Published in final edited form as:

Int Gambl Stud. 2018 ; 18(2): 269–285. doi:10.1080/14459795.2018.1469658.

Relating neural processing of reward and loss prospect to risky decision-making in individuals with and without Gambling Disorder

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Abstract

Neuroimaging studies demonstrate alterations in fronto-striatal neurocircuitry in gambling disorder (GD) during anticipatory processing, which may influence decision-making impairments. However, to date little is known about fronto-striatal anticipatory processing and emotion-based decision-making.

While undergoing neuroimaging, 28 GD and 28 healthy control (HC) participants performed the Monetary Incentive Delay Task (MIDT). Pearson correlation coefficients assessed out-of-scanner Iowa Gambling Task (IGT) performance with the neural activity during prospect (A1) processing on the MIDT across combined GD and HC groups.

The HC and GD groups showed no significant difference in out-of-scanner IGT performance, although there was a trend for higher IGT scores in the HC group on the last two IGT trial blocks.

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There were no constraints on publishing

Conflicts and Disclosures

No funding agencies had input into the content of this manuscript, and none of the authors have any relevant conflicts of interests. Dr. Potenza has consulted for Ironwood, Lundbeck, Shire, INSYS, Rivermend Health, Opiant/Lakelight Therapeutics, and Jazz Pharmaceuticals; has received research support (to Yale) from Pfizer, Mohegan Sun Casino and the National Center for Responsible Gaming; has participated in surveys, mailings or telephone consultations related to drug addiction, impulse-control disorders or other health topics; has consulted for gambling and legal entities on issues related to impulse-control/addictive disorders; provides clinical care in a problem gambling services program; has performed grant reviews for the National Institutes of Health and other agencies; has edited journals and journal sections; has given academic lectures in grand rounds, CME events and other clinical or scientific venues; and has generated books or book chapters for publishers of mental health texts. The other authors have no disclosures.

Whole-brain correlations across combined HC and GD groups showed that MIDT BOLD signal in the ventral striatum/caudate/ventromedial prefrontal cortex and anterior cingulate regions during the prospect of winning positively correlated with total IGT scores. The GD group also contained a higher proportion of tobacco smokers, and correlations between neural activations in prospect on the MIDT may relate in part to gambling and/or smoking pathology.

In this study, fronto-striatal activity during the prospect of reward and loss on the MIDT was related to decision-making on the IGT, with blunted activation linked to disadvantageous decision-making. The findings from this work are novel in linking brain activity during a prospect-of-reward phase with performance on a decision-making task in individuals with and without GD.

Introduction

Gambling disorder (GD) is a behavioral addiction characterized by persistent and recurrent betting that leads to clinically significant impairment or distress (American Psychiatric Association [*DSM-5*] 2013, p. 585). GD is linked to disadvantageous decision-making on measures such as the Iowa Gambling Task (IGT) (Grant et al. 2000, Petry 2001, Cavedini et al. 2002, Goudriaan et al. 2005, Goudriaan et al. 2006, Linnet et al. 2006, Roca et al. 2008), which has been linked to ventral striatal function (Linnet et al. 2010, Linnet et al. 2011, Linnet et al. 2011, Linnet et al. 2012).

Ventral striatal activity differences in GD (as compared to healthy control (HC) groups) may be linked to differences in reward anticipation. The IGT consists of four card decks (A, B, C and D) associated with reward and punishment contingencies, with the objective of IGT performance being to maximize gains. Decks with immediately smaller rewards are associated with long-term gains, while decks with immediately larger rewards are associated with long-term losses. During IGT performance, people may learn over time to select preferentially from advantageous (leading to long-term gains) versus disadvantageous (leading to long-term losses) decks as they acquire knowledge of the reward contingencies associated with each of the four decks. During IGT performance, decision-making may be guided both by neurobiological feedback that may include conscious and subconscious processes, with individual differences noted. People show individual differences in the magnitudes of increased anticipatory skin conductance responses (SCRs) in relation to encountering risky decisions, prior to having conscious or declarative knowledge that choices may be risky (Bechara et al. 1994, Bechara et al. 1997, Bechara et al. 2000, Bechara et al. 2002). Individuals with lesions in the ventromedial prefrontal cortex (vmPFC) often demonstrate low anticipatory SCRs prior to the behavioral response of card selection and also perform disadvantageously on the IGT, perhaps due to insensitivities in processing risk-related signals. Studies of individuals with substance-use disorders (SUDs) (Bechara et al. 2001, Bechara and Damasio 2002, Bechara 2003) or GD (Goudriaan et al. 2006) show reduced anticipatory SCRs compared to HC subjects, suggesting a possible deficient anticipatory neurobiological signal related to risk-reward decision-making in addictions. Therefore, anticipatory neurobiological processes that may help guide decision-making warrant further examination as related to IGT performance.

Brain imaging studies suggest altered brain functions of reward anticipation in GD, which may relate to poor decision-making and disadvantageous IGT performance. IGT performance in individuals with SUDs with or without GD has been linked to cortico-striatal circuitry, with blunted activation of the vmPFC observed in addicted individuals (Tanabe et al., 2007). Given that IGT performance involves risk-reward decision-making, the neural correlates of reward and loss processing also warrant consideration. A meta-analysis by (Luijten et al. 2017) showed that anticipatory processing in SUDs and GD is characterized by decreased striatal activation when compared with HC subjects. Balodis et al. (2012) found reduced anticipatory BOLD activation toward gains and losses in the medial prefrontal cortex (mPFC, including vmPFC), anterior cingulate and left ventral striatum of individuals with GD compared with HC subjects during performance of the Monetary Incentive Delay Task (MIDT). Choi et al. (2012) found reduced anticipatory BOLD activation during MIDT performance in the caudate in individuals with GD compared with HC subjects and those with obsessive-compulsive disorder (OCD). Romanczuk-Seiferth et al. (2015) found reduced anticipatory BOLD activation in the right ventral striatum toward loss anticipation in individuals with GD compared with HC subjects and those with alcohol-use disorder during MIDT performance. Sescousse et al. (2013) found that individuals with GD had a blunted anticipatory BOLD activation response in the ventral striatum toward erotic images, but not toward monetary cues, compared with HC subjects. Additional studies of the processing of near-miss losses and when making decisions to chase or accept losses also implicate the vmPFC and ventral striatum (Worhunsky et al. 2014, Worhunsky et al. 2017). While these studies provide evidence for reduced anticipatory BOLD activation in GD toward gains and losses, reduced BOLD activation is also involved in other aspects of decision-making in GD including those related to temporal discounting (e.g., Miedl et al., 2015) and response perseveration (e.g., de Ruiter et al., 2009). Furthermore, some studies report relatively increased activation of the ventral striatum and vPFC during reward anticipation in GD. For instance, van Holst et al. (2012) found that individuals with GD had significantly increased anticipatory BOLD activation in the bilateral ventral striatum and left orbitofrontal cortex toward gain-related expected value compared to HC subjects during performance of a monetary guessing task.

As noted above, the MIDT is a widely used task to assess the neural correlates of reward and loss processing. Although not observed across all studies, relatively blunted activation of the ventral striatum has been observed in multiple addictive disorders during anticipatory phases of reward processing (Balodis and Potenza 2015). While the original MIDT assessed two phases of reward processing, our modified version permits the modeling of three phases: prospect, anticipation and consumption/outcome, which we have termed A1, A2 and OC, respectively (Andrews et al. 2011). The A1 and A2 phases were designated as such as they may be considered as two forms of anticipation, with the former anticipating task performance (needing to push the button while the target is on screen) and the latter anticipating reporting of performance outcome (having successfully won or avoided loss, or not). The designation of prospect for the A1 phase is derived from its position following information given to participants about the type of trial (i.e., a win or loss trial, along with high, low or null values). The ability to parse two anticipation phases is important as each is not only linked to specific psychological features of reward loss processing, but also to

specific neural correlates in individuals family history positive for alcoholism (Andrews et al. 2011), with GD (Balodis et al. 2012) and with binge-eating disorder (Balodis et al. 2013).

While there is evidence for altered brain functions of reward anticipation in GD, little is currently known about the possible association between neural correlates of reward and loss processing as assessed using functional magnetic resonance imaging (fMRI) and decision-making deficits on behavioral tasks such as the IGT. In the present study, we aimed to study relationships between anticipatory processing of rewards and losses on the MIDT and out-of-scanner measures of risk-reward decision-making on the IGT. Given differences in the neural correlates of A1 and A2 phases of the MIDT, we examined both phases with respect to IGT performance. Given prior findings, we hypothesized that anticipatory BOLD responses in the ventral striatum during anticipatory phases of the MIDT, and particularly A2 given prior findings in GD (Balodis et al. 2012), would be positively associated with IGT performance. We hypothesized that this tendency would be observed in both GD and HC groups given findings of blunted ventral striatal activation that transcends diagnostic groupings (Balodis et al., 2013; Balodis and Potenza, 2015), including HC subjects at greater risk for addictions (Andrews et al., 2011). Given the association between vmPFC activation and IGT performance and mPFC contributions to MIDT processing including in but not limited to anticipatory phases, we hypothesized that vmPFC activation during anticipatory phases of reward processing would also be positively correlated with IGT performance.

Methods

Participants included 28 individuals who met criteria for GD and 28 healthy control (HC) participants (demographic information displayed in Table 1). Participants consisted of a community sample recruited through advertisements and flyers in the New Haven area. GD status was assessed with the Structured Clinical Interview for Pathological Gambling, which has clinical validity and reliability in GD populations (Grant et al. 2004); other co-occurring disorders were assessed via a Structured Clinical Interview for DSM-IV Disorders (First et al. 2002). In the GD group, 14 individuals identified as tobacco smokers, as compared with 7 individuals in the HC group ($X^2_{(1,56)} = 0.053$). The following other co-occurring disorders were noted: in the GD group, 7 individuals met criteria for past alcohol dependence, 7 for past alcohol abuse, 2 for past opioid dependence, 1 for past cannabis abuse, 2 for past cannabis dependence, 4 for past cocaine dependence, 1 for past substance-induced mood disorder, 2 for past major depression, 1 for current obsessive/compulsive disorder, 1 for current specific phobia, 1 for current social phobia, 1 for current alcohol abuse, 1 for current cocaine dependence, 1 for current alcohol dependence, 1 for current generalized anxiety disorder, 1 for past phencyclidine abuse and 1 for past stimulant abuse. In the HC group, 1 individual reported past panic disorder.

Urine toxicology at the time of scanning confirmed that participants were free of illicit substances. All participants provided written informed consent. Participants completed the MIDT and the IGT on separate days. The study was approved by the University's Human Investigations Committee.

Monetary Incentive Delay Task (MIDT) Experimental Procedure

All participants completed the MIDT. The task and experimental methods have previously been described (Andrews et al. 2011, Balodis et al. 2012). In brief, participants completed two runs of the MIDT in two 10-minute sessions, with each run consisting of 55 trials, and each trial lasting 12 seconds each. The current study focused on the anticipatory phases (A1W for win prospect, A1L for loss prospect, A2W for win anticipation and A2L for loss anticipation). The A1 phase modeled the period when participants viewed a cue signaling the potential win or loss of money (either \$1 or \$5) and then fixated on a crosshair, anticipating working to win or avoid loss via button press.

fMRI volume acquisitions were time-locked to the offset of each cue, and trial types were pseudorandomly ordered within each session. Task difficulty was based on practice reaction times collected prior to the scanning session and set so that participants would experience a positive outcome on 66% of trials. All participants were informed that their compensation on the task was performance-based. The main effects of the MIDT in thirteen individuals in the GD group have previously been published (Balodis et al. 2012). The focus of the current manuscript is on the correlation of prospect-related processing activity on the MIDT with IGT performance.

Image Acquisition and Analysis

Images were obtained on a Siemens 3 Tesla scanner (Trio; Siemens AG, Erlangen, Germany) at the University's Magnetic Resonance Research Center at the University School of Medicine. Localizer images were acquired aligning the eighth slice parallel to the plane transecting the anterior and posterior commissures. Functional images were acquired with a T2*-weighted blood oxygen level dependent (BOLD) sequence with a TR of 1500ms, TE of 27, flip angle of 60°, 64 × 64 in-plane matrix, field of view of 220 × 220 and 25 4mm slices with a 1mm skip. High-resolution 3D MPRAGE structural images were also acquired with a TR of 2530ms, TE of 3.34ms, flip angle of 7°, 256 × 256 in-plane matrix, and 176 1mm slices. Voxel size in the T1 scan was 3mm. Each MIDT fMRI run comprised 486 volumes, including an initial rest period of 9 seconds for signal stability, which was subsequently removed from analyses. Functional images were processed using SPM5 (Wellcome Functional Imaging Laboratory, London, United Kingdom), normalized to the Montreal Neurological Institute template, and smoothed with a 6-mm kernel full-width at half maximum. First-level modeling was conducted using robust regression to reduce the influence of strong outliers. Motion parameters and high-pass filter parameters were included as additional regressors of no interest. The Neuroelf analysis package (www.neuroelf.net) was used for second-level random-effects analysis. Correction for multiple comparisons was conducted using Monte-Carlo simulation (i.e. AlphaSim), using a combined voxelwise and cluster threshold to result in a family-wise-error (FWE) rate of 5%. Statistical analyses used a robust general linear model approach and each phase of each trial type was separately modeled. Analyses combined “Win \$1” and “Win \$5” trials, “Lose \$1” and “Lose \$5” trials, and “Win \$0” and “Lose 0” trials in reward (W), penalty (L) and neutral (N) conditions in order to increase power. Specific correlations consisted of the contrasts A1W>A1N, A1L>A1N, A2W>A2N, and A2L>A2N correlated with IGT scores. Whole-brain correlations were conducted across and within each group. Correlations were

conducted across groups initially and within-group analyses were conducted post-hoc if positive findings were observed.

Iowa Gambling Task & Experimental Procedure

The IGT is a computerized card game, which simulates real-life decision-making in the way that it factors reward and punishment. The IGT consists of four card decks (A, B, C and D). In decks A and B (“disadvantageous decks”) choosing a card is followed by an immediately high gain of money, but at unpredictable trials the selection is followed by a high penalty, leading to a net loss over time. In decks C and D (“advantageous decks”) the immediate gain is smaller, but the future loss is also smaller, leading to a net gain over time. The IGT score is calculated as the number of cards selected from advantageous decks minus those from disadvantageous decks $((C + D) - (A + B))$, usually measured across five blocks of 20 trials (1–20, 21–40 and so forth) for a total of 100 cards. A repeated-measures ANOVA tested group and block differences on the IGT. Participants were not reimbursed for IGT task performance.

Results

Behavioral performance on the IGT in GD and HC participants

A repeated-measures ANOVA demonstrated a significant effect of Trial Block [$F_{4,216}=162.5$, $p<.05$], but no Block X Group interaction ($p>.05$). There was no significant between-group difference [$F_{1,54}=2.18$, $p>.05$], although the HC group showed a trend of increasing scores over most trial blocks ($p<.10$). The GD group did not demonstrate a significant increase in IGT score across the 5 trial blocks ($p>.10$) (Figure 1).

Total IGT score correlations with MIDT prospect phase (A1 phase)

GD and HC combined

A1W Phase: Positive correlations between IGT scores and the A1W>A1N0 contrast were observed in three main clusters in the cingulate cortex (Table 2; Figure 2). The first one was in the left anterior cingulate, extending bilaterally into the right anterior cingulate, anteriorly into the orbitofrontal cortex, and posteriorly into the medial and inferior frontal gyri, the caudate, ventral striatum and the left lentiform nucleus. The second cluster was observed bilaterally in the posterior cingulate, extending bilaterally into the culmen, posteriorly into the left cuneus, and anteriorly into the right thalamus, insula, precuneus, and the middle temporal, lingual, and cingulate gyri. The third cluster was observed in the dorsal posterior cingulate cortex, extending bilaterally into the paracentral lobule, the right precentral gyrus, and the left insula, paracentral lobule, precuneus, caudate, superior parietal lobule, the cingulate gyrus, and the superior and middle temporal gyri.

Relationship with Smoking Status: To examine possible effects in A1W related to smoking status, 14 individuals who reported smoking were removed from the GD group and 7 individuals were removed from the HC group. The combined group of nonsmokers (N=35) did not show any significant correlations between IGT performance and neural activations during the A1W phase (Supplemental Materials, Supplemental Table 1). Examining the GD

group of nonsmokers alone ($n=14$) did not result in any correlations surviving correction during the A1W phase (Supplemental Materials, Supplemental Table 1).

A1L Phase: A positive correlation was observed in the left ventral striatum, extending bilaterally into the caudate, and ventrally into the right putamen, lentiform nucleus, medial frontal gyrus, and the parahippocampal gyrus (Table 2; Figure 2).

Relationship with Smoking Status: To examine possible effects in A1L related to smoking status, 14 individuals who reported smoking were removed from the GD group and 7 individuals were removed from the HC group. The combined group of nonsmokers ($N=35$) showed significant correlations between IGT performance and neural activations during the A1L phase in 3 clusters (Supplemental Materials, Supplemental Table 1). Specifically, inverse correlations were observed between IGT performance and neural activations involving the middle frontal gyrus, the cingulate gyrus extending to the posterior cingulate and the superior temporal gyrus, respectively. Examining the GD group of nonsmokers alone ($n=14$) did not result in any correlations surviving correction during the A1L phase (Supplemental Materials, Supplemental Table 1).

GD versus HC Comparison

HC Group

A1W: No correlations were observed at $p = 0.05$ with a k-threshold of 223.

A1L: No correlations were observed at $p = 0.05$ with a k-threshold of 223.

GD Group

A1W Phase: Positive correlations were observed between the total IGT scores and activation during the MIDT in four main clusters (Table 3; Figure 3). The first cluster was seen bilaterally in the anterior cingulate, with the activation extending bilaterally into the orbitofrontal cortex, medial frontal cortex, caudate, insula, and anteriorly into the left inferior frontal gyrus, lentiform nucleus, precuneus, inferior parietal lobule, precentral gyrus and the paracentral lobule. The second cluster was observed bilaterally in the cuneus, extending into the middle occipital gyrus, cuneus, anteriorly into the left inferior occipital, superior occipital, middle temporal and inferior temporal gyri, medially into the left posterior cingulate, laterally into the left precuneus, and into the right lingual gyrus. The third cluster depicted activations in the right paracentral lobule, extending laterally into the inferior parietal lobule, middle temporal gyrus, precuneus, cuneus, and anteriorly into the middle temporal, superior temporal, and precentral gyri. The fourth main cluster was observed in the right precentral gyrus, extending into claustrum, anteriorly into the middle frontal, superior frontal, and precentral gyri, and bilaterally into the medial frontal gyrus.

Entire PG and HC Sample

A2W and A2L: No significant correlations were observed between IGT performance and the neural correlates of reward processing in the entire sample in the A2W and A2L contrasts.

Discussion

In the current study, we found that striatal activity during the prospect of reward and loss on the MIDT (A1W and A1L), but not the anticipation of outcome phase (A2W and A2L), correlated with decision-making performance on the IGT. Correlations were also significant within the GD group but not the HC group. Differences in neural correlates were observed when smoking status was considered. These findings suggest that impaired striatal activation in the formulation of prospects is associated with impaired decision-making across GD and HC groups and within GD participants, with smoking status representing an important consideration. These findings suggest possible biological mechanisms for disadvantageous decision-making in people generally and in GD specifically.

It is important to note that findings were observed in the prospect anticipatory phases (A1W and A1L) as opposed to the anticipatory phase related to outcome notification (A2W and A2L). The A2 phase has been linked to blunted ventral striatal signaling in GD (Balodis et al., 2012) and HC subjects at elevated risk for addictions (i.e., those with a positive family history for alcoholism (Andrews et al., 2011)). It is possible that the prospect phase of reward and loss processing may be particularly relevant to IGT performance in both GD and HC subjects. We should note that the correlation between IGT performance and MIDT prospect processing in GD and HC does not preclude group differences between GD and HC participants. It is possible that GD subjects may cluster around the lower end of the correlation and HC subjects may cluster around the higher end of the correlation, as suggested by our data (Figure 2). Regardless, the findings suggest that decision-making may link to biological processes underlying the processing of the prospects of monetary rewards and losses. While individual differences in the neural correlates of prospect formulation may be particularly relevant to GD, they may also be relevant to HC subjects, particularly those at elevated risk for engaging in addictive behaviors, although this notion is somewhat speculative given the current data. However, the notion that smoking status may influence neural processes relating to prospect formation and risky decision-making warrants further consideration and study.

In the present study, we found that activation of the ventral striatum during the prospect phase of considering working for both gaining monetary reward and avoiding monetary losses was linked to performance on the IGT, suggesting that this area may contribute to processing of both positive and negative prospects relating to advantageous decision-making. The results resonate with the original findings by Knutson et al. (Knutson et al. 2003) of recruitment of the ventral striatum in anticipation (involving both prospect and anticipation, in the original MIDT) of monetary rewards, which could suggest that a reduced anticipatory BOLD response of both positive and negative outcomes is a biological marker for decision-making processes that have been linked to addictive disorders. This notion is consistent with findings from the meta-analysis conducted by Luijten et al. (2017).

The association between anticipatory striatal BOLD response and advantageous decision-making is consistent with the SCR literature (Bechara et al. 1997). Both within the GD group, and across the GD and HC groups, individuals with lower prospect-related BOLD response performed poorer on the IGT.

Nevertheless, it is notable that smoking status appears to contribute to the current findings, as the correlation between prospect-reward-related striatal activation and IGT scores was no longer significant once smokers were removed from analyses. Individuals with GD who smoke may represent an important subgroup with respect to problem-gambling severity (Petry and Oncken, 2002), co-occurring psychopathology (Potenza, Steinberg, et al., 2004), and clinical interventions (Grant et al., 2014). Multiple MIDT studies demonstrate alterations in anticipatory responding, particularly in striatal areas in smoking populations (Garrison, Yip, et al., 2017; Nestor, McCabe et al., 2018). Indeed, a recent study demonstrated that acute nicotine increased striatal anticipatory responses on the MIDT (Moran, Stoeckel, et al., in press), with incentive responsiveness relating to greater nicotinic influences on salient stimuli. These findings emphasize the importance of considering smoking status and recency of smoking when conducting neuroimaging studies in populations of individuals who smoke, including studies of conditions that frequently co-occur with tobacco-use disorders like GD. Such considerations may be particularly relevant to understanding constructs related to addictive disorders including incentive responsiveness.

Several limitations should be considered in the interpretation of the present results.

First, we compared MIDT performance in the scanner with IGT performance outside of the scanner. Therefore, the association between MIDT measures and IGT performance is an indirect measure, as MIDT and IGT performances were recorded at different times.

Second, we do not have SCR data available in relation to IGT performance in the present study. Therefore, we do not know if the prospect-related BOLD response on the MIDT is associated with SCR responses on the IGT.

Third, there is a trend toward between-group differences on the last blocks of the IGT. It is possible that we were not able to detect between-group differences due to the sample size in our study. The present study involved 56 individuals equally distributed in GD and HC groups. While this sample size is of sufficient power in relation to neuroimaging studies, and while some IGT studies find significant differences between GD and HC groups with smaller samples sizes, we also note that some IGT studies with smaller sample size do not detect significant differences, (Linnet et al. 2010). In line with this possibility, Bechara and Damasio (2002) compared 46 individuals with SUDs and 49 HC subjects, while (Goudriaan et al. 2006) compared 46 individuals with GD with 47 HC subjects.

Fourth, we do not know how the present data may relate to declarative knowledge on the IGT. The original IGT studies reported an association between more advantageous IGT performance and declarative knowledge, where individuals who were able to describe which decks were better performed better, suggesting that they were learning the task.

Fifth, individuals with GD had more comorbidity than did healthy control subjects. Co-occurring disorders are common in GD, with over 95% of individuals estimated to have one or more disorder (Kessler et al. 2008). While we cannot exclude the possibility that the present results are related to other types of comorbidity than GD, particularly tobacco-use disorders, we note that comorbidity is a common aspect of GD. While this limits the attribution of findings to GD *per se*, the sample studied is arguably more clinically relevant

that a group of GD subjects without co-occurring disorders, increasing the clinical relevance of the findings.

Finally, we note that other explanations for differences in the neural underpinnings of formulating or experiencing prospects could account relationships with disadvantageous IGT performance. For instance, disadvantageous decision-making on the IGT could relate to a general insensitivity for rewards or losses, and individuals with GD who may have experienced tolerance to risk-reward decisions involving lower monetary stakes may be particularly likely to demonstrate such differences. This currently speculative possibility warrants additional direct examination.

In conclusion, these findings highlight how reduced neural activations relating to reward- and loss-related prospects may relate to disadvantageous decision-making (i.e., lower IGT scores). Future studies should investigate whether this altered signaling may relate to the development or progression of GD or to recovery from it. Future studies should also focus on tobacco-smoking as related to gambling, decision-making and addictions, particularly when trying to understand and help people with GD. The findings are novel in linking brain activity during a prospect phase of reward and loss processing with performance on a well-validated decision-making task.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Funding and Acknowledgments

This work was supported in part by R01 DA019039 from the National Institutes of Health; the Connecticut Mental Health Center; and a Center of Excellence in Gambling Research Award from the National Center for Responsible Gaming. IMB was partially supported by the Peter Boris Centre for Addictions Research.

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Fig. 1.

Behavioural performance on the Iowa Gambling Task (IGT) in Gambling Disorder (GD) and Healthy Control (HC) participants. A repeated-measures ANOVA demonstrates a significant effect of trial blocks [$F_{4,216}=162.5, p<.05$], but no Block X Group interaction ($p>.05$). There was no significant between-group difference [$F_{1,54}=2.18, p>.05$], although the HC group showed a trend of increasing scores over trial blocks. The GD group did not demonstrate a significant increase in IGT score across the 5 trial blocks.

Fig. 2.

Positive correlation between ventral striatal activity during the prospect of winning and total IGT score in HC and GD participants (N=56). Whole brain correlations demonstrate that increased ventral striatal activity during the winning prospect (A1W; relative to neutral A1L>N0)) and the losing prospect (A1L>A1N0) are associated with higher IGT scores across both HC and GD groups. Scatterplots depict percent blood-oxygen-level-dependent (BOLD) signal change in the ventral striatum cluster correlated with the total IGT score. All contrast maps are thresholded at an uncorrected level of $p < 0.05$ two-tailed and using a Monte Carlo simulation, family-wise-error-corrected at $p < 0.05$. The right side of the brain is on the right.

Fig. 3.

Positive correlation between ventral striatal activity during the prospect of winning and total IGT score in GD participants ($n=28$). This whole brain correlations demonstrates that increased ventral striatal activity during the winning prospect (A1W; relative to neutral A1L>N0)) is associated with higher IGT scores across the GD group. Scatterplot depicts percent blood-oxygen-level-dependent (BOLD) signal change in the ventral striatum cluster correlated with the total IGT score ($R^2=0.25, p<0.05$). All contrast maps are thresholded at an uncorrected level of $p<0.05$ two-tailed and using a Monte Carlo simulation, family-wise-error-corrected at $p<0.05$. The right side of the brain is on the right.

Table 1.

Demographic information for Gambling Disorder (GD) and Healthy Control (HC) groups

	GD	HC
<i>N</i>	28	28
Male/Female	19/9	19/9
Age (SD)	40.61 (10.6)	41.36 (10.21)
White/Black/Asian/American Indian	18/10	20/6/1/1
NonHispanic/Hispanic	26/2	27/1
Years of education	13.79 (1.8)	14.82 (2.53)
Current Smoker	14	7
SOGS [*]	13.3(3.9)	0.7 (1.25)

SD= Standard Deviation

*
 $P < 0.05$

Table 2.

Correlation between total Iowa Gambling Task (IGT) scores with A1Win (A1W) and A1Loss (A1L) activity on the Monetary Incentive Delay Task (MIDT) in combined HC and GD participants (N= 56)

HC + GD Combined	Structure	BA	L/R	x	y	z	k	Peak r-value
Total IGT Scores								
A1W > N	Anterior Cingulate/Lentiform Nucleus/Orbitofrontal cortex/Medial Frontal Gyrus/Clastrum/Inferior Frontal Gyrus/Caudate/Ventral Striatum	32	L	-12	36	6	521	0.488
	Posterior Cingulate/Thalamus/Precuneus/Culmen/Middle Temporal Gyrus/Insula/Cingulate Gyrus/Cuneus/Middle Occipital Gyrus/Lingual Gyrus	30	L	-6	-54	3	560	0.427
	Dorsal Posterior Cingulate Cortex/Cingulate Gyrus/Insula/Paracentral Lobule/Precuneus/Precentral Gyrus/Caudate/Middle Temporal Gyrus/Superior Parietal Lobule/Superior Temporal Gyrus/Paracentral Lobule	31	L	-18	-44	30	461	0.427
A1L > N	Ventral Striatum/ Caudate/ Putamen/Lentiform Nucleus/Medial Frontal Gyrus/Parahippocampal Gyrus	-	L	-9	6	-6	300	0.473

BA = Brodmann's area

k = voxel size

r = Pearson correlation coefficient

Table 3.

Correlation between total IGT scores with AIW and A2L activity on the MIDT in GD participants (N= 28)

GD	Structure	BA	L/R	x	y	z	k	Peak r-value
Total IGT Scores								
A1W > N	Anterior Cingulate/Limbic Lobe/Cingulate Gyrus/Inferior Frontal Gyrus/Medial Frontal Gyrus/Orbitofrontal Cortex/Lentiform Nucleus/Precuneus/Insula/Caudate/Inferior Parietal Lobule/Precentral Gyrus/Paracentral Lobule	24	L	0	30	6	1064	0.651
	Cuneus/Middle Occipital Gyrus/Inferior Occipital Gyrus/Precuneus/Posterior Cingulate/Inferior Temporal Gyrus/Middle Temporal Gyrus/Lingual Gyrus/Superior Occipital Gyrus	18	L	-9	-99	21	645	0.65
	Paracentral Lobule/Inferior Parietal Lobule/Middle Temporal Gyrus/Precuneus/Precentral Gyrus/Superior Temporal Gyrus/Cuneus/Angular Gyrus	5	R	12	-40	60	515	0.637
	Precentral Gyrus/Clastrum/Middle Frontal Gyrus/Superior Frontal Gyrus/Medial Frontal Gyrus	6	R	59	-5	42	531	0.6
A2L > N	Uncus/Middle Frontal Gyrus/Orbitofrontal Cortex/Superior Frontal Gyrus/Medial Frontal Gyrus/Parahippocampal Gyrus/Inferior Frontal Gyrus	28	L	-33	0	-33	774	-0.745
	Cingulate Gyrus/Precentral Gyrus/Postcentral Gyrus/Paracentral Lobule/Precuneus/Supramarginal Gyrus/Inferior Parietal Lobule	31	R	18	-27	45	360	-0.687

BA = Brodmann's area

k = voxel size

r = pearson correlation coefficient

Note: negative correlations were observed in all of these