Behavioural Brain Research 291 (2015) 237–243

Contents lists available at ScienceDirect

Behavioural Brain Research

journal homepage: www.elsevier.com/locate/bbr

Interactions among attention-deficit hyperactivity disorder (ADHD) and problem gambling in a probabilistic reward-learning task

Mehdi Abouzari*, Scott Oberg, Aaron Gruber, Matthew Tata

Department of Neuroscience, The University of Lethbridge, Alberta, Canada

HIGHLIGHTS

- We hypothesized that problem gambling and ADHD are linked by dysregulation of the neural processing involved in both reward processing and attention control.
- ADHD additionally impairs reinforcement-driven choice adaptation in subjects with problem gambling.
- Nongamblers participants tend to tolerate losses following good bets.
- Unmedicated ADHD gamblers tend to tolerate losses following bad bets.
- Stabilization of dopamine signaling by treating ADHD is itself also a treatment for certain forms of problem gambling.

ARTICLE INFO

Article history:
Received 16 March 2015
Received in revised form 19 May 2015
Accepted 25 May 2015
Available online 27 May 2015

Keywords:
Problem gambling
Attention-deficit hyperactivity disorder
Iowa gambling task
Decision making
Reward

ABSTRACT

Problem gambling is thought to be highly comorbid with attention-deficit hyperactivity disorder (ADHD). We propose that the neurobiological pathologies underlying problem gambling overlap with those in ADHD. In this study, we used a simplified computerized version of the Iowa Gambling Task (IGT) to assess differences in reinforcement-driven choice adaptation among participants with pathological gambling and/or ADHD. The task contained two choice options with different net payouts over the session; a good bet that resulted in a win of +50 points on 60% of trials (and −50 points on 40%), and a bad bet that resulted in +100 points on 40% of the trials (and −100 points on 60%). We quantified participants' preference for the good bet over the session and their sensitivity to reinforcement. Both the control subjects and medicated ADHD nongamblers significantly increased the proportion of good bets over the 400-trial session. Subjects with problem gambling performed worse than controls and ADHD nongamblers, but better than our limited sample of unmedicated ADHD gamblers. Control subjects, medicated ADHD nongamblers, and unmedicated ADHD nongamblers tended to tolerate losses following good bets, whereas unmedicated ADHD gamblers tended to tolerate losses following bad bets. These data reveal that ADHD, particularly when treated with medication, is not associated with poor choices on the IGT, but may exacerbate pathological choices in problem gamblers. It seems that stabilization of dopamine signaling that occurs when ADHD is treated is itself also a treatment for certain forms of problem gambling.

1. Introduction

Attention-deficit hyperactivity disorder (ADHD) is a prevalent and impairing disorder characterized by developmentally extreme levels of hyperactivity-impulsivity and/or inattention-disorganization [1]. ADHD patients make poor decisions in several aspects of their life. Their increased preference for risky decisions [2] and small immediate rewards rather than large delayed ones [3] suggest that they will perform poorly on decision-making tasks such as the Iowa Gambling Task (IGT). The IGT is designed to study decision-making among choices with uncertain and unequal rewards and penalties [4]. In the original version of this task participants have the choice to select a playing card from one of four decks: two are disadvantageous decks (with high gains and high loses), and two are advantageous decks (with low gains and low loses). Here, we used a simplified computerized version of the IGT to assess differences in reinforcement-driven choice adaptation among subjects with pathological gambling and/or ADHD.

Problem gambling is characterized by uncontrolled gambling despite negative consequences, and is thought to be comorbid with

* Corresponding author at: Canadian Center for Behavioral Neuroscience (CCBN), The University of Lethbridge, 4401 University Drive, Lethbridge, AB T1K 3M4, Canada. Tel.: +1 403 360 4255; fax: +1 403 329 2775.
E-mail address: mehdi.abouzari@uleth.ca (M. Abouzari).

http://dx.doi.org/10.1016/j.bbr.2015.05.041
0166-4328/

ADHD [5]. This comorbidity is superficially paradoxical: ADHD is characterized by an inability to maintain attentional focus, whereas problem gamblers, at least while gambling at video-based games, entail hyper-engagement of attention. However, ADHD is best conceptualized as a disorder of attentional control rather than a deficit of attention itself. Once engaged with a highly rewarding behavior, individuals with ADHD have no systemic deficit in attention or perception [6] and may in fact exhibit better performance than controls [7]. This is consistent with reports by the parents of ADHD children. They indicated that although their children appear to have many difficulties with attention and concentration in many situations, their concentration, performance, distractibility, and motivation all appear to improve when they engage in computer games [7].

Our hypothesis was that problem gambling and ADHD are linked by dysregulation of the neural processing involved in both reward processing and attention control. A likely candidate is the neuromodulator dopamine, which has broad empirical and theoretical support for a central role in signaling information about reinforcements [8], and is centrally implicated in the pathobiology of ADHD [9]. Work from our group and others have proposed neurobiological mechanisms by which dopamine levels can affect attention by regulating the gating of information into working memory [10,11]. One theory of the etiology of ADHD suggests that the normal response of dopamine neurons to reward-predicting cues becomes deficient [12], which would then impair the gating and/or maintenance of information in working memory [13]. By contrast, the increased dopamine release associated with highly reinforcing behaviors (e.g., video games), or commonly prescribed amphetamine-based pharmaceutical therapies for ADHD, may serve to temporarily ameliorate gating problems in ADHD. In addition to attention effects, the firing of dopamine neurons appears to encode a reward prediction error signal that provide a neurobiological learning signal analogous to that in computational models of reinforcement learning [8,14,15]. Such learning models can account for gradual adaptation of animal choice behavior through trial-and-error [16–18]. Alterations of dopamine would thus be expected to impair learning from wins and losses, as has been shown in Parkinsonian patients [19]. Evidence suggests both reduced levels of dopamine signaling [5,20–22] and dopamine receptors [23] in people with problem gambling. Thus, comorbidity of ADHD and problem gambling may produce compounding deficiencies in learning from reinforcements.

This proposed link between the reward processing and attention orienting systems means that a disruption in normal reward processing can be manifested as a disorder of attention. In particular, the normal shift of dopaminergic bursting responses from rewards themselves to the cues that predict these rewards [8,12]. In this view, abnormally high dopamine during gambling or abnormally low dopamine signaling as in ADHD [9] could disrupt the normal disengage-shift-engage cycle by manipulating the attention control system. This framework linking dopamine with both reward processing and gating of information into working memory provides a means to explore the relationship between disorders of reward processing such as problem gambling, and disorders of attention such as ADHD. Here, we examined how subjects with pathological gambling and/or ADHD weigh risks and benefits in a probabilistic reward-learning task, compared with normal controls. To our knowledge, this is the first study comparing the behavioral performance of problem gamblers and ADHD subjects using several IGT-based behavioral measures.

2. Materials and methods

2.1. Participants

We assessed differences in reinforcement-driven choice adaptation among subjects with pathological gambling and/or ADHD, and contrasted these data with a sex and age-matched control group. The gamblers group consisted of a population of young-adult gamblers who screened in the problem range indicated by DSM-IV or in the lower end of the pathological range of scores on the Canadian Problem Gambling Index (CPGI) [24]. In order to assess gambling propensity as well as possible co-morbidities, participants completed the CPGI, the National Institute on Drug Abuse – modified Alcohol, Smoking and Substance Involvement Screening Test (NIDA – modified ASSIST) [25], the National Opinion Research Center DSM Screen for gambling problems (NODS) [26], and the World Health Organization Composite International Diagnostic Review (WHO CIDI) [27]. ADHD subjects were confirmed by the Conners' ADHD scale as well as the WHO Adult ADHD Self-Report Scale (ASRS – v 1.1). Procedures were in accordance with the declaration of Helsinki and were approved by the University of Lethbridge Human Subjects Review Committee; all participants gave written informed consent.

2.2. Gambling task

In our simplified computerized version of the IGT, players could choose either a small (50 points) bet or a large (100 points) bet. The win/loss sequence for each bet type was pseudorandom (randomized within runs of 20 trials) with a 0.6/0.4 win/loss probability for the 50-point bet and a 0.4/0.6 win/loss probability for the 100-point bet. Thus as in the IGT, the optimal strategy over the long run was to choose the small lower-risk bet type to maximize the final score. The display sequence is shown in Fig. 1. The main screen contained

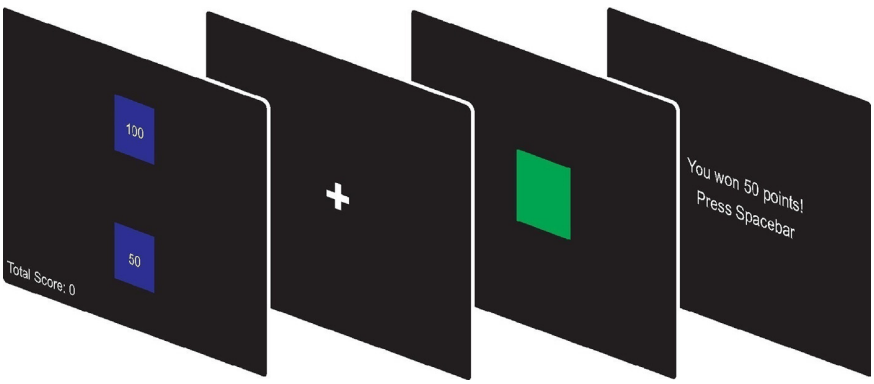

Fig. 1. Schematic of the behavioral task display.
On each trial, subjects chose the size of the wager (50 or 100) with the computer mouse. Fixation cross then appeared and lasted for 800–1200 ms followed by a colored square indicating win (green) or loss (red). This feedback remained visible for 1000 ms followed by text indicating the amount of either won or lost.

Table 1
Demographic data and questionnaire scores for the studied groups.

	Controls	Gamblers	Unmedicated ADHD gamblers	Medicated ADHD nongamblers	Unmedicated ADHD nongamblers	*p* value
Age	22.69 ± 3.24	23.13 ± 2.67	23.5 ± 2.38	22.09 ± 3.82	24.8 ± 3.63	0.79
Sex (M:F)	7:9	9:6	2:2	13:10	2:3	0.42
CPGI	0.5 ± 0.89	9.13 ± 4.05	12.5 ± 7.72	0.26 ± 0.54	0	<0.001*
ASSIST score	6.56 ± 5.20	10 ± 7.34	6.25 ± 4.5	5.08 ± 5.32	1.6 ± 1.52	0.37

Data are presented as mean ± standard deviation for numerical variables. The *p* values come from one-way ANOVA and Pearson chi-square tests for numerical and categorical variables, respectively and those smaller than 0.05 considered significant. CPGI: Canadian Problem Gambling Index; ASSIST: National Institute on Drug Abuse – modified Alcohol, Smoking and Substance Involvement Screening Test.
* <0.05.

two buttons to select bet type as well as a running tally of the participant's score. Upon selecting a bet, the display went blank except for a central fixation cross, which lasted for between 800 and 1200 ms. A colored square then appeared to indicate whether the bet had been won (green) or lost (red). This feedback stimulus remained visible for 1000 ms followed by text indicating the amount either won or lost. The main screen then reappeared to initiate the next trial. The session was divided into four blocks of 100 such trials, and participants received $5 at the end of each block if their total score was any amount equal to or greater than 100 points. If the total score for the block was less than 100, no remuneration was given. Our previous work indicates this threshold to be a reliable discriminant of non-random choice and is used to incentivize subjects to solve the task [28]. Scores were reset to 0 at the end of each block. Participants also received a fixed $20 remuneration after completion of the session, regardless of their performance on the task. Thus their financial success depended substantially but not entirely on their performance on the gambling task.

2.3. Behavioral analysis

Participants' bets were recorded during the course of the experiment and analyzed offline. We quantified subjects' preference for the good bet over the session by subtracting the number of high-risk (large) bets from the number of low-risk (small) bets. This measure was calculated within four quartile time bins to show subjects' learning trends over trials. We also explored the behavioral performance by using the total number of good bets as in previous studies [29,30]. Finally, we computed a metric of participants' tendency to re-engage with a previous bet despite a negative/positive outcome. We defined the 'small-lose-avoid' measure by the mean number of subsequent bets until the participant again selects the small (low-risk) bet after the participant had encountered a loss on a small bet (−50 points). Likewise, a 'large-lose-avoid' measure was defined as the mean number of subsequent bets to choose another large (high-risk) bet after a large loss outcome (−100 points). We also defined the 'small-win-stay' measure by the mean number of subsequent bets until the participant again selects the small (low-risk) bet after the participant had encountered a win on a small bet (+50 points). Likewise, a 'large-win-stay' measure was defined as the mean number of subsequent bets to choose another large (high-risk) bet after a large win outcome (+100 points).

3. Results

Demographic data and questionnaire scores for the groups are shown in Table 1. The groups were not significantly different in age, sex, and NIDA – modified ASSIST score, while CPGI was different among groups as expected (ANOVA test: $F = 42.11$, $p < 0.001$). Bonferroni-corrected post-hoc tests showed no significant differences between controls and nongamblers groups. In other words, CPGI was significantly higher in gamblers ($p < 0.001$) and unmedicated ADHD gamblers ($p < 0.001$) *vs.* controls. Participants' preference for the good bet over the session (small

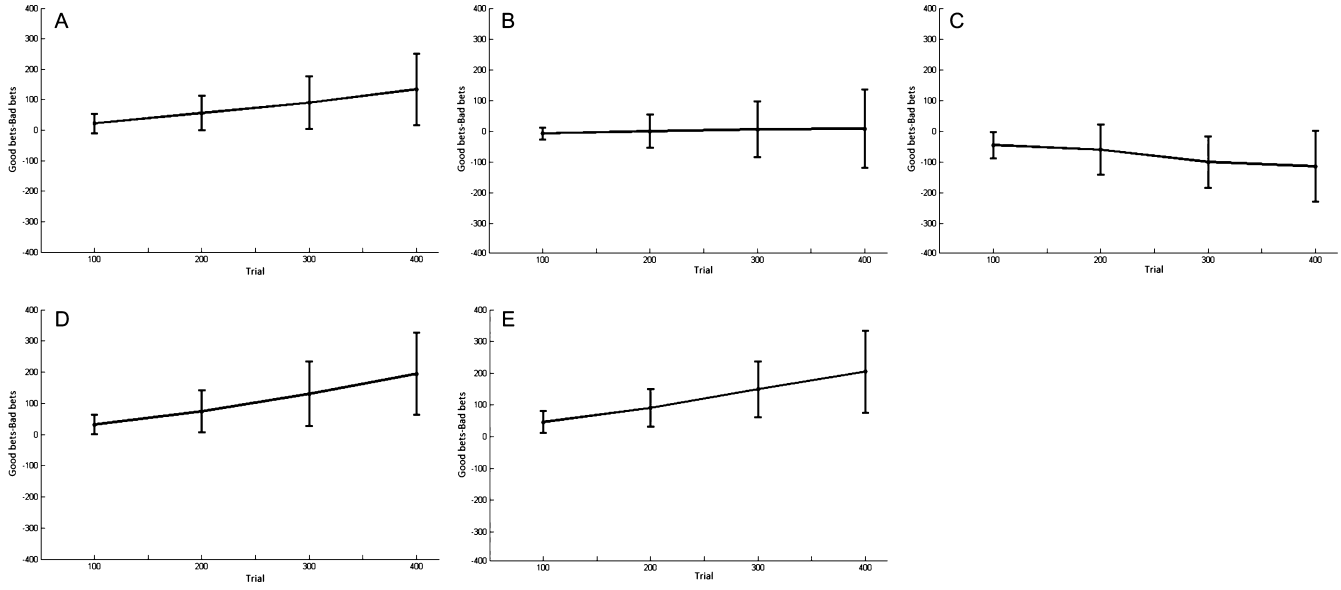

Fig. 2. Pattern of bet selections over trials among different studied groups.
Behavioral performance of 16 normal controls (A), 15 gamblers (B), 4 unmedicated ADHD gamblers (C), 23 medicated ADHD nongamblers (D), and 5 unmedicated ADHD nongamblers (E). Performance was quantified by subtracting the number of high-risk bets from the number of low-risk bets at four time points during the session. Positive slope indicates learning over trials.

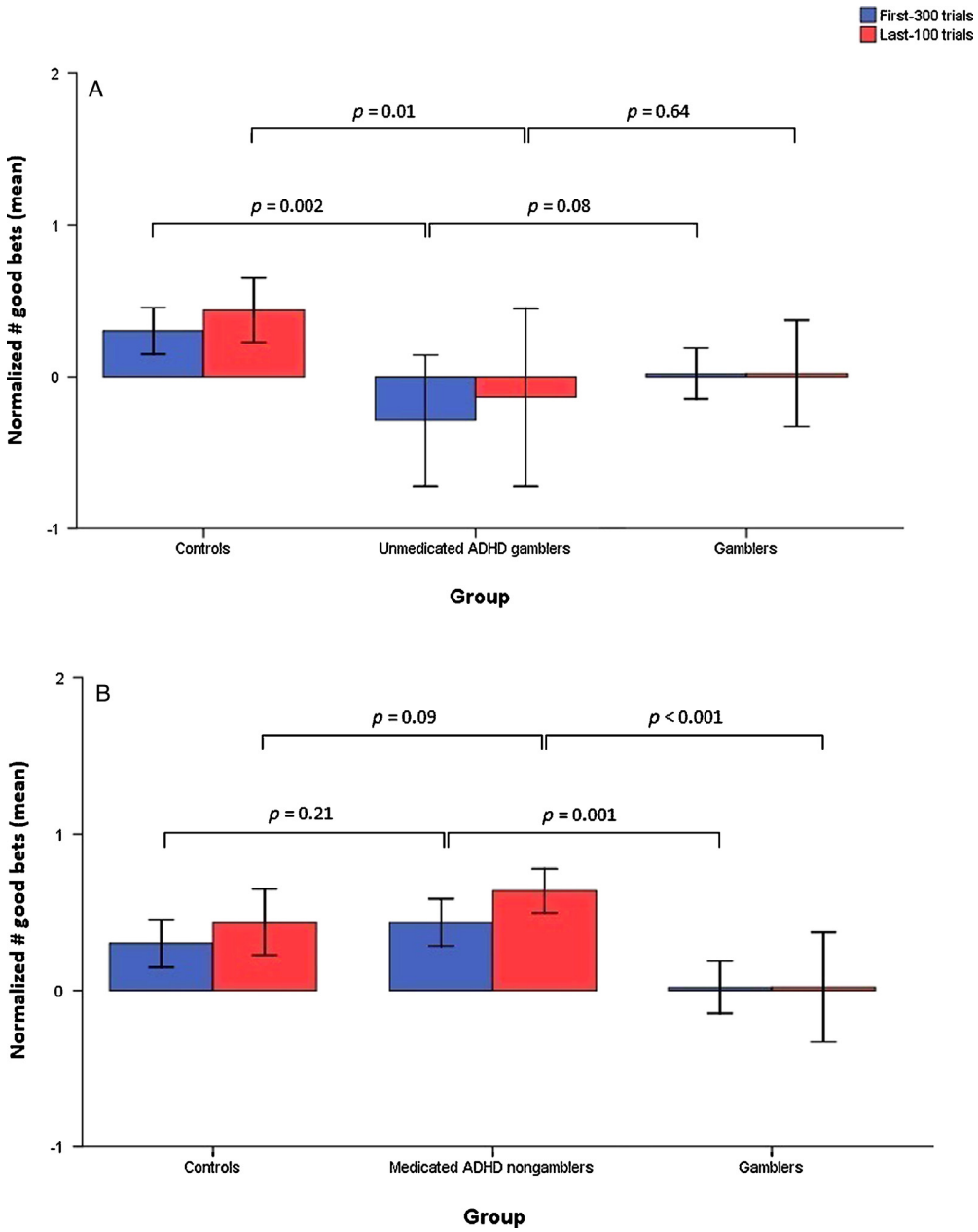

Fig. 3. Comparison of the early trials with the late ones by the means of normalized number of good bets.
The normalized numbers of good bets in the first-300 as well as in the last-100 trials were significantly higher in controls compared with gamblers. (A) Normalized number of good bets for unmedicated ADHD gamblers in the first-300 as well as in the last-100 trials were significantly lower than the controls while not statistically different from the gamblers. (B) In contrast, medicated ADHD nongamblers performed as well as the controls in both the first-300 and the last-100 trials. Error bars indicate ± 2 confidence intervals.

bets minus large bets) was entered as dependent variable and number of trials within four quartile time bins as factor in univariate ANOVA. As shown in Fig. 2, both the control subjects (Kruskal–Wallis ANOVA test: $p = 0.01$) and the medicated ADHD nongamblers (Kruskal–Wallis ANOVA test: $p < 0.001$) significantly increased the proportion of good bets over the 400 trials of the session, indicating that they were able to acquire and use knowledge of the reward outcomes to obtain a positive financial outcome. Subjects with problem gambling performed worse than controls and ADHD nongamblers (both medicated and unmedicated) but better than our limited sample of unmedicated ADHD gamblers. In sum, learning trend was affected by the group (ANOVA test: $F = 9.57$, $p < 0.001$). Between groups' comparisons by the means of Bonferroni post-hoc analysis showed that learning trend was more significant in controls *vs.* unmedicated ADHD gamblers ($p = 0.01$), in unmedicated ADHD nongamblers *vs.* gamblers ($p = 0.04$), in medicated and unmedicated ADHD nongamblers *vs.* unmedicated ADHD gamblers ($p = 0.002$ and $p = 0.001$, respectively).

These results were consistent when we considered the difference between the early versus the late trials. The normalized number of good bets were significantly higher in the last-100 trials as compared with the first-300 trials among controls and medicated ADHD nongamblers (Paired t-test: $t = -1.87$, df = 15, $p = 0.04$; and $t = -4.54$, df = 22, $p < 0.001$, respectively). As expected, the nor-

Table 2
Preference for different amount of loss among subjects of the studied groups.

Group (n)	Small-lose-avoid	Large-lose-avoid	*p* value (*t* value)
Controls (16)	1.75 ± 0.69	3.54 ± 1.77	0.006* (−3.16)
Gamblers (15)	2.49 ± 1.57	2.23 ± 0.70	0.63 (0.49)
Unmedicated ADHD gamblers (4)	3.47 ± 1.11	1.85 ± 0.70	0.16 (1.85)
Medicated ADHD nongamblers (23)	1.45 ± 0.50	8.07 ± 2.23	0.01* (−2.73)
Unmedicated ADHD nongamblers (5)	1.55 ± 0.61	6.60 ± 3.90	0.06 (−2.57)

Data are presented as mean ± standard deviation. The *p* values come from paired *t*-tests and those smaller than 0.05 considered significant. Degree of freedom for the *t*-test in each group is n-1.
* <0.05.

malized number of good bets in the first-300 and the last-100 trials were significantly higher in controls as compared to gamblers (Independent samples *t*-test: $t = 2.66$, df = 29, $p = 0.01$; and $t = 2.21$, df = 29, $p = 0.03$, respectively). In other words, the normalized number of good bets for unmedicated ADHD gamblers in the first-300 as well as in the last-100 trials were significantly lower than the controls (Independent samples *t*-test: $t = 3.71$, df = 18, $p = 0.002$; and $t = 2.61$, df = 18, $p = 0.01$, respectively; Fig. 3A), while not statistically different from the gamblers (Independent samples *t*-test: $t = 1.86$, df = 17, $p = 0.08$; and $t = 0.47$, df = 17, $p = 0.64$, respectively; Fig. 3A). In contrast, medicated ADHD nongamblers perform as well as the controls in both the first-300 and in the last-100 trials (Independent samples *t*-test: $t = -1.27$, df = 37, $p = 0.21$; and $t = -1.73$, df = 37, $p = 0.09$, respectively; Fig. 3B) and also statistically better than the gamblers (Independent samples *t*-test: $t = -3.79$, df = 36, $p = 0.001$; and $t = -3.96$, df = 36, $p < 0.001$, respectively; Fig. 3B).

Our analysis of mean number of bets before a participant returned to a bet that had yielded a loss is shown in Table 2. Small values indicate that the participant was willing to disregard the prior loss and choose the same bet type again within a small number of trials. Large values indicate that the participant tended to avoid that bet type for subsequent trials. The expected value over 400 bets if the participant was betting randomly is 2.0. Control subjects and medicated ADHD nongamblers had significantly lower small-lose-avoid scores as compared to their large-lose-avoid scores (Paired *t*-test: $t = -3.16$, df = 15, $p = 0.006$; and $t = -2.73$, df = 22, $p = 0.01$, respectively), indicating that they tolerated small losses more than large losses. Unmedicated ADHD nongamblers tended to tolerate losses more on good than bad bets (Paired *t*-test: $t = -2.57$, df = 4, $p = 0.06$), whereas gamblers and unmedicated ADHD gamblers did not show a differential loss tolerance on good bets, and rather showed the opposite trend of tolerating losses following bad bets more than on good bets.

An ANOVA over all groups showed that the small-lose-avoid measure was affected by the group ($F = 4.72$, $p = 0.001$) but not the large-lose-avoid measure ($F = 1.68$, $p = 0.15$). The Bonferroni-corrected post-hoc analysis revealed that small-lose-avoid is lower in controls *vs.* unmedicated ADHD gamblers ($p = 0.02$, 95% CI = −3.33–0.10), higher in gamblers *vs.* medicated ADHD nongamblers ($p = 0.02$, 95% CI = 0.08–2.0), higher in unmedicated ADHD gamblers *vs.* medicated ADHD nongamblers ($p = 0.003$, 95% CI = 0.45–3.58), and lower in unmedicated ADHD nongamblers *vs.* unmedicated ADHD gamblers ($p = 0.05$, 95% CI = −0.02–3.86). Furthermore, unmedicated ADHD gamblers' tolerance for small losses was less than controls but not different from the gamblers (Independent samples *t*-test: $t = -3.93$, df = 18, $p = 0.001$; and $t = -1.16$, df = 17, $p = 0.26$, respectively). On the other hand, the small-lose-avoid and large-lose-avoid measures revealed that medicated ADHD nongamblers performed better than the gamblers (Independent samples *t*-test: $t = 2.97$, df = 36, $p = 0.005$; and $t = -1.97$, df = 36, $p = 0.05$, respectively) but not statistically different from the controls.

In Table 3, we show group-wise preference for repeating choices following wins. Small values indicate that the participant was willing to choose the same bet type, while large values indicate that the participant tended to avoid that bet type in subsequent trials. Similar to their loss avoidance scores, controls and medicated ADHD nongamblers had significantly lower small-win-stay scores as compared to their large-win-stay scores (Paired *t*-test: $t = -3.77$, df = 15, $p = 0.002$; and $t = -5.22$, df = 22, $p < 0.001$, respectively), indicating that they preferred to repeat bets for small wins more than large wins. Furthermore, ANOVA over all groups showed that both small-win-stay ($F = 5.95$, $p < 0.001$) and large-win-stay ($F = 3.40$, $p = 0.009$) measures were affected by group. The Bonferroni-corrected post-hoc analysis revealed that small-win-stay is lower in controls *vs.* unmedicated ADHD gamblers ($p = 0.006$, 95% CI = −1.85–0.19), higher in gamblers *vs.* medicated ADHD nongamblers ($p = 0.02$, 95% CI = 0.05–1.04), higher in unmedicated ADHD gamblers *vs.* medicated ADHD nongamblers ($p = 0.001$, 95% CI = 0.31–1.93), and lower in unmedicated ADHD nongamblers *vs.* unmedicated ADHD gamblers ($p = 0.008$, 95% CI = 0.19–2.19). In the same way, large-win-stay measure was significantly higher in gamblers *vs.* medicated ADHD nongamblers ($p = 0.02$, 95% CI = −4.79–0.26).

4. Discussion

Overall, the present study aimed to assess differences in reinforcement-driven choice adaptation among subjects with problem gambling and/or ADHD. Standard performance analysis (simple difference score between good bets and bad bets) revealed that only controls and medicated ADHD nongamblers were able to acquire and use knowledge of the reward outcomes to obtain a positive financial outcome. The available literature on performance of

Table 3
Preference for different amount of win among subjects of the studied groups.

Group (n)	Small-win-stay	Large-win-stay	*p* value (*t* value)
Controls (16)	1.43 ± 0.28	2.97 ± 1.47	0.002* (−3.77)
Gamblers (15)	1.88 ± 0.60	2.32 ± 1.57	0.39 (−0.87)
Unmedicated ADHD gamblers (4)	2.45 ± 1.07	1.42 ± 0.30	0.14 (1.98)
Medicated ADHD nongamblers (23)	1.33 ± 0.44	4.85 ± 2.95	<0.001* (-5.22)
Unmedicated ADHD nongamblers (5)	1.26 ± 0.20	3.52 ± 2.93	0.17 (−1.65)

Data are presented as mean ± standard deviation. The *p* values come from paired *t*-tests and those smaller than 0.05 considered significant. Degree of freedom for the *t*-test in each group is n-1.
* <0.05.

ADHD patients using IGT measurements is conflicting. Our data is in line with those which showed improvement in bet selections over time among medicated and possibly unmedicated (although not statistically) ADHD patients [31–34]. In contrast, some other studies found affective decision-making deficits in ADHD patients using IGT scores [35–37]. Neither the first nor the latter group of studies screened their ADHD patients for gambling. Considering the possible comorbidity between ADHD and problem gambling [5], studies that found decision-making deficits in ADHD patients may have included a disproportionate number of gamblers in their ADHD groups. This potential confound may have distorted the overall IGT performance.

The variety of IGT-based performance scores used in previously published studies is another possible explanation for the inconsistent results of ADHD patients. Some other outcome measures used in this regard include total money won [38], total of cards selected on individual decks [29], comparison between the number of cards selected from the decks A and C (low-frequency loses) and decks B and D (high-frequency loses) [29], and analysis of selections in the later trials versus the earlier ones [30,37]. This issue motivated us to compare the normalized number of good bets in the first-300 versus the last-100 trials. We found that ADHD additionally impairs good bet selections in both later and earlier trials in subjects with problem gambling, but that medicated ADHD nongamblers perform equally or better than controls (Fig. 3). These findings are consistent with our previous results using the standard score (good bets minus bad bets). This suggest that accurate screening of ADHD patients and excluding those who are gamblers may lead to a more consistent result regardless of the type of performance score used.

Routine outcome measures used for analyzing IGT performance have important limitations [39–41]. All of these outcome measures mentioned above do not allow any interpretation of shifts of bet choice between decks, or the tendency to stay on a recent deck. In other words, these measures only take into account long-term outcomes and ignore the short-term strategy used by the participant during the task [42,43]. It means that participants without any strategy might have a score close to or even above zero and do not show a preference for one of the decks. To our knowledge, only one study has employed an analysis based on shift frequencies between the decks across IGT trials in ADHD patients [43]. They concluded that even though differences among groups might not be found when using standard analyses, a shift-frequency analysis can reveal distinct strategies on the execution of the test [43].

Our analyses of the small-lose-avoid and large-lose-avoid measures are in contrast to the staying and shifting pattern analyses performed by Sallum and colleagues [43]. While their standard score analyses failed to show any differences among their studied groups, their ADHD patients shifted more than controls to a disadvantageous deck and chose more consecutive cards from disadvantageous decks, independently of the contingency of loses [43]. In contrast, our analyses based on loss-triggered shift frequencies between decks are in line with those obtained from standard score analyses. This is further evidence that ADHD nongamblers adopt a strategy similar to normal subjects. On the other hand, it is the problem gambling aspect that is associated with a shorter avoidance of the bad choice following a loss than avoidance of the good choice following a loss. Although our data do not lend themselves to implementation of a robust reward-learning model (for example due to limited trials with which to fit model parameters), our analysis of the impact of wins/losses on future decisions was an attempt to capture different sensitivities to errors among groups. This finding begins to speak to the notion of different reward-prediction errors in gamblers and ADHD patients.

Our findings are consistent with the hypothesis that ADHD and problem gambling both involve imbalance of dopamine signaling, while emphasizing that reward-learning system is subtly sensitive to interacting factors. All nongamblers in our study exhibited the advantageous tendency to prefer the small bet over time, while gamblers tended to over-select the large bet. The gambling factor did not cleanly differentiate our groups, however, because those participants with both unmedicated ADHD and gambling tended to be worst performing of any group. We can speculate on the underlying neurobiology: either excessive or insufficient dopamine levels are known to result in cognitive impairment in rodent models [44,45] and impaired learning among medicated children with ADHD [46]. There is also evidence suggesting impaired dopamine transmission in problem gamblers. Abnormal metabolic responses in dopaminergic areas of the brain have been revealed by fMRI in problem gamblers [5,20–22], abnormal medial-frontal electrical activity in problem gamblers have been observed with EEG [28], atypical dopamine D2 receptor genes have been found in a number of addictive conditions including problem gambling [23], and dopamine replacement therapy in Parkinson's disease has been increased the risk of problem gambling [47,48]. Taken together, there appears to be a link between ADHD and problem gambling via common susceptibility to dysregulated dopaminergic signaling. It is important to note that other neuromodulators, particularly 5-hydroxytryptamine, are also important for mediating choice avoidance after losses [49] and are impaired in ADHD [50].

5. Conclusions

These data highlight the need for studies of ADHD in gambling and other decision tasks to screen for problem gambling to avoid confounding altered decision processes related to problem gambling with those related to ADHD alone. Elucidation of the underlying link between problem gambling and ADHD is likely to catalyze novel strategies for treatment and diagnosis of gambling problems. In other words, treating problem gambling as an addiction both scientifically and clinically may improve outcomes [51]. Our results raise the intriguing possibility that the stabilization of dopamine by treatment of ADHD might also remediate certain forms of problem gambling and other addictions.

Acknowledgements

The authors thank Karla Ponjavic-Conte, Sheena MacInnes, Amanda McMullan, and Samantha Dodic for assistance with data collection and Dr. Robert Williams and Dr. Noella Piquette-Tomei for helpful discussions. The work was supported by the Alberta Gambling Research Institute (AGRI) and the Polaris Award from Alberta Innovates Health Solutions (AIHS). We also wish to acknowledge any anonymous reviewer for his/her valuable comments on the original draft to improve our manuscript.

References

[1] American Psychiatric Association, Diagnostic and Statistical Manual of Mental Disorders Text Revision (DSM-IV-TR), 4th ed., American Psychiatric Association, Washington, DC, 2000.
[2] M. Luman, J. Oosterlaan, D.L. Knol, J.A. Sergeant, Decision-making in ADHD: sensitive to frequency but blind to the magnitude of penalty? J. Child Psychol. Psychiatry 49 (2008) 712–722.
[3] I. Antrop, P. Stock, S. Verté, J.R. Wiersema, D. Baeyens, H. Roeyers, ADHD and delay aversion: the influence of non-temporal stimulation on choice for delayed rewards, J. Child Psychol. Psychiatry 47 (2006) 1152–1158.
[4] A. Bechara, A.R. Damasio, H. Damasio, S.W. Anderson, Insensitivity to future consequences following damage to human prefrontal cortex, Cognition 50 (1994) 7–15.
[5] A.E. Goudriaan, J. Oosterlaan, E. de Beurs, W. Van den Brink, Pathological gambling: a comprehensive review of biobehavioral findings, Neurosci. Biobehav. Rev. 28 (2004) 123–141.
[6] C.L. Huang-Pollock, J.T. Nigg, Searching for the attention deficit in attention deficit hyperactivity disorder: the case of visuospatial orienting, Clin. Psychol. Rev. 23 (2003) 801–830.

[7] R. Shaw, A. Grayson, V. Lewis, Inhibition, ADHD and computer games: the inhibitory performance of children with ADHD on computerized tasks and games, J. Atten. Disord. 8 (2005) 160–168.
[8] W. Schultz, P. Dayan, P.R. Montague, A neural substrate of prediction and reward, Science 275 (1997) 1593–1599.
[9] T. Sagvolden, E.B. Johansen, H. Aase, V.A. Russell, A dynamic developmental theory of attention-deficit/hyperactivity disorder (ADHD) predominantly hyperactive/impulsive and combined subtypes, Behav. Brain Sci. 28 (2005) 397–419, discussion 419-68.
[10] A.J. Gruber, P. Dayan, B.S. Gutkin, S.A. Solla, Dopamine modulation in the basal ganglia locks the gate to working memory, J. Comput. Neurosci. 20 (2006) 153–166.
[11] D. Durstewitz, J.K. Seamans, The computational role of dopamine D1 receptors in working memory, Neural Networks 15 (2002) 561–572.
[12] G. Tripp, J.R. Wickens, Research review: dopamine transfer deficit: a neurobiological theory of altered reinforcement mechanisms in ADHD, J. Child Psychol. Psychiatry 49 (2008) 691–704.
[13] A.J. Gruber, P. Dayan, B.S. Gutkin, S.A. Solla, Dopamine modulation in the basal ganglia locks the gate to working memory, J. Comput. Neurosci. 20 (2006) 153–166.
[14] P.R. Montague, P. Dayan, C. Person, T.J. Sejnowski, Bee foraging in uncertain environments using predictive hebbian learning, Nature 377 (1995) 725–728.
[15] R.S. Sutton, A.G. Barto, Reinforcement Learning: and Introduction, MIT Press, Cambridge, 1998.
[16] N.D. Daw, J.P. O'Doherty, P. Dayan, B. Seymour, R.J. Dolan, Cortical substrates for exploratory decisions in humans, Nature 441 (2006) 876–879.
[17] M. Ito, K. Doya, Validation of decision-making models and analysis of decision variables in the rat basal ganglia, J. Neurosci. 29 (2009) 9861–9874.
[18] I. Skelin, R. Hakstol, J. VanOyen, D. Mudiayi, L.A. Molina, V. Holec, et al., Lesions of dorsal striatum eliminate lose-switch responding but not mixed-response strategies in rats, Eur. J. Neurosci. 39 (2014) 1655–1663.
[19] M.J. Frank, L.C. Seeberger, R.C. O'reilly, By carrot or by stick: cognitive reinforcement learning in parkinsonism, Science 306 (2004) 1940–1943.
[20] M.N. Potenza, M.A. Steinberg, P. Skudlarski, R.K. Fulbright, C.M. Lacadie, M.K. Wilber, et al., Gambling urges in pathological gambling: a functional magnetic resonance imaging study, Arch. Gen. Psychiatry 60 (2003) 828–836.
[21] J. Reuter, T. Raedler, M. Rose, I. Hand, J. Gläscher, C. Büchel, Pathological gambling is linked to reduced activation of the mesolimbic reward system, Nat. Neurosci. 8 (2005) 147–148.
[22] D.N. Crockford, B. Goodyear, J. Edwards, J. Quickfall, N. el-Guebaly, Cue-induced brain activity in pathological gamblers, Biol. Psychiatry 58 (2005) 787–795.
[23] K. Blum, P.J. Sheridan, R.C. Wood, E.R. Braverman, T.J. Chen, J.G. Cull, et al., The D2 dopamine receptor gene as a determinant of reward deficiency syndrome, J. R. Soc. Med. 89 (1996) 396–400.
[24] Ferris J, Wynne H. The Canadian problem gambling index: Final report. 2001.
[25] WHO ASSIST Working Group, The alcohol, smoking and substance involvement screening test (ASSIST): development, reliability and feasibility, Addiction 97 (2002) 1183–1194.
[26] D.M.S. Gerstein, M. Toce, J. Hoffman, A. Palmer, R. Johnson, C. Larison, et al., Gambling Impact and Behavior Study: Report to the National Gambling Impact Study Commission, National Opinion Research Center, Chicago, 1999.
[27] R.C. Kessler, G. Andrews, D. Mroczek, B. Ustun, H.U. Wittchen, The world health organization composite international diagnostic interview short-form (cidi-sf), Int. J. Methods Psychiatr. Res. 7 (1998) 171–185.
[28] S.A. Oberg, G.J. Christie, M.S. Tata, Problem gamblers exhibit reward hypersensitivity in medial frontal cortex during gambling, Neuropsychologia 49 (2011) 3768–3775.
[29] Y.C. Chiu, C.H. Lin, Is deck C an advantageous deck in the Iowa Gambling Task, Behav. Brain Funct. 3 (2007) 37.
[30] F.F. da Rocha, N.B. Alvarenga, L. Malloy-Diniz, H. Corrêa, Decision-making impairment in obsessive-compulsive disorder as measured by the Iowa Gambling Task, Arq. Neuropsiquiatr. 69 (2011) 642–647.
[31] H.M. Geurts, S. van der Oord, E.A. Crone, Hot and cool aspects of cognitive control in children with ADHD: decision-making and inhibition, J. Abnorm. Child Psychol. 34 (2006) 813–824.
[32] J. Suhr, D. Hammers, K. Dobbins-Buckland, E. Zimak, C. Hughes, The relationship of malingering test failure to self-reported symptoms and neuropsychological findings in adults referred for ADHD evaluation, Arch. Clin. Neuropsychol. 23 (2008) 521–530.
[33] C.W. Hobson, S. Scott, K. Rubia, Investigation of cool and hot executive function in ODD/CD independently of ADHD, J. Child Psychol. Psychiatry 52 (2011) 1035–1043.
[34] A. Ibáñez, A. Petroni, H. Urquina, F. Torrente, T. Torralva, E. Hurtado, et al., Cortical deficits of emotional face processing in adults with ADHD: its relation to social cognition and executive function, Soc. Neurosci. 6 (2011) 464–481.
[35] M.E. Toplak, U. Jain, R. Tannock, Executive and motivational processes in adolescents with Attention-Deficit-Hyperactivity Disorder (ADHD), Behav. Brain Funct. 1 (2005) 8.
[36] N. Garon, C. Moore, D.A. Waschbusch, Decision making in children with ADHD only, ADHD-anxious/depressed, and control children using a child version of the Iowa Gambling Task, J. Atten. Disord. 9 (2006) 607–619.
[37] M. Miller, M. Sheridan, S.L. Cardoos, S.P. Hinshaw, Impaired decision-making as a young adult outcome of girls diagnosed with attention-deficit/hyperactivity disorder in childhood, J. Int. Neuropsychol. Soc. 19 (2013) 110–114.
[38] R. van den Bos, B.B. Houx, B.M. Spruijt, The effect of reward magnitude differences on choosing disadvantageous decks in the Iowa Gambling Task, Biol. Psychol. 71 (2006) 155–161.
[39] M.T. Buelow, J.A. Suhr, Construct validity of the Iowa Gambling Task, Neuropsychol. Rev. 19 (2009) 102–114.
[40] E. Ferguson, P.A. Bibby, S. Rosamond, C. O'Grady, A. Parcell, C. Amos, et al., Alexithymia, cumulative feedback, and differential response patterns on the Iowa Gambling Task, J. Pers. 77 (2009) 883–902.
[41] R. Visagan, A. Xiang, M. Lamar, Comparison of deck- and trial-based approaches to advantageous decision making on the Iowa Gambling Task, Psychol. Assess 24 (2012) 455–463.
[42] A. Horstmann, A. Villringer, J. Neumann, Iowa gambling task: there is more to consider than long-term outcome. Using a linear equation model to disentangle the impact of outcome and frequency of gains and losses, Front Neurosci. 6 (2012) 61.
[43] I. Sallum, F. Mata, D.M. Miranda, L.F. Malloy-Diniz, Staying and shifting patterns across IGT trials distinguish children with externalizing disorders from controls, Front Psychol. 4 (2013) 899.
[44] G.V. Williams, P.S. Goldman-Rakic, Modulation of memory fields by dopamine D1 receptors in prefrontal cortex, Nature 376 (1995) 572–575.
[45] B.L. Murphy, A.F. Arnsten, J.D. Jentsch, R.H. Roth, Dopamine and spatial working memory in rats and monkeys: pharmacological reversal of stress-induced impairment, J. Neurosci. 16 (1996) 7768–7775.
[46] J.M. Swanson, D. Cantwell, M. Lerner, K. McBurnett, G. Hanna, Effects of stimulant medication on learning in children with ADHD, J. Learn Disabil. 24 (1991) 219–230.
[47] K.J. Black, J.H. Friedman, Repetitive and impulsive behaviors in treated Parkinson disease, Neurology 67 (2006) 1118–1119.
[48] V. Voon, K. Hassan, M. Zurowski, S. Duff-Canning, M. de Souza, S. Fox, et al., Prospective prevalence of pathologic gambling and medication association in Parkinson disease, Neurology 66 (2006) 1750–1752.
[49] H.E. den Ouden, N.D. Daw, G. Fernandez, J.A. Elshout, M. Rijpkema, M. Hoogman, et al., Dissociable effects of dopamine and serotonin on reversal learning, Neuron 80 (2013) 1090–1100.
[50] R.D. Oades, Dopamine-serotonin interactions in attention-deficit hyperactivity disorder (ADHD), Prog. Brain Res. 172 (2008) 543–565.
[51] J.E. Grant, M.N. Potenza, E. Hollander, R. Cunningham-Williams, T. Nurminen, G. Smits, et al., Multicenter investigation of the opioid antagonist nalmefene in the treatment of pathological gambling, Am. J. Psychiatry 163 (2006) 303–312.