimates for any mood disorder (estimates ranging from 15.9% to 77.5%), any anxiety disorder (7.2–40%), a substance use disorder (31–60%), alcohol use disorder (26–63%) and major depression (33.3–76%) [7]. Thus, the current results suggest that high levels of comorbidity characterizes problem and pathological gamblers in the community, and not simply those seeking treatment.

Results generally indicated high prevalence estimates for nicotine dependence, alcohol use disorder, illicit drug abuse/dependence and substance use disorders co-occurring with problem and pathological gambling. Nicotine dependence, alcohol use and substance use share several common features, frequently co-occur [41,42] and are referred to as addictive disorders [43]. Although pathological gambling is classified currently as an impulse control disorder, there is evidence to suggest that similar predispositions (genetic, environmental and social) may influence the co-development and maintenance of addictive disorders as well as pathological gambling [43]. Similar to problem and pathological gambling, substance use disorders have high rates of psychiatric comorbidity [44] and there is some evidence that problem and pathological gambling, alcohol, substance and nicotine use have similar personality profiles [45]. In addition, the current revision of the Diagnostic and Statistical Manual (DSM-V) is proposing to re-classify problem and pathological gambling as a 'behavioural addiction' [14].

Results also indicated that mood and anxiety disorders were highly prevalent in problem and pathological gambling. Unlike the addictive disorders which may co-develop with problem and pathological gambling, it has been suggested that mood and anxiety disorders may often precede gambling problems [34,46]. Blaszczynski & Nower's [13] pathways model highlights a subgroup of gamblers who may gamble to alleviate symptoms of depression and anxiety. For this subtype, gambling behaviours may be viewed as a manifestation of maladaptive coping, with a more general underlying psychopathology involving a mood or anxiety disorder. However, a recent review reported that mood disorders are also likely to be secondary symptoms of increasing financial losses in pathological gambling [47]. In addition, a recent longitudinal study reported that the relationship between problem and pathological gambling and mood disorders may not necessarily be causal [48], and further research using longitudinal methods is required to provide a greater insight into the onset and pattern of comorbid conditions in problem and pathological gambling.

The current results indicated that the prevalence of ASPD in problem and pathological gambling was considerably higher (mean effect size = 28.8%) than the rate reported in the general population (0.6–3.6% [49,50]). Blaszczynski & Nower's pathway model proposes a subgroup, 'antisocial impulsivist', who have severe psychopathology, high levels of impulsivity and high rates of ASPD [13]. The current results are consistent with such a subgroup. Furthermore, a twin study reported that 66% of the overlap between ASPD and pathological gambling was accounted for by familial factors, suggesting a genetic association between the two disorders [51].

Interpretation of mean prevalence estimates should be considered in light of moderate heterogeneity across studies. Planned subgroup analyses were conducted for alcohol use disorder, major depression and bipolar disorder, in an attempt to explain some of this heterogeneity. No consistent patterns were evident across the results from the three comorbid disorders; however, there was some evidence that self-report questionnaires produced less heterogeneity in the prevalence estimate for major depression, combined samples of problem and pathological gamblers produced a lower prevalence estimate with minimal heterogeneity for bipolar disorder and past-year problem and pathological gambling diagnosis produced a lower and less heterogeneous prevalence estimate for alcohol use disorder. Life-time estimates may be confounded by age, and do not necessarily suggest that the two conditions occurred at the same point in time. However, these subgroup analyses are based on a small number of studies and should be interpreted with caution.

While all problem and pathological gambling assessment tools have evidence supporting their reliability and

validity [52–57], variations in the gambling diagnostic tools may have influenced the results. The DSM, a structured clinical interview, has good reliability and validity for both clinical and general population settings [54], whereas the SOGS, a self-report questionnaire, has only satisfactory psychometrics in general population surveys with a high false positive rate [55]. Furthermore, there has been some discordance between classification using the NODS and the DSM-IV [58]. The comorbid disorder diagnostic tool may have also influenced the results; however, most studies used a structured clinical interview based on the DSM criteria for diagnosis of comorbid disorder, which has good inter-rater reliability [59]. Other factors which may have influenced the results and were not analysed formally include methodological quality and country of origin. In addition, several limitations of this review should be noted. General population prevalence studies in problem and pathological gambling are still relatively rare, have been conducted predominantly in the United States and Canada, and the total sample size of gamblers was still quite small ($n = 21–265$). In addition, previous research has suggested that gamblers commonly have multiple comorbid conditions [34], and future research should consider the co-occurrence of comorbid disorders in problem and pathological gambling.

Overall, this study suggests strongly that problem and pathological gamblers have high prevalence rates for many comorbid disorders, thus treatment providers should assess for comorbid conditions. The presence of comorbid conditions may produce difficulties for treatment and it may be beneficial to tailor treatments to different types of gamblers [13,60]. For example, for gamblers with comorbid addictive disorders, it may be useful to focus on the underlying predispositions to addictive behaviour, rather than treating the conditions separately. In contrast, where mood/anxiety disorders are comorbid with problem and pathological gamblers, the clinician may wish to consider whether the mood/anxiety disorder has preceded the gambling problems and whether it may be beneficial to focus treatment on the preceding mood/anxiety disorder. However, it is important to note that moderate variability existed between studies that could not be accounted for by sampling error alone; thus, prevalence estimates should be interpreted with caution.

Declarations of interest

The Problem Gambling Research and Treatment centre is supported by the Department of Justice, Victorian State Government, Australia. The Department of Justice had no involvement in the current publication. The authors have no other conflicts of interest to declare.

Acknowledgements

Many thanks to Stephanie Merkouris for assisting in the data validation.

References

1. Welte J. W., Barnes G. M., Wieczorek W. F., Tidwell M.-C., Parker J. Gambling participation in the U.S.—results from a national survey. *J Gambl Stud* 2002; **18**: 313–37.
2. Shaffer H. J., Hall M. N., Bilt J. V. Estimating the prevalence of disordered gambling behavior in the United States and Canada: a research synthesis. *Am J Public Health* 1999; **89**: 1369–75.
3. Shaffer H. J., Hall M. N. Updating and refining prevalence estimates of disordered gambling behaviour in the United States and Canada. *Can J Public Health* 2001; **92**: 168.
4. Jackson A., Wynne H., Dowling N., Tomnay J., Thomas S. Using the CPGI to determine problem gambling prevalence in Australia: measurement issues. *Int J Ment Health Addict* 2010; **8**: 570–82.
5. Grant J. E., Kim S. W. Quality of life in kleptomania and pathological gambling. *Compr Psychiatry* 2005; **46**: 34–7.
6. Argo T. R., Black D. W. Clinical characteristics. In: Grant J. E., Potenza M. N., editors. *Pathological Gambling: A Clinical Guide to Treatment*. Arlington, VA: American Psychiatric Publishing Inc.; 2004.
7. Petry N. Comorbidity of disordered gambling and other psychiatric disorders. In: Petry N., editor. *Pathological Gambling: Etiology, Comorbidity and Treatment*. Washington, DC: American Psychological Association; 2005.
8. Crockford D. N., El-Guebaly N. Psychiatric comorbidity in pathological gambling: a critical review. *Can J Psychiatry* 1998; **43**: 43–50.
9. Ladd G. T., Petry N. M. A comparison of pathological gamblers with and without substance abuse treatment histories. *Exp Clin Psychopharmacol* 2003; **11**: 202–9.
10. Hall G. W., Carriero N. J., Takushi R. Y., Montoya I. D., Preston K. L., Gorelick D. A. Pathological gambling among cocaine-dependent outpatients. *Am J Psychiatry* 2000; **157**: 1127.
11. Winters K. C., Kushner M. G. Treatment issues pertaining to pathological gamblers with a comorbid disorder. *J Gambl Stud* 2003; **19**: 261–77.
12. Dell'Osso B., Allen A., Hollander E. Comorbidity issues in the pharmacological treatment of pathological gambling: a critical review. *Clin Pract Epidemol Ment Health* 2005; **1**: 21.
13. Blaszczynski A., Nower L. A pathways model of problem and pathological gambling. *Addiction* 2002; **97**: 487–99.
14. Miller G., Holden C. Proposed revisions to psychiatry's canon revealed. *Science* 2010; **327**: 770–1.
15. Black D., Shaw M. Psychiatric comorbidity associated with pathological gambling: a clear connection with other impulse-control disorders. *Psychiatr Times* 2008; **25**: 14.
16. Ibanez A., Blanco C., Donahue E., Lesieur H. R., Perez de Castro I., Fernandez-Piqueras J. *et al*. Psychiatric comorbidity in pathological gamblers seeking treatment. *Am J Psychiatry* 2001; **158**: 1733–5.
17. Black D. W., Moyer T. Clinical features and psychiatric comorbidity of subjects with pathological gambling behavior. *Psychiatr Serv* 1998; **49**: 1434–9.
18. Slutske W. S. Natural recovery and treatment-seeking in pathological gambling: results of two U.S. national surveys. *Am J Psychiatry* 2006; **163**: 297–302.

19. Volberg R. A. The prevalence and demographic of pathological gamblers: implications for public health. *Am J Public Health* 1994; **84**: 237–41.
20. Berkson J. Limitations of the application of four fold table analysis to hospital data. *Biomed Bull* 1946; **2**: 4753.
21. Rosenthal R., DiMatteo M. R. Meta-analysis: recent developments in quantitative methods for literature reviews. *Ann Rev Psychol* 2001; **52**: 59–82.
22. Normand S. T. Meta-analysis: formulating, evaluating, combining, and reporting. *Stat Med* 1999; **18**: 321–59.
23. Wallace B. C., Schmid C. H., Lau J., Trikalinos T. A. Meta-analyst: software for meta-analysis of binary, continuous and diagnostic data. *BMC Med Res Methodol* 2009; **9**: 80.
24. Borenstein M., Hedges L. V., Higgins J. P. T., Rothstein H. R. *Introduction to Meta-Analysis*. New York: Wiley; 2009.
25. Higgins J. P. T., Thompson S. G., Deeks J. J., Altman D. G. Measuring inconsistency in meta-analysis. *BMJ* 2003; **327**: 557–60.
26. Thompson S. G., Sharp S. G. Explaining heterogeneity in meta-analysis: a comparison of methods. *Stat Med* 1999; **18**: 2693–708.
27. Cunningham-Williams R. M., Cottler L. B., Compton W. M., III, Spitznagel E. L. Taking chances: problem gamblers and mental health disorders—results from the St. Louis Epidemiologic Catchment Area study. *Am J Public Health* 1998; **88**: 1093–6.
28. Welte J., Barnes G., Wieczorek W., Tidwell M.-C., Parker J. Alcohol and gambling pathology among U.S. adults: prevalence, demographic patterns and comorbidity. *J Stud Alcohol* 2001; **62**: 706–12.
29. American Psychriatric Association (APA). *Diagnostic and Statistical Manual of Mental Disorders (DSM-IV-TR)*. Washington, DC: APA; 2000.
30. Lesieur H. R., Blume S. B. The South Oaks gambling screen (SOGS)—a new instrument for the identification of pathological gamblers. *Am J Psychiatry* 1987; **144**: 1184–8.
31. Ferris J., Wynne H. *The Canadian Problem Gambling Index Draft User Manual*. Toronto: Canadian Centre on Substance Abuse; 2001.
32. Gerstein D., Hoffmann J., Larison C., Laszlo E., Murphy S., Palmer A. *et al. Gambling Impact and Behavior Study: Report to the National Gambling Impact Study Commission*. Chicago: National Opinion Research Center at the University of Chicago; 1999.
33. Petry N. M., Stinson F. S., Grant B. F. Comorbidity of DSM-IV pathological gambling and other psychiatric disorders: results from the national epidemiologic survey on alcohol and related conditions. *J Clin Psychiatry* 2005; **66**: 564–74.
34. Kessler R. C., Hwang I., Labrie R., Petukhova M., Sampson N. A., Winters K. C. *et al*. DSM-IV pathological gambling in the National Comorbidity Survey Replication. *Psychol Med* 2008; **38**: 1351–60.
35. Park S., Cho M. J., Jeon H. J., Lee H. W., Bae J. N., Park J. I. *et al*. Prevalence, clinical correlations, comorbidities, and suicidal tendencies in pathological Korean gamblers: results from the Korean Epidemiologic Catchment Area Study. *Soc Psychiatry Psychiatr Epidemiol* 2010; **45**: 621–9.
36. Feigelman W., Wallisch L. S., Lesieur H. R. Problem gamblers, problem substance users, and dual-problem individuals: an epidemiological study. *Am J Public Health* 1998; **88**: 467–70.
37. Bondolfi G., Jermann F., Ferrero F., Zullino D., Osiek C. H. Prevalence of pathological gambling in Switzerland after the opening of casinos and the introduction of new preventive legislation. *Acta Psychiatr Scand* 2008; **117**: 236–9.
38. Bondolfi G., Osiek C., Ferrero F. Prevalence estimates of pathological gambling in Switzerland. *Acta Psychiatr Scand* 2000; **101**: 473–5.
39. Marshall K., Wynne H. Against the odds: a profile of at-risk and problem gamblers. *Canadian Social Trends* 2004; **73**: 25–9.
40. Afifi T. O., Cox B. J., Martens P. J., Sareen J., Enns M. W. The relationship between problem gambling and mental and physical health correlates among a nationally representative sample of Canadian women. *Can J Public Health* 2010; **101**: 171–5.
41. Dani J. A., Harris R. A. Nicotine addiction and comorbidity with alcohol abuse and mental illness. *Nat Neurosci* 2005; **8**: 1465–70.
42. Hasin D. S., Stinson F. S., Ogburn E., Grant B. F. Prevalence, correlates, disability, and comorbidity of DSM-IV alcohol abuse and dependence in the United States: results from the national epidemiologic survey on alcohol and related conditions. *Arch Gen Psychiatry* 2007; **64**: 830–42.
43. Potenza M. N. Should addictive disorders include non-substance-related conditions? *Addiction* 2006; **101**: 142–51.
44. Merikangas K. R., Mehta R. L., Molnar B. E., Walters E. E., Swendsen J. D., Aguilar-Gaziola S. *et al*. Comorbidity of substance use disorders with mood and anxiety disorders: results of the international consortium in psychiatric epidemiology. *Addict Behav* 1998; **23**: 893–907.
45. Slutske W. S., Caspi A., Moffitt T. E., Poulton R. Personality and problem gambling: a prospective study of a birth cohort of young adults. *Arch Gen Psychiatry* 2005; **62**: 769–75.
46. Kennedy S. H., McIntyre R., Milev R., le Melledo J., Bisserbe J., Zimmerman M. *et al. Frequency and correlates of gambling problems in depressed and bipolar outpatients*. Ontario Problem Gambling Research Centre; 2008. Available at: http://www.gamblingresearch.org/content/research.php?appid=2368 (accessed 26 July 2010) (Archived by WebCite® at http://www.webcitation.org/5ss8ThMLS).
47. Kim S. W., Grant J. E., Eckert E. D., Faris P. L., Hartman B. K. Pathological gambling and mood disorders: clinical asso ciations and treatment implications. *J Affect Disord* 2006; **92**: 109–16.
48. Quilty L., Watson C., Robinson J., Toneatto T., Bagby R. The prevalence and course of pathological gambling in the mood disorders. *J Gambl Stud* 2010; 1–11.
49. Lenzenweger M. F., Lane M. C., Loranger A. W., Kessler R. C. DSM-IV personality disorders in the National Comorbidity Survey Replication. *Biol Psychiatry* 2007; **62**: 553–64.
50. Grant B., Hasin D., Stinson F., Dawson D., Chou S., Ruan W. *et al*. Prevalence, correlates, and disability of personality disorders in the United States: results from the national epidemiologic survey on alcohol and related conditions. *J Clin Psychiatry* 2004; **65**: 948–58.
51. Slutske W. S., Eisen S., Xian H., True W. R., Lyons M. J., Goldberg J. *et al*. A twin study of the association between pathological gambling and antisocial personality disorder. *J Abnorm Psychol* 2001; **110**: 297–308.
52. Wickwire E. M., Burke R. S., Brown S. A., Parker J. D., May R. K. Psychometric evaluation of the national opinion research center DSM-IV screen for gambling problems (NODS). *Am J Addict* 2008; **17**: 392–5.

53. Hodgins D. C. Using the NORC DSM screen for gambling problems as an outcome measure for pathological gambling: psychometric evaluation. *Addict Behav* 2004; **29**: 1685–90.
54. Stinchfield R. Reliability, validity, and classification accuracy of a measure of DSM-IV diagnostic criteria for pathological gambling. *Am J Psychiatry* 2003; **160**: 180–2.
55. Stinchfield R. Reliability, validity, and classification accuracy of the South Oaks Gambling Screen (SOGS). *Addict Behav* 2002; **27**: 1–19.
56. Orford J., Sproston K., Erens B. SOGS and DSM-IV in the British gambling prevalence survey: reliability and factor structure. *Int Gambl Stud* 2003; **3**: 53–65.
57. Holtgraves T. Evaluating the problem gambling severity index. *J Gambl Stud* 2009; **25**: 105–20.
58. Murray V., Ladouceur R., Jacques C. Classification of gamblers according to the NODS and a clinical interview. *Int Gambl Stud* 2005; **5**: 57–61.
59. Wittchen H.-U. Reliability and validity studies of the WHO-Composite International Diagnostic Interview (CIDI): a critical review. *J Psychiatr Res* 1994; **28**: 57–84.
60. Dannon P. N., Lowengrub K., Gonopolski Y., Musin E., Kotler M. Pathological gambling: a review of phenomenological models and treatment modalities for an underrecognized psychiatric disorder. *J Clin Psychiatry* 2006; **8**: 334–9.

Supporting information

Additional Supporting Information may be found in the online version of this article:

Appendix S1 Detailed search strategy.
Appendix S2 Flow diagram of search results.

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APPENDIX B: EMOTIONAL STROOP QUESTIONNAIRE

Please place X in the category (gambling, neutral, emotional) the word belongs to.

	Gambling	Neutral	Emotional
Anguish			
Arguing			
Bathtub			
Bed			
Believe			
Bet			
Books			
Bowl			
Clock			
Container			
Credits			
Cup			
Debt			
Door			
Dryer			
Enjoyable			
Fear			
Gamble			
Gambling			
Happy			
Hero			
Hope			
Hurt			
Iron			
Jackpot			
Keys			
Lose			
Love			
Luck			
Machine			
Mailbox			
Money			
Odds			
Picture			
Pillow			
Play			
Resent			
Ruin			
Shelves			
Track			
War			
Win			
Worrying			
Wrong			

On the scale please indicate how much you think each word is relevant to gambling.

	Not relevant at all	Not very relevant	Neutral	Somewhat relevant	Extremely relevant
Anguish	1	2	3	4	5
Arguing	1	2	3	4	5
Bathtub	1	2	3	4	5
Bed	1	2	3	4	5
Believe	1	2	3	4	5
Bet	1	2	3	4	5
Books	1	2	3	4	5
Bowl	1	2	3	4	5
Clock	1	2	3	4	5
Container	1	2	3	4	5
Credits	1	2	3	4	5
Cup	1	2	3	4	5
Debt	1	2	3	4	5
Door	1	2	3	4	5
Dryer	1	2	3	4	5
Enjoyable	1	2	3	4	5
Fear	1	2	3	4	5
Gamble	1	2	3	4	5
Gambling	1	2	3	4	5
Happy	1	2	3	4	5
Hero	1	2	3	4	5
Hope	1	2	3	4	5
Hurt	1	2	3	4	5
Iron	1	2	3	4	5
Jackpot	1	2	3	4	5
Keys	1	2	3	4	5
Lose	1	2	3	4	5
Love	1	2	3	4	5
Luck	1	2	3	4	5
Machine	1	2	3	4	5
Mailbox	1	2	3	4	5
Money	1	2	3	4	5
Odds	1	2	3	4	5
Picture	1	2	3	4	5
Pillow	1	2	3	4	5
Play	1	2	3	4	5
Resent	1	2	3	4	5
Ruin	1	2	3	4	5
Shelves	1	2	3	4	5
Track	1	2	3	4	5
War	1	2	3	4	5
Win	1	2	3	4	5
Worrying	1	2	3	4	5
Wrong	1	2	3	4	5