COACTION PUBLISHING

# Pathological gambling and the loss of willpower: a neurocognitive perspective

Damien Brevers, PhD[1,2]* and Xavier Noël, PhD[1]

[1]Psychological Medicine laboratory, Faculty of Medicine, Brugmann-campus, Université Libre de Bruxelles, Brussels, Belgium; [2]Department of Psychology, Brain and Creativity Institute, University of Southern California, Los Angeles, CA, USA

The purpose of this review is to gain more insight on the neurocognitive processes involved in the maintenance of pathological gambling. Firstly, we describe structural factors of gambling games that could promote the repetition of gambling experiences to such an extent that some individuals may become unable to control their gambling habits. Secondly, we review findings of neurocognitive studies on pathological gambling. As a whole, poor ability to resist gambling is a product of an imbalance between any one or a combination of three key neural systems: (1) an hyperactive 'impulsive' system, which is fast, automatic, and unconscious and promotes automatic and habitual actions; (2) a hypoactive 'reflective' system, which is slow and deliberative, forecasting the future consequences of a behavior, inhibitory control, and self-awareness; and (3) the interoceptive system, translating bottom-up somatic signals into a subjective state of craving, which in turn potentiates the activity of the impulsive system, and/or weakens or hijacks the goal-driven cognitive resources needed for the normal operation of the reflective system. Based on this theoretical background, we focus on certain clinical interventions that could reduce the risks of both gambling addiction and relapse.

Keywords: *pathological gambling*; *willpower*; *decision making*; *impulsive system*; *reflective system*; *craving*

Received: 31 May 2013; Revised: 9 August 2013; Accepted: 19 August 2013; Published: 26 September 2013

Gambling, defined as an activity in which something of value is risked on the outcome of an event when the probability of winning or losing is less than certain (Korn & Shaffer, 1999), is a very popular recreational activity. Indeed, gambling is widespread in our society (50–80% of the general population buy a lottery ticket $\leq$1 time per year; INSERM, 2008). However, for some individuals (about 15% of frequent gamblers and about 1.6% of the general population; INSERM, 2008; Wardle et al., 2007), gambling can spiral out of control and become a burden.

Pathological gambling is defined as persistent and recurrent maladaptive gambling behavior that is characterized by an inability to control gambling that disrupts personal, family, or vocational pursuits (American Psychiatric Association [APA], 1994). More specifically, similarly as in substance (e.g. alcohol or cocaine) addictions, pathological gamblers exhibit a loss of willpower to resist gambling: they persist in gambling for many 'good' reasons (e.g. to achieve the desired excitement, escape from problems, or relieve a dysphoric mood) but also despite the occurrence of negative consequences directly associated with gambling (e.g. loss of a significant relationship, job, or career opportunity) (APA, 1994).

In this article, we argue that, similarly as in substance addiction, the loss of willpower to resist gambling reflects a pathological usurpation of mechanisms of learning that under normal circumstances serve to shape survival behaviors related to the pursuit of rewards and the cues that predict them (Duka, Crombag, & Stephens, 2011; Hyman, 2005; Milton & Everitt, 2012). Specifically, we will first describe how structural factors (the contingency of loss and reward, near misses, providing gamblers with choice, and the casino-related context) could promote the repetition of gambling experiences and bias learning mechanisms to such an extent that vulnerable individuals may become unable to control their gambling habits. Within the second section of this article, we will focus on neurocognitive processes potentially associated with impaired ability to resist gambling. Specifically, findings from neurocognitive studies on pathological gambling have been divided into three subsections on the basis of recent models of addiction (Hofmann, Friese, & Wiers, 2008; Hofmann, Friese, & Strack, 2009; Noël, Bechara, Brevers, Verbanck, & Campanella, 2010; Noël, Brevers, & Bechara, 2013; Redish et al., 2008; Verdejo-Garcia & Bechara, 2009; Stacy & Wiers, 2010), which view the loss of willpower to resist enactment of addiction-related


Citation: Socioaffective Neuroscience & Psychology 2013, **3**: 21592 - http://dx.doi.org/10.3402/snp.v3i0.21592

behavior as a product of an imbalance between any one or a combination of three key neural systems: (a) an hyperactive 'impulsive' system, which promotes fast and automatic processing of gambling-related cues triggered by addicts' enhanced motivation to gamble coupled with a decreased motivation for other goals (see the 'Hypersensitization toward gambling-related cues' section); (b) a 'hypoactive reflective' system, which is slow and deliberative, forecasting the future consequences of a behavior, efforts to control (or cut back or stop) gambling, and self-awareness (see the 'Disruption of reflective processes' section); and (c) the interoceptive system, translating bottom-up somatic signals into subjective output (e.g. craving), which in turn potentiates the activity of the impulsive system, and/or weakens or hijacks the goal-driven cognitive resources needed to recognize and describe one's own behaviors, cognitions, and mental states (see the 'Between impulsive and reflective systems: the role of interoceptive processes' section). These three subsections start with a short description of the concepts at hand and how these relate to pathological gambling. This description is followed by a review of neurocognitive studies in pathological gambling in connection with the concept. Each subsection ends with a summary of the research findings and a discussion on potential directions for future studies. This review concludes with a general discussion of the reviewed findings and of cognitive interventions that could enhance willpower to resist gambling in pathological gamblers.

## Addictive properties of gambling

How is it possible to develop a state of gambling addiction, that is, without substance intake? In this section, we detail the structural properties of gambling that encourage repeat play.

### *Intermittent schedule for reward and loss*

A possible behavioral explanation for why gamblers sometimes persist in gambling despite increasing losses is that gambling is characterized by intermittent wins and losses delivered on a variable ratio, which entails imperfect prediction of reward (Schultz, 2002). For instance, researchers have observed that behaviors learned under intermittent reward schedules are much more resistant to extinction than behaviors initiated by continuous rewards (in both humans and animals; for a review, see Schultz, Tremblay, & Hollerman, 2003). More specifically, it has been shown that, after an initial learning phase characterized by a continuous reward schedule, subjects almost immediately cease the activity when it is no longer rewarded. By contrast, after a primary phase characterized by intermittent rewards, subjects persist for some time in the activity that was previously rewarded. For instance, Hogarth and Villeval (2010) showed that intermittent schedules of monetary rewards lead to more persistence in behavior when payment stops, while participants in the continuous-reward-schedule condition exit as soon as payment stops.

According to Reward Prediction Error Models of Learning (Montague, Dayan, & Sejnowski, 1996; Schultz, Paul, & Tomas, 1993), intermittent reward learning is much more resistant to extinction because it entails imperfect prediction of reward. More specifically, these models posit that rewarding events that are better than predicted (i.e. a positive reward prediction error) induce high subjective feelings of pleasure and positive emotional states. These models also suggest that subjective feelings of pleasure remain uninfluenced by events that are as good as predicted (i.e. the reward prediction error equals zero), and are depressed by events that are worse than predicted (i.e. a negative reward prediction error) (Schultz et al., 2003). For instance, Fiorillo, Tobler, and Schultz (2003) observed that the magnitude of dopamine (i.e. a neurotransmitter that plays a major role in reward-driven learning for every type of reward) activation in monkeys co-varied with the uncertainty of reward delivery, such that activation was greatest following a signal that predicted reward on 50% of occasions – that is, the signal associated with maximal uncertainty. As such, when we pull the lever and win some money during gambling, we experience a potent rush of pleasure precisely because the reward was so uncertain or unexpected.

In addition to this imperfect prediction of reward, the fickle nature of the payouts in gambling provides us with the illusion of a pattern. That is, we get enough reward that we keep on playing (Peters, Hunt, & Harper, 2010). As a result, the prospect of a 'big win' actually exists on every gambling trial (Redish, Jensen, Johnson, & Kurth-Nelson, 2007). This fallacious expectation of winning may then lead to persistent gambling despite suffering large losses. In this context, when a gambler starts with a very big gain (or a statistically unlikely sequence of wins), the memory of this 'positive surprise' or 'big unexpected strike' persists and can drive betting behavior despite repeated losses (Redish et al., 2007). As a result, pauses in reward acquisition in gambling fail to extinguish gambling action as they would extinguish most learned responses (Redish et al., 2007).

### *'Near-miss'*

In gambling, a near-miss refers to a loss that looks almost the same as a win, such as when two reels of a slot machine display the same symbol and the third wheel displays that symbol immediately above or below the payoff line. In games of skill, near-misses provide useful information for players to gauge their performance. In gambling, however, near-misses do not provide any useful information to the player. In some instances, they can prove to be misleading, such as when a gambler interprets the near-miss as a positive sign of their strategy or when


Citation: Socioaffective Neuroscience & Psychology 2013, 3: 21592 - http://dx.doi.org/10.3402/snp.v3i0.21592

it promotes the view that a win is 'just around the corner' and might promote the continuation of gambling (Griffiths, 1991; Parke & Griffiths, 2004). For instance, by using the functional magnetic resonance imaging (fMRI) technique, Chase and Clark (2010) observed that near-misses activated the ventral striatum in frequent gamblers. They also found that problem gambling severity was associated with higher striatal responses for near-miss events. Thus, in severe problem gamblers, a near-miss might be processed as a reward, which may promote repeat of play in those individuals.

### *Providing gamblers with choice*

Another important feature of gambling games is that individuals are given the opportunity to arrange the gamble themselves (e.g. choosing a favorite number for a lottery, choosing a number or a color for a forthcoming bet at the roulette, and choosing when to stop the reel on a slot machine). This can inflate the gambler's confidence that he or she could win (Ladouceur & Sévigny, 2005). This process is referred to as the 'illusion of control' and was first highlighted in a series of classic experiments by Langer (1975). In these experiments, people had to buy tickets for an office raffle. Half of the people could choose their ticket number, and half were just given a numbered ticket. Later, each person was asked if she could sell back her raffle ticket. People who were able to choose the ticket number valued their tickets significantly more than did those who did not get to choose their tickets, although both groups clearly understood that the outcome of the raffle was random. For instance, subjects who were initially able to choose their ticket asked for more money (e.g. $7) to exchange compared with the group who were allocated a ticket at random (e.g. $2). In a follow-up experiment, subjects who had chosen their ticket were more likely to refuse a swap for a ticket in a second lottery with a higher chance of winning (Langer, 1975). This illustrates how perceived control can actually cause subjects to reject a genuine opportunity to increase their chances of winning. Thus, providing the player with choice in an event that is understood to be random has a powerful effect on the player.

Illusory perceived control has also been reported in gambling. For instance, in craps, consistent with an effect of personal control, when it is a player's turn to shoot the dice (in craps, gamblers play in a team where they take turns throwing the dice onto the craps table), he is more likely to place higher bets than when other players are shooting (Davis, Sundahl, & Lesbo, 2000). Similarly, when given a choice between control over chip placement and random chip placement, roulette players have been shown to prefer to select their own number (Dixon, Hayes, & Ebbs, 1998). In each of these examples, the presence of personal control has no effect whatsoever on the likelihood of winning.

In a recent study, Clark and collaborators (2012) observed that illusory perceived control can also modulate the impact of near-misses. More specifically, these authors monitored electrodermal activity (EDA) and heart rate (HR) activity of non-gambler student participants during a simulated slot-machine task involving unpredictable monetary wins. Perceived personal control was manipulated by allowing participants to select the play icon on some trials and by having the computer automatically select the play icon on other trials. Through this design, Clark, Crooks, Clarke, Aitken, and Dunn (2012) observed that, on trials that involved personal choice, near-misses produced higher ratings of 'continue to play' than full-misses. Importantly, compared to full-misses, near-miss outcomes also elicited an EDA increase, which was greater on personal-choice trials. Near-misses were also associated with greater HR acceleration than other outcomes. Altogether, the results of Clark and colleagues (2012) suggest that, in gambling, providing the player with choice (i.e. play icon selection on some trials) has a powerful effect on the player's illusory perceived control. This in turn heightens the capacity of near-miss outcomes to elicit excitement, despite their objective non-win status.

### *Casino-related context: sounds, light, alcohol, and pairs*

The topics discussed in this article state that gambling games have their own inner logic. However, it must be remembered that gambling occurs in a typical environment, usually casino settings, in which nothing is left to chance in order to encourage gamblers to stay and spend their money. The combination of the structural characteristics of the actual game being played (i.e. intermittence of wins and losses, near-misses, and providing gamblers with choice) and the situational characteristics of gambling environments has been identified as a critical ingredient in determining the repetition of gambling behavior (e.g. Finlay, Marmurek, Kanetkar, & Londerville, 2007). Indeed, entering a casino is normally an arousing experience for individuals as they enter a pleasurable atmosphere induced by general noise, colors, and sounds (Hess & Diller, 1969). The situational characteristics of the casino setting are typically those features of the environment that often encourage people to gamble in the first place and in some cases may facilitate further gambling (Griffiths & Parke, 2003). Examples of such characteristics include sensory factors (e.g. atmospherics, light, color, and sound effects), access to alcohol, and the presence of other people in the vicinity.

#### Music and sounds

Researchers have consistently argued that sound effects contribute to the encouragement of gambling (e.g. Griffiths, 1993). For instance, Dixon, Trigg, &

Griffiths, (2007) found that fast-tempo music (i.e. fast music) significantly influenced a participant's betting speed when gambling. Furthermore, the music played when one wins is distinctive and memorable and could also lead to further plays (Spenwyn, Barrett, & Griffiths, 2010). For instance, slot machine wins are routinely accompanied by bright flashing lights and loud noises. Wagenaar (1988) suggested that this sensory stimulation heightens the recall of past wins rather than past losses. By distorting the memory of past outcomes, this may bias the decision to continue playing.

#### Lights

Playing the tables in a casino can be a disorienting experience, thanks, in part, to a lack of clocks and natural daylight. Casinos can even simulate daylight during the dark hours to lull players into remaining at the tables and slot machines. 'Warm' colors are used in order to attempt to arouse consumers. For instance, red is often used in gambling environments (e.g. Griffiths & Swift, 1992). This color has been found to be stronger, more exciting, and more arousing than blue (e.g. Yoto, Katsuura, Iwanaga, & Shimomura, 2007). Stark, Saunders, and Wookey (1982) provide one of the only empirical contributions assessing the effects of colored light on gambling behavior. Their study found that gambling under red light (compared to blue light) led to more risk taking, higher stakes, and more frequent bets. More recently, Spenwyn and collaborators (2010) observed that the combined effects of both high-tempo music and red light result in faster bets in a computerized version of roulette.

#### Alcohol

Engaging in gambling while drinking is common (Lesieur, Blume, & Zoppa, 1986). Indeed, one tactic used in some casinos to keep gamblers betting is to offer free alcoholic drinks. Drinks may be brought to people gambling to ensure that they don't stop playing to go get a drink. More importantly, the co-occurrence of gambling and alcohol use might, in itself, serve to increase the repetition of bets. Evidence suggests that alcohol consumption can seriously damage cognitive (e.g. self-reflection and attention) processes, leading to poor decision making (e.g. Baron & Dickerson, 1999) and increased risk taking (Breslin, Sobell, & Cappell, 1999). For instance, several studies (e.g. Cronce & Corbin, 2010) reported that alcohol use contributes to longer duration of gambling episodes and increased amount of money spent. One explanation of the impact of alcohol use on gambling behavior is that alcohol intake may restrict attention to the most salient and immediate cues only, leading to less regard for the actual odds of a gamble and previous betting losses (Steele & Josephs, 1988).

#### Gambling 'with' others

On the casino floor, despite the fact that gamblers are always attempting to beat the odds against the machine, they are also in a sense in competition with others. For instance, when someone has had a big win on a machine, it will somehow mean lower immediate future payouts on this specific machine. In other words, gamblers will usually stick with a machine that has not paid out recently in the hopes that the payout is coming (Harrigan, 2009). Moreover, the attention paid to winners on the casino floor is also in a sense a form of competition (Harrigan, 2009). For instance, the entrances to casinos all have photos of large checks being handed to the winners.

## Gambling habits: how they take control

In the 'Addictive properties of gambling' section, we have seen that gambling is characterized by structural properties that encourage repeat play. But how is it possible to keep gambling despite growing monetary losses? Here, we advance that gambling-related behavior and stimuli can acquire properties for triggering impulsive, automatic, and involuntary motivational states. If strong enough, these processes could interfere or 'hijack' high-order cognitive and affective mechanisms that are necessary for exerting control and enable an individual to resist the temptation to exhibit addiction-related behaviors (Verdejo-Garcia & Bechara, 2009).

### *Hypersensitization toward gambling-related cues*

Throughout the repetition of gambling experiences, learned associations between gambling-rewards hedonic effects and stimuli in the environment endow these gambling-related cues with the ability to directly access the mental representations associated with the action of gambling and, like gambling itself, make them attractive (Hofmann et al., 2009). These associations are created and strengthened gradually through classical conditioning processes, that is, by the learning history of temporal or spatial coactivation between external stimuli and affective reactions (Hofmann et al., 2008, 2009). More specifically, through repeated experience with gambling, an associative cluster may be formed that links (1) gambling cues, (2) positive mood change, and (3) the behavioral schema that has led to the positive affect (e.g. the action of gambling) (Hofmann et al., 2009). These associative clusters endow the organism with a sense of preparedness, that is, the ability to evaluate and respond to the environment quickly in accordance with one's current needs and previous learning experiences (Hofmann et al., 2008, 2009). When, for example, the gambler encounters gambling-related cues, the 'gambling cluster' may get reactivated, which will automatically trigger a corresponding impulse, consisting of a positive incentive value attributed to gambling and a corresponding behavioral schema to approach it (Stacy & Wiers, 2010). Put differently, the broad 'working hypothesis' here is that a repeated and marked 'high' through gambling action results in long-lasting sensitization of impulsive processes for gambling behavior and related cues. As a result, gambling-related cues may be flagged as salient and grab the addicts' attention (Field, Munafò, & Franken, 2009) and may also automatically trigger motivation-relevant associative memories (Stacy & Wiers, 2010). In the remainder of this section, we detail findings of studies that have examined the presence of implicit cognition in problem gambling, that is, processes that are fast and automatic, 'grab' attention (i.e. *attentional bias*), as well as trigger automatic implicit memory associations (i.e. *implicit association*).

### Attentional bias

Attentional bias is a form of modified attentional processing for addiction-relevant stimuli (Franken, 2003). In terms of gambling, this means that, relative to non-gamblers, gambling-related stimuli catch problem gamblers' attention to a greater degree than non-gambling stimuli (Molde et al., 2010).

Several studies have emphasized the presence of attentional bias for gambling-related stimuli in problem gamblers. For instance, using a modified Stroop paradigm, participants with compulsive gambling took longer to name the color of words relating to gambling compared to healthy controls or frequent non-problem gamblers (Boyer & Dickerson, 2003; McCusker & Gettings, 1997; Molde et al., 2010). Other evidences for the presence of attentional bias in problem gambling come from Zack and Poulos (2004), who investigated whether gambling-like drugs could prime the addiction-related implicit cognition network. More specifically, these authors observed that, during a rapid reading task in which target words were degraded with asterisks (e.g. w*a*g*e*r), a dopamine agonist amphetamine heightened pathological gamblers' readiness to read gambling-related words while concurrently slowing their reading speed of neutral words (Zack & Poulos, 2004). In addition, Zack and Poulos (2004) showed that the dopamine agonist enhanced self-reported motivation to gamble in pathological gamblers. These results suggest that activation of the mesolimbic dopamine system gives rise to an incentive-'seeking' state, which also involves the collateral suppression of alternative motivations. Enhanced saliency for gambling-related cues in problem gamblers has also been highlighted by research on cue reactivity. More specifically, as compared with controls, several fMRI studies found that, while viewing gambling-related pictures or videos, pathological gamblers exhibited higher activation in brain areas associated with a salience or motivational circuitry, including the amygdala, orbitofrontal cortex (OFC), and ventral striatum (Crockford, et al., 2005; Goudriaan, De Ruiter, Van den Brink, Oosterlaan, & Veltman, 2010; van Holst, Van Holstein, Van den Brink, Veltman, & Goudriaan, 2012a; but see Potenza et al., 2003).

In two recent studies, Brevers and collaborators (2011a, 2011b) have investigated the time course of attentional bias for gambling-related information in problem gamblers. The assessment of attentional bias at different levels of attentional processing allows one to examine whether heightened salience for gambling cues acts at an automatic and/or at a more conscious deliberate level. More specifically, an early level of attentional processing (e.g. attentional encoding, or the initial orientation of attention) depends essentially on automatic-habit processes (Browning, Holmes, & Harmer, 2010; Cisler & Koster, 2010), whereas later attentional processes (i.e. maintenance of attention and disengagement of attention) involve higher levels of consciousness (Cisler & Koster, 2010). In a first study, in order to examine gambling-related attentional bias at the level of attentional encoding, Brevers et al. (2011a) used an attentional blink (AB) paradigm. The AB phenomenon refers to the observation that the second of two-masked targets (T1 and T2), which appears in a rapid serial visual presentation (RSVP) stream of distracters, is usually poorly identified when it is presented within a short time interval after T1 (e.g. within several hundred milliseconds; Raymond, Shapiro, & Arnell, 1992). Using this task, Brevers et al. (2011a) observed that, in problem gamblers and compared with neutral words, gambling-related cues were less affected by the interference of other RSVP items within a short time interval after T1. This result suggests that problem gamblers are more likely to identify gambling-related words than neutral words under conditions of limited attentional resources, which is consistent with an enhanced attentional bias for gambling cues at the encoding level in problem gamblers. In another study, Brevers et al. (2011b) monitored eye movements during a change detection task. They showed that, compared with their controls, problem gamblers were faster to detect gambling-related than neutral-related change. In addition, these authors observed that problem gamblers directed their first eye movements more frequently toward gambling-related than toward neutral stimuli, exhibited more gaze fixation counts on gambling stimuli, and spent more time looking at gambling-related than neutral stimuli. These results suggest that problem gamblers exhibit attentional bias toward gambling-related cues at both levels of initial engagement (i.e. first eye movement) and maintenance of attention (i.e. fixation length and fixation count).

### Implicit association

Implicit association refers to spontaneous associations between addiction-related cues and affective, arousal, and motivational representation in memory. This association tends to reveal automatic, impulsive, cognitive-motivational mental processes, which are sparsely dependent on or not available to conscious awareness (Stacy & Wiers, 2010). In other words, implicit association could be defined as an introspectively unidentified (or inaccurately identified) trace of past experience that mediates feeling, thought, or action (Greenwald & Banaji, 1995).

The Implicit Association Task (IAT; Greenwald, McGhee, & Schwartz, 1998) is a paradigm that is commonly used to assess implicit association. In a typical IAT, stimuli belonging to one of four possible categories are presented one by one on a computer screen. On each trial, participants categorize (as fast as they can) the presented stimulus by pressing one of two keys. The assumption underlying the IAT effect is that performance should be better in a task where associated categories are assigned to the same motor responses. For instance, when classifying names of flowers or insects (i.e. target stimuli) and positive or negative words (i.e. attribute stimuli), people are faster when flowers and positive words are assigned to one key and insects and negative words to the second key, as compared with the condition in which insects and positive words are assigned to one key and flowers and negative words to the other key.

So far, two studies (Brevers et al., 2013a; Yi & Kanetkar, 2010) have directly investigated implicit association toward gambling in gamblers. Yi and Kanetkar (2010) showed that problem gamblers held more positive attitudes toward gambling than did both non-problem gamblers and non-gamblers. However, a limitation of Yi and Kanetkar's study (2010) was that they used a bipolar version of the IAT, which measures the relative implicit attitude toward gambling (i.e. gamblers hold stronger positive than negative associations toward gambling). More specifically, the bipolarity of the attribute dimension (i.e. positive versus negative words) implies that the IAT effect only indicates whether the target stimuli (i.e. gambling pictures) are associated more strongly with one attribute category (e.g. negative) relative to the other attribute category (e.g. positive). Consequently, the IAT effect is difficult to interpret, and meaningful information may be lost when assessing implicit associations toward objects for which ambivalence can be high, such as addiction (see Miller & Rolnick, 1991, who developed the idea that ambivalence toward addictive behaviors is a highly prevalent phenomenon in addicts). For instance, it is theoretically possible that two participants show an IAT effect of the same size even though one participant only has negative implicit associations with gambling while the other participant has both strong negative implicit associations with gambling and somewhat weaker positive implicit associations with gambling (Houben & Wiers, 2008). In order to track a possible state of dual attitudes (both positive and negative) toward gambling (i.e. ambivalence), Brevers et al. (2013a) used a unipolar variant of the IAT that presents the attribute dimension in a unipolar format (Houben & Wiers, 2008). Specifically, while the bipolar IAT contrasts two attribute categories with each other (e.g. positive vs. negative), unipolar IATs contrast the same attribute categories with neutral categories (e.g. positive vs. neutral and negative vs. neutral). Through this method, Brevers et al. (2013a) found that problem gamblers exhibited positive but not negative implicit associations toward gambling. These results are consistent with findings from Yi and Kanetkar (2010). Importantly, the use of a unipolar measure of implicit associations rules out the possibility that problem gambling was associated with both positive and negative automatic associations.

Overall, findings from Yi and Kanetkar (2010) and Brevers et al. (2013a) are important because they suggest that, in gamblers who had experienced a number of deleterious consequences in relation to their gambling behaviors (e.g. most participants agreed with the assumption that they feel that they ever had a problem with betting or money gambling), there is no sign of dual implicit (both positive and negative) attitudes toward their gambling behaviors. Thus, positive implicit attitudes toward gambling might be one of the driving forces behind the persistence of gambling despite the occurrence of severe deleterious consequences.

### Summary and future directions

Findings highlighted in this section indicate that problem gambling is characterized by implicit cognitions toward gambling-related information. More specifically, research on attentional bias and implicit association in problem gambling indicates that gambling-related cues are flagged as salient, grab the addicts' attention, and automatically trigger positive-rewarding representations. Taken together, these findings suggest that problem gambling is underlined by powerful impulsive motivational-habit machinery that might be set in motion outside awareness and perhaps in the absence of deliberate cognitive control.

In addition to attentional bias and implicit association, future research should examine whether gambling-related stimuli induce automatic action tendencies in problem gamblers. For instance, research on substance addiction has shown that substance-related stimuli can trigger an automatic motor response of approach (for a review, see Stacy & Wiers, 2010). Several paradigms have been developed to assess this action tendency. Consider, for example, the stimulus–response compatibility task (Mogg, Bradley, Field, & De Houwer, 2003), in which participants are instructed, in one block, to move as fast as they can a manikin (i.e. a little man) toward substance-related pictures and away from neutral pictures (the 'approach substance' block), and, in another block, to move the manikin away from the substance-related pictures and


Citation: Socioaffective Neuroscience & Psychology 2013, **3**: 21592 - http://dx.doi.org/10.3402/snp.v3i0.21592

toward neutral pictures (the 'avoid substance' block). Through this task, substance abusers (of alcohol, cigarettes, or marijuana) exhibited relatively fast approach movements toward substance cues (Field, Eastwood, Bradley, & Mogg, 2006; Field, Kiernan, Eastwood, & Child, 2008; Mogg et al., 2003). Hence, by highlighting that addiction-related cues automatically trigger a corresponding impulse that consists of a behavioral schema to approach it (Stacy & Wiers, 2010), this type of study provides strong evidence for the presence of automatic incentive habits in gambling addiction.

### *Disruption of reflective processes*

While the hyperactivity of impulsive processes may explain addicts' motivation to seek out relevant rewards, it is clear that it does not explain how one controls his or her gambling behavior. This function refers to the action of the so-called reflective system, which is necessary to control basic impulses and allow more flexible pursuit of long-term goals.

The action of the reflective system depends on the integrity of two sets of neural systems: a 'cool' and a 'hot' executive functions system (Zelazo & Muller, 2002). Cool executive functions are mediated by the lateral inferior and dorsolateral prefrontal cortex (Kerr & Zelazo, 2004) involved in working memory operations such as maintaining and updating relevant information, shifting back and forth between multiple tasks, and deliberately suppressing prepotent responses that are no longer relevant (Zelazo & Muller, 2002). Hot executive functions are mediated by the orbitofrontal (OFC) and ventromedial prefrontal (VMPC) structures involved in triggering somatic states from memories, knowledge, and cognition, which allow activation of numerous affective and emotional (somatic) responses that conflict with each other (Zelazo & Muller, 2002); the end result is that an overall positive or negative signal emerges (Bechara & Damasio, 2005). Thus, adequate decision making reflects the integration of cognitive (i.e. cool executive functions) and affective (i.e. hot executive functions) systems, which results in the ability to advantageously weigh short-term gains against long-term losses, that is, to optimally anticipate the potential outcomes of a given decision (Damasio, 1996). These operations are achieved through relatively slow, controlled processes and allow one to hold onto a mental representation for contemplation and self-reflection, through which immediate stimulus control can be overcome (Smith & DeCoster, 2000).

#### Disruption in 'hot' reflective function

Disruption in hot reflective function could impact decision making that is mainly influenced by affect and emotion (Brand, Labudda, & Markowitsch, 2006; Krain, Wilson, Arbuckle, Castellanos, & Milham, 2006), such as decision making under ambiguity (i.e. situations of decision making with missing information on reward probability), in which memories of the rewards and losses from previous trials have to be triggered in order to anticipate both the short-term (e.g. monetary gains) and long-term consequences (e.g. accumulation of monetary losses) of a given choice (Bechara, 2004). Decision making under ambiguity in pathological gambling has been examined with the Iowa Gambling Task (IGT). This task was introduced as a tool to measure 'risk-anticipation', which involves probabilistic learning via monetary rewards and punishments. Several studies (e.g. Brevers et al., 2012a; Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2005) have shown that pathological gamblers exhibit a stubborn preference for options featuring high rewards but higher losses instead of options featuring low rewards and losses.

Results from behavioral studies investigating IGT performance in pathological gamblers suggest that pathological gambling is characterized by impaired hot reflective function. In other words, pathological gamblers may be hampered in their ability to trigger somatic states from previous emotional experiences of rewards and losses, which are necessary for advantageously pondering the pros and cons of a forthcoming choice. Supporting this idea, anticipatory psychophysiological reactions to disadvantageous choices during the IGT were lower in pathological gamblers than in non-gamblers (Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2006). However, recent brain-imaging studies suggest that disadvantageous performances of pathological gamblers during the IGT may not be due to a fundamental impairment in their ability to trigger a somatic state but rather to hypersensitivity for immediate and larger monetary rewards. Recent positron emission tomography (PET) studies found that, as compared with healthy controls, pathological gamblers exhibited more dopaminergic release in the ventral striatum (which is involved in the anticipation of monetary rewards; Knutson, Fong, Bennett, Adams, & Hommer, 2003) in response to high-risk choice during the IGT (Linnet, Møller, Peterson, Gjedde, & Doudet, 2011; Linnet, Peterson, Doudet, Gjedde, & Møller, 2010). More specifically, whereas in healthy controls dopamine is released in response to advantageous deck choices (i.e. options featuring low rewards and losses), for pathological gamblers, dopamine release (Linnet et al., 2010, 2011) and excitement (Linnet et al., 2010) are higher in response to disadvantageous deck selections (i.e. options featuring high rewards and higher losses). Using the fMRI technique, Power and collaborators (2012) have observed that, during high-risk choice in the IGT, pathological gamblers exhibited increased activation in regions encompassing the extended reward pathway, including brain areas involved in the integration of emotional and cognitive input (i.e. the OFC; Rolls & Grabenhorst, 2008) and in reactivity to emotional information (i.e. the amygdala; Gallagher & Chiba, 1996). In another fMRI study, Miedl and collaborators (2010) have observed that, before taking high-risk decisions in a quasi-realistic blackjack scenario, pathological gamblers exhibited enhanced brain responses in the inferior OFC and in the medial pulvinar nucleus (the pulvinar is a relay thalamic nucleus that receives interoceptive input and in turn projects to the insula, all of which are brain areas associated with impulsive urges; Craig, 2009; Sewards & Sewards, 2003), whereas controls showed a significant signal increase in low-risk conditions (Miedl, Fehr, Meyer, & Herrmann, 2010), which might reflect a cue-induced signal increase for high-risk situations in pathological gamblers. Finally, van Holst and collaborators (2012b) recently showed that, compared with non-gamblers, pathological gamblers exhibited higher activity in the ventral striatum and the OFC during the expectation (i.e. the period in which the subject has made a decision and awaits the outcome) of gambling outcome. Altogether, these results suggest that pathological gamblers' hypersensitivity toward high immediate gratification may literally 'hijack' the goal-driven reflective resources that are ordinarily needed for choosing according to both long- and short-term outcomes.

### Disruption in 'cool' reflective function

Recent findings on abnormal gambling suggest that the ability to suppress automatic responses could be critical to gambling addictive behavior. For instance, impaired prepotent response inhibition is thought to accelerate the course of addiction by aggravating problem gambling (Brevers et al., 2012b) and compromising abstinence from gambling (Goudriaan, Oosterlaan, de Beurs, & van den Brink, 2008). Reductions in inhibition of prepotent responses may essentially make incentive habits more powerful, increasing their status as a 'default' automatic-habit system (Houben & Wiers, 2009). In other words, impaired response inhibition could lead to abnormal salience attribution toward gambling cues in PG.

The inhibition of prepotent motor responses can be indexed by stop-signal (Dougherty, 2003) and go/no-go tasks (e.g. Newman, Widom, & Nathan, 1985), which require the subject to withhold simple motor responses either when a stop signal occurs (stop-signal task) or when a particular kind of stimulus is presented (go/no-go task). Impaired response inhibition performance (i.e. prolonged latency of motor response inhibition) has been previously highlighted in pathological gambling by using the stop-signal task (Odlaug, Chamberlain, Kim, Schreibe, & Grant, 2011) and the go/no-go paradigm (Goudriaan et al., 2005, 2006; Kertzman et al., 2008; Roca et al., 2008). Several studies (e.g. Grant, Chamberlain, Schreiber, Odlaug, & Kim, 2011; Lawrence, Luty, Bogdan, Sahakian, & Clark, 2009) also reported intact response inhibition using a stop-signal task but in a group of mostly problem (rather than pathological) gamblers. Besides, the absence of behavioral difference between controls and problem gamblers on response inhibition is not necessarily indicative of intact response inhibition processes. More specifically, results from recent studies suggest that problem gambling is underlined by a disruption of brain circuits involved in motor response inhibition. For instance, de Ruiter, Oosterlaan, Veltman, Van den Brink, and Goudriaan (2012) highlighted diminished dorsomedial prefrontal cortex activity during a stop-signal task in problem gamblers who exhibited a similar behavioral performance as their controls on motor response inhibition. Conversely, van Holst et al. (2012a) observed increased dorsolateral and anterior cingulate cortex activity in pathological gamblers compared to controls during inhibition of neutral stimuli on a go/no-go task. In other words, a more effortful strategy (i.e. higher brain activation) is undertaken in pathological gamblers to perform at a similar level as their controls (van Holst et al., 2012a).

Importantly, Goudriaan and colleagues (2008) observed that poor inhibition of motor response in adult outpatients with pathological gambling is a critical factor responsible for the pathological gambler's weak capacity to remain abstinent 1 year after being enrolled in cognitive-behavioral treatment for pathological gambling. Moreover, a couple of studies have shown that response inhibition deficits are directly associated with the severity of gambling problems (Brevers et al., 2012b; Odlaug et al., 2011). Taken together, findings from these studies suggest that, once impaired, prepotent response inhibition may dramatically increase the risk to become (or remain) addicted to gambling.

### Summary and future directions

Findings described in this section suggest that pathological gambling is associated with hampered hot and cool reflective processes. Nevertheless, with regard to hot reflective function, it seems that pathological gamblers' stubborn preference for options featuring high-uncertain rewards may not be due to a fundamental impairment in their ability to trigger a somatic state but, rather, to a hypersensitivity for immediate and larger monetary rewards. In other words, in pathological gamblers, the hyperactive salience directed at high-uncertain rewards seems to elicit gambling-related behaviors regardless of harmful consequences (e.g. monetary loss). A limitation of previous studies is that they did not specifically examine the impact of prior risk experience on pathological gamblers' subsequent decisions (i.e. risky vs. safe choices). Exploring this factor may be particularly relevant for the study of pathological gambling. Indeed, pathological gamblers are less sensitive to monetary reward and loss than non-gamblers (de Ruiter et al., 2009; Reuter et al., 2005; Tanabe et al., 2007; but see


Citation: Socioaffective Neuroscience & Psychology 2013, 3: 21592 - http://dx.doi.org/10.3402/snp.v3i0.21592

Hewig et al., 2010), which could lead those persons to persist in high-risk choices despite suffering large losses (de Ruiter et al., 2009).

With regard to cool reflective processes, impaired response inhibition in pathological gamblers suggests that this process may represent an important neurocognitive mechanism in the maintenance of their severe gambling problems. However, such correlational findings are difficult to interpret securely when referred to the hypothesis advancing that dysfunction of the inhibitory control system could further exacerbate automatic processes. Indirect evidence for this hypothesis in pathological gambling comes from a study by Zack and Poulos (2009). These authors observed that modafinil decreased the reinforcing effects of a slot machine game (i.e. decreased reactivity to rewards) in pathological gamblers and improved their inhibitory control performances during a stop-signal task. More direct evidence of the interaction between motor response inhibition and saliency directed at gambling-related cues comes from a recent study by van Holst and collaborators (2012a). These authors showed that pathological gamblers activated the ventral striatum and dorsolateral prefrontal cortex to a greater extent while viewing gambling-related pictures (as compared with neutral ones) and that they obtained better performances than control participants during motor response inhibition of gambling-related pictures on a go/no-go task. These findings suggest that saliency toward gambling cues (evidenced through ventral striatal activation) facilitates motor response inhibition of gambling-related pictures in pathological gamblers. Nevertheless, further studies are needed in order to examine if saliency toward gambling cues could also be overwhelming, resulting in an overload of attentional resources directed at gambling stimuli and in deficient inhibitory control (Verdejo-Garcia et al., 2012), such as when abstinent addicts experience a high subjective state of an urge to gamble. In the "Between impulsive and reflective systems" section, we focus on the potential impact of subjective craving on impulsive and reflective processes in problem gambling.

## *Between impulsive and reflective systems: the role of interoceptive processes*

In addition to the imbalance between the impulsive and the reflective processes, it has recently been argued that interoceptive processes may contribute to the onset and maintenance of addiction by translating sensory signals into what one subjectively experiences as a feeling of desire, anticipation, or urge (Goldstein et al., 2009; Goldstein & Volkow, 2011; Naqvi & Bechara, 2009; Verdejo-Garcia et al., 2012). The insular cortex has emerged as the primary neural hub of interoceptive processing (Craig, 2009).

### Insula as a 'gate' system

The formation of interoceptive representation through insular cortex activation is crucial for building advantageous decision making (Naqvi & Bechara, 2009). For example, activation of the insular cortex has been found in anticipating and experiencing both monetary gain (Clark, Lawrence, Astley-Jones, & Gray, 2009; Delgado, Nystrom, Fissell, Noll, & Fiez, 2000; Elliott, Friston, & Dolan, 2000; Izuma, Saito, & Sadato, 2008) and loss (Paulus, Rogalsky, Simmons, Feinstein, & Stein, 2003; Samanez-Larkin, Hollon, Carstensen, & Knutson, 2008). Other studies have shown that the insula is also sensitive to risk level (e.g. Xue, Lu, Levin, & Bechara, 2010). The insula is also triggered by excessive prices when deciding on whether or not to purchase a product (Knutson, Rick, Wimmer, Prelec, & Loewenstein, 2007). Thus, by working together with the orbitofrontal and ventromedial brain regions, the insula can trigger bodily states, map bodily states, and represent the relationship between changes in the bodily states and the objects that elicited them (Naqvi & Bechara, 2009).

However, it has recently been suggested that the insula may also hamper the ability to decide advantageously. Indeed, in addicted individuals, hyperactivity of impulsive processes can bias the action of the insula cortex toward the enactment of addiction-related behaviors (Naqvi & Bechara, 2009). More specifically, the insula may play a key role in translating interoceptive signals into what one subjectively experiences as a feeling of urge toward addiction-related actions or cues (Craig, 2009; Naqvi & Bechara, 2009). For instance, imaging studies evidenced activity within the insula correlating with the subjects' rating or urge for cigarettes, cocaine, alcohol, and heroin (Craig, 2009; Naqvi & Bechara, 2009, 2010; Verdejo-Garcia et al., 2012). Strokes that damage the insula tend to literally wipe out the urge to smoke in individuals who were previously addicted to cigarette smoking (Naqvi, Rudrauf, Damasio, & Bechara, 2007). In this study, smokers with brain damage involving the insula were $>100$ times more likely than smokers with brain damage not involving the insula to undergo a 'disruption of smoking addiction' characterized by the ability to quit smoking easily, that is to say, immediately, without relapse, and without a persistence of the urge to smoke (Naqvi et al., 2007).

Using functional connectivity analyses, several studies have highlighted interconnectivity between the insula and the striatum in addicts when viewing addiction-related cues (e.g. Nummenmaa et al., 2012). These findings suggest that the insula integrates autonomic and visceral signals into reward-motivational functions. With regard to pathological gambling, a couple of studies showed that problem gamblers exhibit high gambling-related cravings after viewing a series of gambling-related pictures (Goudriaan et al., 2010) or videos (Crockford, Goodyear, Edwards, Quickfall, & el-Guebaly, 2005; Wulfert et al., 2009). Moreover, Goudriaan and colleagues (2010) found brain activation patterns in the insula and in the VMPC during gambling cue reactivity in pathological gamblers, which correlated positively with scores of subjective gambling craving. Similar activations have also been highlighted in nicotine addiction (e.g. Janes et al., 2010). Importantly, recent studies show that disruptions in response inhibition might be more pronounced during heightened motivational states, such as when abstinent addicts experience a high subjective state of an urge to take drugs (Verdejo-Garcia et al., 2012) or drink alcohol (Gauggel et al., 2010). Thus, saliency toward addiction-related cues may be particularly overwhelming under a high subjective state of urge, resulting in an overload of attentional resources toward these affective stimuli and in disrupted inhibitory control, which could lead to relapse in abstinent addicts (Gauggel et al., 2010; Verdejo-Garcia et al., 2012).

In addition, recent theoretical accounts (Goldstein et al., 2009; Goldstein & Volkow, 2011) advance that deprivation interoceptive signals may also hamper metacognitive abilities (i.e. the ability to apply introspection toward one's own behavior, which may be operationalized as the ability to discriminate correct from incorrect performance; Cleeremans, Timmermans, & Pasquali, 2007) in addicts. Such impairment of metacognitive capacity in individuals suffering from addiction may be reflected in one of the most common observations from the clinic of addiction, that is, impairment in recognition of the severity of the disorder by the addict (i.e. lack of insight; Goldstein et al., 2009). For instance, only 4.5% of the 21.1 million persons classified as needing (but not receiving) substance use treatment reported a perceived need for therapy (SAMHSA, 2007). Hence, when metacognitive judgment becomes exceedingly disrupted, the repetition of addiction-related behaviors may be heightened by an underestimation of addiction severity. Dissociations between self-perception and actual behavior have been found in cocaine users (Moeller et al., 2010), with nicotine dependence (Chiu, Lohrenz, & Montague, 2008), in methamphetamine-dependent individuals (Payer, Lieberman, & London, 2011), and in young marijuana abusers (Hester, Nestor, & Garavan, 2009), as well as in pathological gambling (Brevers et al., 2013b, c).

### Summary and future direction

By translating deprivation interoceptive signals into what may become subjectively experienced as a feeling of urge or craving, activation in the insular cortex increases the drive and motivation to smoke, take drugs, or gamble in addicts by (1) sensitizing or exacerbating the activity of the habit or impulsive system; and (2) subverting attention, decision-making, and metacognitive processes to seek and access gambling. Put differently, the insula is viewed as a 'gate' system that responds to homeostatic perturbations and, in turn, has the capacity to 'hijack' or overlap reflective processes toward addiction-related cues at the expense of the cognitive resources necessary for exerting inhibitory control (Sutherland, McHugh, Pariyadath, & Stein, 2012; Verdejo-Garcia & Bechara, 2009). However, future studies are needed to directly examine the impact of gambling-related craving on impulsive (i.e. salience attribution directed at gambling-related cues) and reflective (i.e. response inhibition) processes. For instance, one may expect that, under a high state of gambling-related craving, pathological gamblers would be more hampered in their ability to inhibit gambling-related stimuli as compared with neutral stimuli. With regard to metacognition, the abnormal degree of dissociation found in pathological gamblers between the 'object' and the 'meta' level raised the possibility that poor metacognition leads to poor action and decision-making monitoring and adjustment (Nelson & Narens, 1990). However, additional studies are needed in order to identify how interoceptive signals bias accurate judgment performance in addicts.

## Discussion

In this article, we reviewed the neurocognitive processes potentially involved in pathological gamblers' loss of willpower to resist gambling temptation, that is, their inability to resist high-uncertain rewards despite mounting monetary losses leading to personal, familial, financial, professional, and legal negative consequences.

As a whole, findings suggest that the stubborn persistence of gambling habits in pathological gamblers might be underlined by increased automatic motivational responses directed at gambling-related behaviors coupled with a lowered efficiency of impulse control and self-reflective processes. Put differently, results from cognitive and brain-imaging studies suggest that the failure at self-control in gambling addiction may involve a deregulation in both impulsive and reflective processes, which hampers pathological gamblers' capacity to bypass immediate temptations in the service of long-term goals. In addition, such a dual-process approach also emphasizes the transitional processes from recreational to disorder gambling. Specifically, when a 'prospective' pathological gambler begins to gamble, he is able to contain his gambling within socially acceptable limits. During this 'first stage', gambling induces fun, excitement, new ideas, and stimulation. However, as gambling behavior grows in frequency, it starts to lose some of its seductiveness. Gambling retains its ability to change positively one's mood, but, meanwhile, it grows to exploit and tease apart functions in learning, motivation, and assessment of the salience of a stimulus to such an extent that the vulnerable individual acts out more and more to cover up an extreme need (and sometimes urge) to gamble again. The development of


Citation: Socioaffective Neuroscience & Psychology 2013, **3**: 21592 - http://dx.doi.org/10.3402/snp.v3i0.21592

such motivational machinery is incremental, that is, set in motion spontaneously and independently of explicit cognitive control, and thus relatively impervious to gaining awareness about its triggers. In other terms, the addictive process begins long before the occurrence of negative consequences induced by the repetition of gambling habits. As such, not only pathological but also recreational and low-problem gamblers could benefit from cognitive evaluations aiming at assessing motivational (e.g. attention bias and implicit memory association) and self-regulatory (e.g. inhibition of gambling-related pictures and metacognition) processes associated with their gambling behaviors. Such types of evaluation may help the individual to gain a better insight on processes involved in his own gambling habits, which would allow him to better prevent the development of exaggerated gambling behaviors.

The theoretical framework developed in the present article is in line with other models of addiction, such as the impaired response inhibition and salience attribution (I-RISA) model of addiction (Goldstein & Volkow, 2002). The I-RISA was developed to integrate the increased salience of drug-related cues as a result of repeated drug consumption (in line with hyperactive impulsive processes) with premorbid deficiencies in top-down inhibitory control (in line with hypoactive reflective processes) that leave an individual susceptible to addiction. Findings described in this article are also in line with other theoretical accounts that view addictive behaviors as the results of an increase in approach behavior to addiction-related stimuli. Specifically, according to the allostatic (stability through change) model (Koob & Le Moal, 1997), throughout the development of an addiction, opponent-processes that are part of normal homeostatic limitations of the reward function fail to return within the normal homeostatic range. In this model, addiction is thus viewed as a chronic deviation of a brain reward system's set point that progressively increases, resulting in compulsive drug-seeking and drug-taking behaviors. In line with this account, the incentive sensitization theory (Robinson & Berridge, 1993, 2001, 2008) predicts that the repeated pairing of the drug (triggering a large incentive response) with associated environmental stimuli leads these stimuli to acquire increased salience and capture attention, over and above naturally rewarding stimuli (Robinson & Berridge, 1993). Furthermore, Everitt et al. (2001) argued that addiction-related stimuli elicit stimulus–response mechanisms that are habitual and automatic. As a result, drug-seeking and -taking behavior ultimately becomes compulsive, being inflexible, persistent, and insensitive to devaluation or punishment (Belin & Everitt, 2008; Everitt & Robbins, 2005). Taken together, these three models are in line with studies reviewed in this article that showed that comparable sensitization to addiction-related cues occurs in pathological gambling, which encompasses the presence of implicit cognition toward gambling stimuli, gambling-related craving during gambling-cues reactivity, and higher activity in the brain reward system during the anticipation and expectation of gambling outcomes. It is noteworthy that while these theoretical accounts view addictive behaviors as the results of an increase in impulsive processes toward addiction cues, it does not diminish the importance of the top-down prefrontal inhibitory control in the development of addiction-related behaviors (Goldstein & Volkow, 2011). For instance, the incentive salience hypothesis acknowledges that dispositional weaknesses in executive function may explain why only a subset of individuals exposed to addictive drugs develop a full-blown addiction (Robinson & Berridge, 2008).

Impairments highlighted in pathological gamblers through this review correspond well to disruptions of impulsive (e.g. attentional bias at an early level of attentional processing) and reflective (e.g. disrupted prepotent response inhibition) processes highlighted in drug and alcohol dependence (for a review, see Leeman & Potenza, 2012; Noël et al., 2010, 2013; Stacy & Wiers, 2010), suggesting that gambling addiction shares common mechanisms with substance addiction. In line with the classification of pathological gambling in the DSM-V, gambling disorder can thus be viewed as a 'behavioral addiction' which shares common mechanisms with substance dependence but where, critically, there is no administration of an exogenous substance to cause harmful effects in the brain. Hence, given the absence of the confounding effect of chemical substances that can alter the brain in many non-specific ways, the study of pathological gambling offers perhaps one of the best approaches to understanding and extracting components specifically involved in the development of addiction. Noteworthy, the present article reviewed findings highlighted in samples of problem and pathological gamblers with no comorbid substance diagnoses. Hence, by taking into account that up to 73% of pathological gamblers have a lifetime comorbid alcohol use disorder and up to 38% have a lifetime substance use disorder (Petry, Stinson, & Grant, 2005), we may be focused on a super-selected sample of problem and pathological gamblers. This limits the generalizability of findings reviewed in the present paper. For instance, a number of studies have highlighted that, as compared with pathological gamblers without substance use disorders, pathological gambling subjects with substance abuse disorders are characterized by higher decreased self-control processes (e.g. poor ability to delay gratification [Petry, 2001; Petry & Casarella, 1999] and impairment in decision making under risk [Ledgerwood, Alessi, Phoenix, & Petry, 2009]).

Finally, with regard to clinical practice, the adoption of cognitive interventions aiming at moderating the actions of impulsive processes or at boosting reflective resources may provide a useful tool for helping pathological gamblers to better cope with their inability to resist gambling. For instance, based on findings showing (early and late) attentional bias toward gambling cues in problem gamblers (Brevers et al., 2011a, b), future studies should test whether cognitive procedures (e.g. attentional bias modification training during a modified visual probe task; MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002) diminish gambling behaviors in pathological gamblers. More specifically, in alcohol abuse disorders, it has recently been demonstrated that, when randomly assigned to either the attending (i.e. directing attention toward the location of alcohol-related cues) or avoiding (i.e. directing attention away from the location of alcohol-related cues) condition of a modified probe task, only alcohol-dependent participants who were required to systematically avoid alcohol cues showed decreased craving for alcohol and reduced risk of relapsing within the days and weeks following the attentional bias modification training intervention (Schoemakers et al., 2010). With regard to reflective processes, given that disrupted inhibitory control processes characterize severe pathological gamblers (Brevers et al., 2012b) and are a strong predictor of gambling relapse (Goudriaan et al., 2008), improving motor response inhibition may be crucial for recovery from gambling abuse. For instance, by experimentally priming either disinhibited (i.e. participants were told that they should try to inhibit responding to "Stop" stimuli if possible, but that this was less important than rapid responding to the "Go" stimuli) or restrained behaviors (i.e. participants were told that they should try to respond quickly to Go stimuli if possible, but that this was less important than successful inhibition on Stop trials) while participants completed a Stop-Signal task, Jones et al. (2011) found increased consumption of beer during a test phase in the "disinhibition group" as compared with the "inhibited group." This finding led to the idea that motor inhibition shares mechanisms with alcohol use in social drinkers, and that improving motor inhibitory control impacts behavior in decreasing alcohol use. Studies are needed in order to test whether a similar training procedure impacts positively on gambling behaviors in pathological gamblers. Thus, from the standpoint of the present framework, therapeutic intervention may be most effective if it simultaneously changes people's reasoned attitudes, beliefs, and control standards (e.g. through common interventions for cognitive restructuring, education, or persuasion) and, in addition, changes problematic impulsive behavior precursors by retraining impulsive and reflective processes though novel neurocognitive intervention. This association would create situational and dispositional circumstances that are conducive for effective self-control by increasing self-monitoring, self-efficacy, coping skills, control capacity, and intrinsic motivation for gambling cessation.

## Acknowledgements

DB is a Research Fellow at the Belgium Fund for Scientific Research (F.R.S/FNRS). XN is a Research Associate at the Belgium Fund for Scientific Research (F.R.S/FNRS).

## Conflict of interest and funding

The authors have not received any funding or benefits from industry or elsewhere to conduct this study.

## References

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: American Psychiatric Press.

Baron, E., & Dickerson, M. (1999). Alcohol consumption and self-control of gambling behaviour. *Journal of Gambling Studies*, *15*, 3–15.

Bechara, A. (2004). The role of emotion in decision-making: Evidence from neurological patients with orbitofrontal damage. *Brain and Cognition*, *55*, 30–40.

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

Belin, D., & Everitt, B. J. (2008). Cocaine seeking habits depend upon dopaminedependent serial connectivity linking the ventral with the dorsal striatum. *Neuron*, *57*, 432–441.

Boyer, M., & Dickerson, M. (2003). Attentional bias and addicitve behaviour: Automaticity in a gambling-specific modified Stroop task. *Addiction*, *98*, 61–70.

Brand, M., Labudda, K., & Markowitsch, H. J. (2006). Neuropsychological correlates of decision-making in ambiguous and risky situations. *Neural Networks*, *19*, 1266–1276.

Breslin, F. C., Sobell, M. B., & Cappell, H. (1999). The effects of alcohol, gender, and sensation seeking on the gambling choices of social drinkers. *Psychology of Addictive Behaviors*, *13*, 243–252.

Brevers, D., Cleeremans, A., Bechara, A., Greisen, M., Kornreich, C., Verbanck, P., et al. (2013b). Impaired self-awareness in pathological gamblers. *Journal of Gambling Studies, 29*, 119–129.

Brevers, D., Cleeremans, A., Bechara, A., Kornreich, C., Verbanck, P., & Noël, X. (2013c). Impaired metacognitive capacities in problem gamblers. *Journal of Gambling Studies*. doi:10.1007/s10899-012-9348-3.

Brevers, D., Cleeremans, A., Bechara, A., Laloyaux, C., Kornreich, C., Verbanck, P., et al. (2011b). Time course of attentional bias for gambling information in problem gambling. *Psychology of Addictive Behavior*, *25*, 675–682.

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

Brevers, D., Cleeremans, A., Hermant, C., Tibboel, H., Kornreich, C., Verbanck, P., et al. (2013a). Implicit gambling attitudes in problem gamblers: Positive but not negative implicit associations. *Journal of Behavior Therapy and Experimental Psychiatry*, *44*, 94–97.

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

Brevers, D., Cleeremans, A., Verbruggen, F., Bechara, A., Kornreich, C., Verbanck, P., et al. (2012b). Impulsive action but impulsive choice determines problem gambling severity. *Plos One*, *7*, e50647.

Browning, M., Holmes, E. A., & Harmer, C. J. (2010). The modification of attentional bias to emotional information: A review of the techniques, mechanisms, and relevance to emotional disorders, Cognitive. *Affective & Behavioral Neuroscience*, *10*, 8–20.

Cisler, J. M., & Koster, E. H. W. (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review*, *30*, 203–216.

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

Chiu, P. H., Lohrenz, T. M., & Montague, P. R. (2008). Smokers' brains compute, but ignore, a fictive error signal in a sequential investment task. *Nature Neuroscience*, *11*, 514–520.

Clark, L., Crooks, B., Clarke, R., Aitken, M. R. F., & Dunn, B. D. (2012). Physiological responses to near-miss outcomes and personal control during simulated gambling. *Journal of Gambling Studies*, *28*, 123–137.

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*, 481–490.

Cleeremans, A., Timmermans, B., & Pasquali, A. (2007). Consciousness and metarepresentation: A computational sketch. *Neural Networks*, *20*, 1032–1039.

Craig, A. D. (2009). How do you feel—now? The anterior insula and human awareness. *Nature Reviews Neuroscience*, *10*, 59–70.

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

Cronce, J. M., & Corbin, W. R. (2010). Effects of alcohol and initial gambling outcomes on within-session gambling behavior. *Experimental and Clinical Psychopharmacology*, *18*, 145–157.

Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society of London*, *351*, 1413–1420.

Davis, D., Sundahl, I., & Lesbo, M. (2000). Illusory personal control as a determinant of bet size and type in casino craps games. *Journal of Applied Social Psychology*, *30*, 1224–1242.

de Ruiter, M. B., Oosterlaan, J., Veltman, D. J., Van den Brink, W., & Goudriaan, A. E. (2012). 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.

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*, 1027–1038.

Delgado, M. R., Nystrom, L. E., Fissell, C., Noll, D. C., & Fiez, J. A. (2000). Tracking the hemodynamic responses to reward and punishment in the striatum. *Journal of Neurophysiology*, *84*, 3072–3077.

Dixon, M. R., Hayes, L. J., & Ebbs, R. E. (1998). Engaging in 'illusory control' during repeated risk-taking. *Psychological Reports*, *83*, 959–962.

Dixon, L., Trigg, R., & Griffiths, M. (2007). An empirical investigation of music and gambling behaviour. *International Gambling Studies*, *7*, 315–326.

Dougherty, D. M. (2003). *Laboratory behavioral measures of impulsivity: General information manual*. Houston: University of Texas Health Science Center at Houston.

Duka, T., Crombag, H. S., & Stephens, D. N. (2011). Experimental medicine in drug addiction: Towards behavioral, cognitive and neurobiological biomarkers. *Journal of Psychopharmacology*, *25*, 1235–1255.

Elliott, R., Friston, K. J., & Dolan, R. J. (2000). Dissociable neural responses in human reward systems. *Journal of Neuroscience*, *20*, 6159–6165.

Everitt, B. J., Dickinson, A. D., & Robbins, T. W. (2001). The neuropsychological basis of addictive behaviour. *Brain Research Review*, *36*, 129–138.

Everitt, B. J., & Robbins, T. W. (2005). Neural systems of reinforcement for drug addiction: From actions to habits to compulsion. *Nature Neuroscience*, *8*, 1481–1489.

Field, M., Eastwood, B., Bradley, B. P., & Mogg, K. (2006). Selective processing of cannabis cues in regular cannabis users. *Drug and Alcohol Dependence*, *85*, 75–82.

Field, M., Kiernan, A., Eastwood, B., & Child, R. (2008). Rapid approach responses to alcohol cues in heavy drinkers. *Journal of Behavior Therapy and Experimental Psychiatry*, *39*, 209–218.

Field, M., Munafò, M. R., & Franken, I. H. (2009). A meta-analytic investigation of the relationship between attentional bias and subjective craving in substance abuse. *Psychological Bulletin*, *135*, 589–607.

Finlay, K., Marmurek, H. H. C., Kanetkar, V., & Londerville, J. (2007). Trait and state emotion congruence in simulate casinos: Effects on at-risk gambling intention and restoration. *Journal of Environmental Psychology*, *27*, 166–175.

Fiorillo, C. D., Tobler, P. N., & Schultz, W. (2003). Discrete coding of reward probability and uncertainty by dopamine neurons. *Science*, *299*, 1898–1902.

Franken, I. A. (2003). Drug craving and addiction: Integrating psychological and neuropsychopharmacological approaches. *Progress in Neuro-Psychopharmacology and Biological Psychiatry*, *27*, 563–579.

Gallagher, M., & Chiba, A. A. (1996). The amygdala and emotion. *Current Opinion in Neurobiology*, *6*, 221–227.

Gauggel, S., Heusinger, A. Z., Forkmann, T., Boecker, M., Lindenmeyer, J., Cox, W. M., et al. (2010). Effects of alcohol cue exposure on response inhibition in detoxified alcohol-dependent patients. *Alcoholism Clinical and Experimental Research*, *34*, 1584–1589.

Goldstein, R. Z., Craig, A. D., Bechara, A., Garavan, H., Childress, A. R., Paulus, M. P., et al. (2009). The neurocircuitry of impaired insight in drug addiction. *Trends in Cognitive Science*, *13*, 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. *The American Journal of Psychiatry*, *159*, 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*, 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*, 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*, 137–151.

Goudriaan, A. E., Oosterlaan, J., de Beurs, E., & van den Brink, W. (2006). Psychophysiological determinants and concomitants of deficient decision-making in pathological gamblers. *Drug and Alcohol Dependence*, *84*, 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 prediction of relapse in pathological gamblers. *Psychological Medicine*, *38*, 41–50.

Grant, J. E., Chamberlain, S. R., Schreiber, L. R. N., Odlaug, B. L., & Kim, S. W. (2011). Selective decision-making deficits in at-risk gamblers. *Psychiatry Research*, *189*, 115–120.

Greenwald, A. G., & Banaji, M. R. (1995). Implicit social cognition: Attitudes, self-esteem, and stereotypes. *Psychological Review*, *102*, 4–27.

Greenwald, A. G., McGhee, D. E., & Schwartz, J. K. (1998). Measuring individual differences in implicit cognition: The Implicit Association Test. *Journal of Personality and Social Psychology*, *74*, 1464–1480.

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

Griffiths, M. (1993). Fruit machine gambling: The importance of structural characteristics. *Journal of Gambling Studies*, *9*, 133–152.

Griffiths, M. D., & Parke, J. (2003). The environmental psychology of gambling. In G. Reith (Ed.), *Gambling: Who wins? Who loses?* (pp. 277–292). New York: Prometheus Books.

Griffiths, M. D., & Swift, G. (1992). The use of light and colour in gambling arcades: A pilot study. *Society for the Study of Gambling Newsletter*, *21*, 16–22.

Harrigan, K. A. (2009). Slot machines: Pursuing responsible gaming practices for virtual reels and near misses. *International Journal of Mental Health and Addiction*, *7*, 68–83.

Hess, H. F., & Diller, J. V. (1969). Motivation for gambling as revealed in the marketing methods of the legitimate gaming industry. *Psychological Reports*, *25*, 19–27.

Hester, R., Nestor, L., & Garavan, H. (2009). Impaired error awareness and anterior cingulate cortex hypoactivity in chronic cannabis users. *Neuropsychopharmocoly*, *34*, 2450–2458.

Hewig, J., Kretschmer, N., Trippe, R. H., Hecht, H., Coles, M. H., Holroyd, C. B., et al. (2010). Hypersensitivity to reward in problem gamblers. *Biological Psychiatry*, *67*, 781–783.

Hofmann, W., Friese, M., & Strack, F. (2009). Impulse and self-control from a dual-systems perspective. *Perspectives on Psychological Science*, *4*, 162–176.

Hofmann, W., Friese, M., & Wiers, R. W. (2008). Impulsive versus reflective influences on health behavior: A theoretical framework and empirical review. *Health Psychology Review*, *2*, 111–137.

Hogarth, R. M., & Villeval, M. C. (2010). *Intermittent reinforcement and the persistence of behavior: Experimental evidence*. IZA Discussion Paper 5103. Bonn: Institute for the Study of Labor.

Houben, K., & Wiers, R. W. (2008). Implicitly positive about alcohol? Implicit positive associations predict drinking behavior. *Addictive Behaviors*, *33*, 979–986.

Houben, K., & Wiers, R. W. (2009). Response inhibition moderates the relationship between implicit associations and drinking behavior, Alcoholism. *Clinical and Experimental Research*, *33*, 626–633.

Hyman, S. E. (2005). Addiction: A disease of learning and memory. *The American Journal of Psychiatry*, *162*, 1414–1422.

INSERM. (2008). *Expertise collective: Jeux de hasard et d'argent, contexte et addiction* [Collective expert report: Gambling, context and addiction]. Paris: Author.

Izuma, K., Saito, D. N., & Sadato, N. (2008). Processing of social and monetary rewards in the human striatum. *Neuron*, *58*, 284–294.

Janes, A. C., Pizzagalli, D. A., Richardt, S., Frederick, B. D., Chuzi, S., Pachas, G., et al. (2010). Brain reactivity to smoking cues prior to smoking cessation predicts ability to maintain tobacco abstinence. *Biological Psychiatry*, *67*, 722–729.

Jones, A., Guerrieri, R., Fernie, G., Cole, J., Goudie, A., & Field, M. (2011). The effects of priming restrained versus disinhibited behaviour on alcohol-seeking in social drinkers. *Drug and Alcohol Dependence*, *113*, 55–61.

Kerr, A., & Zelazo, P. D. (2004). Development of 'hot' executive function: The children's gambling task. *Brain and Cognition*, *55*, 148–157.

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.

Knutson, B., Fong, G. W., Bennett, S. M., Adams, C. M., & Hommer, D. (2003). A region of mesial prefrontal cortex tracks monetarily rewarding outcomes: Characterization with rapid event-related Fmri. *NeuroImage*, *18*, 263–272.

Knutson, B., Rick, S., Wimmer, G. E., Prelec, D., & Loewenstein, G. (2007). Neural predictors of purchases. *Neuron*, *53*, 147–156.

Koob, G. F., & Le Moal, M. (1997). Drug abuse: hedonic homeostatic dysregulation. *Science*, *278*, 52–58.

Korn, D. A., & Shaffer, H. J. (1999). Gambling and the health of the public: Adopting a public health perspective. *Journal of Gambling Studies*, *15*, 289–365.

Krain, A. L., Wilson, A. M., Arbuckle, R., Castellanos, F. X., & Milham, M. P. (2006). Distinct neural mechanisms of risk and ambiguity: A meta-analysis of decision-making. *NeuroImage*, *32*, 477–484.

Ladouceur, R., & Sévigny, S. (2005). Structural characteristics of video lotteries: Effects of a stopping device on illusion of control and gambling persistence. *Journal of Gambling Studies*, *21*, 117–131.

Langer, E. J. (1975). The illusion of control. *Journal of Personality and Social Psychology*, *32*, 311–332.

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*, 163–172.

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.

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

Lesieur, H. R., Blume, S. B., & Zoppa, R. M. (1986). Alcoholism, drug abuse, and gambling, Alcoholism. *Clinical and Experimental Research*, *10*, 33–38.

Linnet, J., Møller, A., Peterson, E., Gjedde, A., & Doudet, D. (2011). Dopamine release in ventral striatum during Iowa Gambling Task performance is associated with increased excitement levels in pathological gambling. *Addiction*, *106*, 383–390.

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

MacLeod, C., Rutherford, E., Campbell, L., Ebsworthy, G., & Holker, L. (2002). Selective attention and emotional vulnerability: Assessing the causal basis of their association through the experimental manipulation of attentional bias. *Journal of Abnormal Psychology*, *111*, 107–123.

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

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*, 165–173.

Miller, W. R., & Rollnick, S. (1991). *Motivational interviewing: Preparing people to change addictive behavior*. New York: Guilford Press.

Milton, A. L., & Everitt, B. J. (2012). The persistence of maladaptive memory: Addiction, drug memories and anti-relapse treatments. *Neuroscience and Biobehavioral Reviews*, *36*, 1119–1139.

Moeller, S. J., Maloney, T., Parvaz, M. A., Alia-Klein, N., Woicik, P. A., Telang, F., et al. (2010). Impaired insight in cocaine addiction: Laboratory evidence and effects on cocaine-seeking behaviour. *Brain*, *133*, 1484–1493.

Mogg, K., Bradley, B. P., Field, M., & De Houwer, J. (2003). Eye movements to smoking-related pictures in smokers: Relationship between attentional biases and implicit and explicit measures of stimulus valence. *Addiction*, *98*, 825–836.

Molde, H., Pallesen, S., Saetrevik, B., Hammerborg, D. K., Laberg, J. C., & Johnsen, B. H. (2010). Attentional biases among pathological gamblers. *International Gambling Studies*, *10*, 45–49.

Montague, P. R., Dayan, P., & Sejnowski, T. J. (1996). A framework for mesencephalic dopamine systems based on predictive Hebbian learning. *Journal of Neurosciences*, *16*, 1936–1947.

Naqvi, N. H., & Bechara, A. (2009). The hidden island of addiction: The insula. *Trends in Neurosciences*, *32*, 56–67.

Naqvi, N. H., & Bechara, A. (2010). The insula and drug addiction: an interoceptive view of pleasure, urges, and decision-making. *Brain Structure and Function*, *214*, 435–450.

Naqvi, N. H., Rudrauf, D., Damasio, H., & Bechara, A. (2007). Damage to the insula disrupts addiction to cigarette smoking. *Science*, *315*, 531–534.

Nelson, T. O., & Narens, L. (1990). Metamemory: a theoretical framework and new findings. *Psychology, Learning and Motivation*, *26*, 125–173.

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*, 1316–1327.

Noël, X., Bechara, A., Brevers, D., Verbanck, P., & Campanella, S. (2010). Alcoholism and the loss of willpower: A neurocognitive perspective. *Journal of Psychophysiology*, *24*, 240–248.

Noël, X., Brevers, D., & Bechara, A. (2013). A neurocognitive approach to understanding the neurobiology of addiction. *Current Opinion in Neurobiology*, *23*(4), 632–638.

Nummenmaa, L., Hirvonen, J., Hannukainen, J. C., Immonen, H., Lindroos, M. M., Salminen, P., et al. (2012). Dorsal striatum and its limbic connectivity mediate abnormal anticipatory reward processing in obesity. *Plos One*, *7*, e31089.

Odlaug, B. L., Chamberlain, S. R., Kim, S. W., Schreibe, L., & Grant, J. E. (2011). A neurocognitive comparison of cognitive flexibility and response inhibition in gamblers with varying degrees of clinical severity. *Psychological Medicine*, *41*, 2111–2119.

Parke, A., & Griffiths, M. (2004). Aggressive behaviour in slot machine gamblers: A preliminary observational study. *Psychological Reports*, *95*, 109–114.

Paulus, M. P., Rogalsky, C., Simmons, A., Feinstein, J. S., & Stein, M. B. (2003). Increased activation in the right insula during risk-taking decision making is related to harm avoidance and neuroticism. *NeuroImage*, *19*, 1439–1448.

Payer, D. E., Lieberman, M. D., & London, E. D. (2011). Neural correlates of affect processing and aggression in methamphetamine dependence. *Archives of General Psychiatry*, *68*, 271–282.

Peters, H., Hunt, M., & Harper, D. (2010). An animal model of slot machine gambling: The effect of structural characteristics on response latency and persistence. *Journal of Gambling Studies*, *26*, 521–531.

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.

Petry, N. M., & Casarella, T. (1999). Excessive discounting of delayed rewards in substance abusers with gambling problems. *Drug and Alcohol Dependence*, *56*, 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. *The Journal of Clinical Psychiatry*, *66*, 564–574.

Potenza, M. N., Steinberg, M. A., Skudlarski, P., Fulbright, R. K., Lacadie, C. M., Wilber, M. K., et al. (2003). Gambling urges in pathological gambling: A functional magnetic resonance imaging study. *Archives of General Psychiatry*, *60*, 828–836.

Power, Y., Goodyear, B., & Crockford, D. (2012). Neural correlates of pathological gamblers preference for immediate rewards during the Iowa Gambling Task: An fMRI study. *Journal of Gambling Studies*, *28*, 623–636.

Raymond, J. E., Shapiro, K., & 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*, 849–860.

Redish, A. D., Jensen, S., Johnson, A., & Kurth-Nelson, Z. (2007). Reconciling reinforcement learning models with behavioral extinction and renewal: Implications for addiction, relapse, and problem gambling. *Psychological Review*, *114*, 784–805.

Redish, A. D., Jensen, S., & Johnson, A. (2008). A unified framework for addiction: vulnerabilities in the decision process. *Behavioral Brain Science*, *31*, 415–437.

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

Robinson, T. E., & Berridge, K. C. (1993). The neural basis of drug craving: An incentive sensitization theory of addiction. *Brain Research. Brain Research Reviews*, *18*, 247–291.

Robinson, T. E., & Berridge, K. C. (2001). Incentive-sensitization and addiction. *Addiction*, *96*, 103–114.

Robinson, T. E., & Berridge, K. C. (2008). Review. The incentive sensitization theory of addiction: Some current issues, Philosophical Transactions of the Royal Society of London. Series B. *Biological Sciences*, *363*, 3137–3146.

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

Rolls, E. T., & Grabenhorst, F. (2008). The orbitofrontal cortex and beyond: From affect to decision-making. *Progress in Neurobiology*, *86*, 216–244.

Samanez-Larkin, G. R., Hollon, N. G., Carstensen, L. L., & Knutson, B. (2008). Individual differences in insular sensitivity during loss anticipation predict avoidance learning. *Psychological Science*, *19*, 320–323.

SAMHSA. (2007). *Results from the 2006 National Survey on Drug Use and Health: national findings* (Publication No. SMA 07–4293). Washington, DC: Office of Applied Studies, DHHS.

Schoenmakers, T. M., de Bruijn, M., Lux, I. M., Goertz, A. G., van Kerkhof, D. T., & Wiers, R. W. (2010). Clinical effectiveness of attentional bias modification training in abstinent alcoholic patients. *Drug and Alcohol Dependence*, *109*, 30–36.

Schultz, W. (2002). Getting formal with dopamine and reward. *Neuron*, *36*, 241–263.

Schultz, W., Paul, A., & Tomas, L. (1993). Responses of monkey dopamine neurons to reward and conditioned stimuli during successive steps of learning a delayed response task. *Journal of Neuroscience*, *13*, 900–913.

Schultz, W., Tremblay, L., & Hollerman, J. R. (2003). Changes in behavior-related neuronal activity in the striatum during learning. *Trends in Neurosciences*, *26*, 321–328.

Sewards, T. V., & Sewards, M. A. (2003). Representations of motivational drives in mesial cortex, medial thalamus, hypothalamus and midbrain. *Brain Research Bulletin*, *61*, 25–49.

Smith, R. S., & DeCoster, J. (2000). Dual-process models in social and cognitive psychology: Conceptual integration and links to underlying memory systems. *Personality and Social Psychology Review*, *4*, 108–131.

Spenwyn, J., Barrett, D. K., & Griffiths, M. D. (2010). The role of light and music in gambling behaviour: An empirical pilot study. *International Journal of Mental Health and Addiction*, *8*, 107–118.

Stacy, A. W., & Wiers, R. W. (2010). Implicit cognition and addiction: A tool for explaining paradoxical behavior. *Annual Review of Clinical Psychology*, *6*, 551–575.

Stark, G. M., Saunders, D. M., & Wookey, P. E. (1982). Differential effects of red and blue coloured lighting on gambling behaviour. *Current Psychological Research*, *2*, 95–99.

Steele, C. M., & Josephs, R. A. (1988). Drinking your troubles away II: An attention–allocation model of alcohol's effect on psychological stress. *Journal of Abnormal Psychology*, *97*, 196–205.

Sutherland, M. T., McHugh, M. J., Pariyadath, V., & Stein, E. A. (2012). Resting state functional connectivity in addiction: Lessons learned and a road ahead. *NeuroImage*, *62*, 2281–2295.

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

van Holst, R. J., Van Holstein, M., Van den Brink, W., Veltman, D. J., & Goudriaan, A. E. (2012a). Response inhibition during cue reactivity in problem gamblers: An fMRI study. *PloS One*, *7*, e30909.

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*, 741–748.

Verdejo-Garcia, A., & Bechara, A. (2009). A somatic marker theory of addiction. *Neuropharmacology*, *56*, 48–62.

Verdejo-Garcia, A., Lubman, D. I., Schwerk, A., Roffel, K., Vilar-Lopez, R., MacKenzie, T., et al. (2012). Effect of craving induction on inhibitory control in opiate dependence. *Psychopharmacology*, *219*, 519–526.

Wagenaar, W. A. (1988). *Paradoxes of gambling behavior*. Hillsdale, NJ: Erlbaum.

Wardle, H., Sproston, K., Orford, J., Erens, B., Griffiths, M., & Constantine, R. (2007). *British Gambling Prevalence Survey*. London: National Centre for Social Research.

Wulfert, E., Maxson, J., Jardin, B., Wulfert, E., Maxson, J., & Jardin, B. (2009). Cue-specific reactivity in experienced gamblers. *Psychology of Addictive Behaviors*, *23*, 731–735.

Xue, G., Lu, Z., Levin, I. P., & Bechara, A. (2010). The impact of prior risk experiences on subsequent risky decision-making: The role of the insula. *NeuroImage*, *50*, 709–716.

Yi, S., & Kanetkar, V. (2010). Implicit measures of attitudes toward gambling: An exploratory study. *Journal of Gambling Issues*, *24*, 140–163.

Yoto, A., Katsuura, T., Iwanaga, K., & Shimomura, Y. (2007). Effects of object colour stimuli on human brain activities in perception and attention referred to EEG alpha band response. *Journal of Physiological Anthropology*, *26*, 373–379.

Zack, M., & Poulos, C. X. (2004). Amphetamine primes motivation to gamble and gambling-related semantic networks in problem gamblers. *Neuropsychopharmacology*, *29*, 195–207.

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

Zelazo, P. D., & Müller, U. (2002). Executive function in typical and atypical development. In U. Goswami (Ed.), *Handbook of childhood cognitive development* (pp. 445–469). Oxford: Blackwell.

***Damien Brevers**
Laboratory of Medical Psychology and Addictology, CHU-Brugmann
Université Libre de Bruxelles
Van Gehuchten 4, 1020, Brussels
Belgium
Email: dbrevers@ulb.ac.be