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ORIGINAL PAPER

Executive Function in Pathological Gamblers and Healthy Controls

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Abstract Executive function (EF) deficits may underlie some of the impulse control problems seen in pathological gambling. Pathological gamblers (PGs, $n = 45$) and controls ($n = 45$) were compared on several measures of EF (including measures of response inhibition, working memory, cognitive flexibility and perseveration, planning and decision-making), as well as memory and intelligence tests to examine whether PGs evidence EF dysfunction. Compared with controls, PGs exhibited specific deficits on measures of planning and decision-making. PGs also exhibited relative deficits on a measure of perseveration, but this deficit was no longer significant after controlling for group differences in intelligence. These results suggest that PGs may experience deficits on specific components of EF.

Keywords Gambling · Pathological gambling · Executive function · Impulse control · Decision-making

Introduction

Pathological gambling (PG) is classified as an impulse control disorder in the DSM-IV-TR (American Psychiatric Association 2000), and impulse control problems are considered to be a prominent feature of PG. Many studies, for example, have found correlations between PG, and behavioral and self-report measures of impulsivity (e.g., Blaszczynski and Steel 1998; Ledgerwood et al. 2009; Petry 2001; Steel and Blaszczynski 1998; Vitaro et al. 1998). However, despite this initial understanding of the relationship between impulse

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control and PG, relatively little research has investigated the underlying neurocognitive deficits of this complex association.

Specifically, impulse control is thought to be associated with underlying deficits in function in particular areas of the brain (e.g., prefrontal cortex) that are related to executive function (EF; Hinson et al. 2003). EF involves higher-level cognitive processes implicated in the formation of successful goal-directed behavior (Lezak et al. 2004), including planning and initiating behaviors, anticipating (positive and negative) consequences of actions, and the ability to adjust behaviors based on environmental feedback. Because EF deficits frequently underlie addictive behaviors (e.g., Hester and Garavan 2004), it is essential to study potential EF dysfunction in pathological gamblers (PGs). This is especially important because EF deficits may have implications for the capacity of individual gamblers to benefit from psychosocial treatments for PG (Leblond et al. 2003).

A limited number of published studies have explored EF in PGs (see van Holst et al. 2010 for review). Goudriaan et al. (2006) found that treatment-seeking PGs demonstrated greater impairment on response inhibition, time estimation, cognitive flexibility and planning tasks relative to healthy controls. Goudriaan did not report significant differences between PGs and controls on measures of perseveration. Cavedini et al. (2002) compared 20 treatment-seeking PGs and 40 healthy controls on the Iowa Gambling Task, Weigle's Sorting Test and the Wisconsin Card Sorting Test. They found that, compared to controls, PGs made significantly more disadvantageous card choices on the Iowa Gambling Task, but that the two groups did not differ in respect of their performance on the other two tasks. Thus, PGs may experience some impaired decision-making in situations where clear "right or wrong" feedback is not provided, but be relatively unimpaired when it comes to set-shifting measures such as is required of the Wisconsin Card Sorting Test. However, it is important to note that PGs and controls were not matched on demographic factors. As such, PGs were older (38.5 vs. 30.3 years) and more likely to be male (95% vs. 45%). Brand et al. (2005) further examined decision-making deficits associated with PG by having PG patients and healthy controls complete a gambling task. Relative to controls, PGs exhibited significantly more disadvantageous risk taking, which in turn was correlated with poor function on categorization, cognitive flexibility and set-shifting measures of EF. It is important to note that each study sampled only treatment-seeking PGs, who, as a sub-population, may experience differing EF issues than non-treatment seeking PGs.

Functional magnetic resonance imaging (fMRI) studies have confirmed preliminary findings suggestive of greater EF dysfunction in PGs. Potenza et al. (2003b), for example, reported that PGs displayed decreased activity in several areas of the brain associated with EF, including the frontal and orbitofrontal cortex, caudate/basal ganglia, and thalamus. In another study, Potenza et al. (2003a) found significant differences between PGs and controls in functioning in the ventromedial prefrontal cortex during completion of a Stroop task, which measures cognitive flexibility.

Taken together, these studies suggest that PGs may experience significant deficits in EF compared with non-PGs, meaning that PG may be associated with significant comorbid neurological dysfunction in many gamblers. This is clinically significant when considering appropriate treatment strategies for this population, as EF difficulties may hinder an individual's ability to benefit from treatment for PG. For example, individuals with impaired planning ability and disinhibition would benefit from treatment interventions designed to help them learn to anticipate consequences, both negative and positive. Clearly, further research is warranted to assess the specific areas of deficit in PGs, which would help tailor appropriate treatment approaches with the highest likelihood of success.

The primary aim of the present study was to compare PGs and non-problem gamblers on performance tests of EF. The EF measures in this study assessed five primary cognitive areas: (1) response inhibition; (2) working memory; (3) cognitive flexibility and perseveration; (4) planning; and (5) decision-making. Based on the available, yet limited prior research, we predicted that PGs would evidence significant deficits on response inhibition, cognitive flexibility, planning and decision-making measures, relative to controls. As an extension of past research, we also examined aspects of cognitive functioning, including intelligence and non-executive aspects of memory that are not explicitly related to EF. We predicted that the outcomes of these measures would not differ between PGs and controls.

Methods

Participants

Participants included PGs ($n = 45$) and non-pathological gambler controls ($n = 45$) recruited from the community of Windsor, Ontario (Fig. 1). PGs and non-PGs were recruited using newspaper and/or radio advertising, and by word of mouth. PGs were also recruited from the Problem Gambling Services division of Windsor Regional Hospital, one of the most utilized gambling treatment facilities in the province. We sampled PGs from both sources because past EF studies have primarily sampled only treatment-seeking PGs (e.g., Goudriaan et al. 2006). Treatment seekers may experience a differing profile of gambling symptoms and consequences that may in turn be related to EF dysfunction.

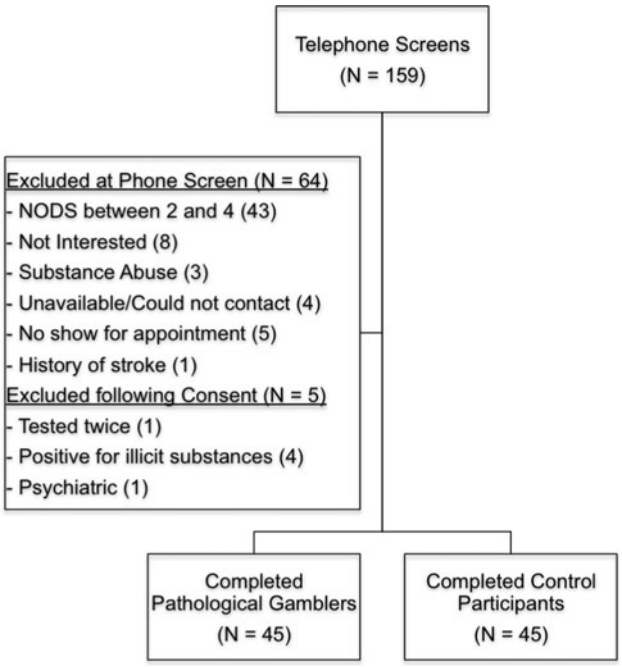

Fig. 1 Flow of participants through the study

PGs met current DSM-IV (i.e., past year) diagnostic criteria for PG as assessed by the NORC DSM Screen for Gambling Problems (NODS, described below); were 18 years or older; were English speaking; and were able to provide informed consent. They were excluded if they had current mania, psychosis or suicidality that was not adequately controlled, or were dependent on any substances other than nicotine or caffeine. They were also excluded if they provided a positive toxicology screen for any substances (including cocaine, opioids, marijuana, and hallucinogens) using Ezscreen test sticks (Editek, Burlington, NC) unless they could demonstrate receiving prescription medication that was used only as directed. They were also excluded if they provided a positive breathalyzer reading for alcohol consumption as assessed by an Alcosensor IV Alcometer (Intoximeters, St. Louis, MO) with results greater than 0.003 ng/dl considered positive. Control participants met the same inclusion and exclusion criteria as PGs, except that control participants were required to obtain lifetime and past year NODS scores of no more than 1.

Measures

Demographics, Gambling, Inclusion and Exclusion Measures

A *demographic form* and the *Canadian Problem Gambling Index* (CPGI; Ferris and Wynne 2001) were used to collect basic demographic information (e.g., age, gender, race, employment, etc.), and gambling history. The CPGI is a valid and reliable measure of gambling behavior and symptoms (Ferris and Wynne 2001).

The *NORC DSM Screen for Gambling Problems (NODS)* was used to diagnose PG. The NODS is based on DSM-IV criteria for PG, and assesses lifetime and current (i.e., within the past year) PG (American Psychiatric Association 2000; Gerstein et al. 1999). The NODS has been found to be a valid and reliable diagnostic measure of PG (Hodgins 2004).

Sections of the *Structured Clinical Interview for the DSM-IV* (SCID; First et al. 1997) were used to assess exclusion criteria related to alcohol and drug dependence, and severe psychiatric difficulties.

Executive Function, Intelligence and Memory Measures

Wisconsin Card Sorting Test (WCST). The WCST assesses abstraction and the ability to shift or maintain cognitive set (Berg 1948; Milner 1963). Inability to shift cognitive set in the face of new information is indicative of perseveration. In this task, participants are asked to sort cards displayed on a computer screen by using rules that are not known to the participant. The computer provides a "right" or "wrong" response after each sort. Following 10 consecutive correct responses, the program changes the response rules without warning to the participant, and he/she must shift his/her strategy to adjust to the new rules. Percent perseverative responses and number of categories completed were used as measures of perseveration in the present study. The WCST has previously been used to assess perseveration and set-shifting in several populations, including PGs (Goudriaan et al. 2006).

Stroop Test. The Stroop test is a measure of cognitive flexibility that assesses ability to suppress a habitual response to perform a novel one (Stroop 1935; Golden 1978). During the first phase of the test, participants are asked to read names of colors that are printed in black ink on a white card. In the next phase, they are shown non-word stimuli ('XXXX') that are presented in different colors of ink. Participants are asked to name the ink color. Finally, participants are presented with color names printed in a different ink color than the

name and they are asked to name the ink color, disregarding the printed verbal word. Greater difficulty adapting to rule changes during this task is associated with EF dysfunction. The Stroop Interference score was used as a measure of cognitive flexibility in the present study.

Controlled Oral Word Association Test (COWAT). The COWAT is a measure of verbal fluency. Participants are given 1 min each to list aloud as many words as possible that begin with the letters F, A and S. Proper names, numbers, and multiple words beginning with the same word stem (e.g., fond and fondly) are not allowed, nor are perseverative responses (i.e., the same word repeated more than once). The dependent measures used in the current study were the total number of words listed (fluency) and total number of rule breaks. Verbal fluency measures assess spontaneous cognitive flexibility, or one's ability to generate novel responses to a particular problem (Strauss et al. 1998).

Tower of London (TOL). The TOL is a planning test in which the participant must place a set of colored balls onto pegs on a pegboard from a standard start position to an end position that is presented by the examiner. They must do so by moving one ball at a time, using the fewest possible number of moves (Shallice 1982). Participants receive a point for each TOL solution that they complete correctly within the allotted time frame. The TOL test measures the participant's ability to identify and organize the steps involved in realizing a complex goal. In this study, two measures, total move score and rule break score, were analyzed.

Iowa Gambling Task (IGT). The IGT is a computer-based measure of decision-making in which participants are given a hypothetical amount of money to play, and must choose between four decks of cards (labelled A, B, C and D) that are presented on the computer screen (Bechara et al. 1997). Decks A and B are associated with higher (hypothetical) monetary rewards, but also associated with higher punishment (money lost) than decks C and D. Overall, decks A and B result in losses, while decks C and D result in gains. The gains and losses associated with each card turn are not predictable. Risky decision-making is associated with more selection from decks A and B than decks C and D. The task ends after 100 cards are selected. This task has been used to assess decision-making in multiple studies, including studies of PGs (e.g., Goudriaan et al. 2005).

GoStop Impulsivity Paradigm (GoStop). The GoStop task measures response inhibition (Dougherty 2003). Participants are presented with a series of 5-digit numbers on a computer screen, and they are instructed to click the mouse when presented with the 'go' stimulus, but refrain from clicking the mouse when presented with a subsequent 'stop' signal. Go signals are 5-digit numbers that are identical to the immediately preceding number and are presented in black font. Stop signals are numbers that are identical to the immediately preceding number but change from black to red font at latency intervals ranging from 50 to 350 ms. Half of the responses are novel numbers that are not identical to the ones that preceded them. In this study, percentage of inhibited responses (proportion of correctly inhibited responses to the number of stop signals presented) was analyzed as a measure of response inhibition.

Wechsler Memory Scale, 3rd Edition (WMS-III). The WMS-III was developed to assess learning, memory and working memory (The Psychological Corporation 1997). It consists of eight primary memory indexes, including Auditory Immediate, Visual Immediate, Immediate Memory, Auditory Delayed, Visual Delayed, Auditory Reception Delayed, General Memory, and Working Memory. Working memory involves the temporary storage of information in short-term memory for the purposes of performing complex cognitive and planning tasks, and it is often associated with EF. Other scaled scores for specific subtests (i.e., Logical Memory I, Faces I, Verbal Paired Associates I, Logical Memory II,

Faces II, Verbal Paired Associates II and Auditory Recognition) were also analyzed and served as general memory measures in the present study to discriminate EF from other cognitive processes.

Wechsler Abbreviated Scale of Intelligence (WASI). The WASI is a valid and reliable brief assessment of intellectual functioning (The Psychological Corporation 1999). The WASI can be used to assess full scale intelligence quotient (IQ), Performance IQ and Verbal IQ. The four sub-tests of the WASI include Matrix Reasoning (a measure of fluid abilities), Block Design (visuomotor skills), Vocabulary and Similarities (a measure of concept formation). Full scale IQ was evaluated in the current study.

Procedure

The study received Institutional Review Board approval prior to recruitment. Participants provided written informed consent prior to participation. A research assistant collected and tested urine and breath samples to detect the presence of drugs or alcohol. An intake interview followed including screening and self-report measures. The participant completed all tasks noted above in a sound resistant room that included a desk, chair and laptop computer with a 14″ monitor. All tasks were administered in the same order to all participants. Testing was conducted by a trained and supervised clinical psychology Ph.D. candidate, or by the principal investigator. After completion of the tasks, the research assistant answered any questions, and provided payment. Participants received $100 upon completion of the study testing, plus $20 for transportation and lunch. If a participant was found to be ineligible during the initial consent or interview portion of the study day, he/she was informed and given $20 to compensate for his/her time.

Data Analysis

Initial data analysis involved assessing differences between PGs and controls on demographic and gambling variables, using parametric or non-parametric statistics as appropriate.

Multivariate analysis of variance (MANOVA) was used to examine the effect of the independent variable (pathological gambling status) on the following dependent variables: WMS-III Working Memory Scale, Stroop Interference, COWAT total correct, COWAT rule breaks, TOL total moves, TOL rule breaks, WCST perseverative responses and WCST categories. Log or square root data transformations were performed when appropriate prior to analysis. Intercorrelations among the EF variables and full scale IQ were also examined. IGT and GoStop task data were analyzed separately using repeated measures analysis of variance (ANOVA), as the values for these scales are most suited to a within subject analysis. With respect to the IGT, the 100 trials were grouped into 5 blocks of 20 responses. The repeated factor was the time block (i.e., first block, second block, and so on). With regard to the GoStop, the repeated factor was delay interval (i.e., 50, 150, 250, and 350 ms). For all repeated measures analyses, gambling group was the between subjects independent variable (PG vs. control). The analyses were repeated to control for full scale IQ and again controlling for both IQ and history of depression or dysthymia as these variables differed between PGs and controls (as described below). ANOVAs were not corrected for multiple comparisons.

A MANCOVA was conducted to examine potential differences between PGs and controls on 7 subtests of the WMS-III: Logical Memory I; Faces I; Verbal Paired Associates I; Logical Memory II; Faces II; Verbal Paired Associates II; and Auditory

Recognition. These subscales were selected because they are thought to measure cognitive functions that are relatively unrelated to executive function. The independent variable was gambling status (PG vs. control), and full scale IQ was included as a covariate.

Results

Demographic and Gambling Variables

Demographic and gambling variables, as well as full scale IQ and history of mood disorder (major depression or dysthymia), are presented in Table 1. PGs and control participants were well matched on gender, age, race and education (all $P > .05$). PGs were more likely than controls to be employed and less likely to be married or cohabitating. As expected, PGs scored significantly higher than controls on all measures of gambling disorder severity (all $P < .05$). PGs also scored significantly lower on full scale IQ than did the controls ($P < .05$). However, this difference (5 IQ points) was not large given that both groups received mean scores in the Average range. Nonetheless, we conducted subsequent EF analyses both with and without IQ included as a covariate. PGs also were significantly

Table 1 Demographic and gambling variables

Variable	Pathological gamblers ($n = 45$)	Controls ($n = 45$)	t, χ^2, or U	$P<$
Age M(SD)	46.1(13.9)	45.8(17.3)	$t(88) = -.07$	.95
Gender N(%)			$\chi^2(1,N = 90) = .18$	.67
Female	21(46.7)	23(51.1)		
Male	24(53.3)	22(48.9)		
Race N(%)			$\chi^2(3,N = 90) = 3.11$	.38
Caucasian	40(88.9)	43(95.6)		
Asian	1(2.2)	0(0)		
African Canadian	2(4.4)	0(0)		
Other	2(4.4)	2(4.4)		
Employed N(%)	33(73.3)	23(51.1)	$\chi^2(1,N = 90) = 4.73$	.05
Marital status N(%)			$\chi^2(3,N = 90) = 12.90$	.01
Married/cohabitating	18(40.0)	27(60.0)		
Never married	14(31.1)	13(28.9)		
Divorced/separated	13(28.9)	2(4.4)		
Widowed	0(0)	3(6.6)		
Education M(SD)	14.2(2.5)	14.4(2.5)	$t(88) = .32$	.75
WASI full scale IQ M(SD)	101.0(10.3)	106.3(10.4)	$t(88) = 2.40$	.05
Mood disorder history N(%)	57.8(26)	11.1(5)	$\chi^2(1,N = 90) = 21.70$	.001
NODS—lifetime M(SD)	8.0(1.7)	.3(.4)	$t(88) = -29.1$	.001
NODS—past year M(SD)	7.5(1.8)	.2(.4)	$t(88) = -27.0$	.001
Typical $ (/30 days) median(interquartile range)	$730($1,205)	$35($117)	$U = 1{,}859.0$	.001

N(%) number and percent, *M(SD)* mean and standard deviation, *WASI* Wechsler Abbreviated Scale of Intelligence, *NODS* NORC DSM screen for gambling problems

more likely than controls to have a history of mood disorder ($P < .001$). Because depression symptoms can affect EF, we conducted additional analyses controlling for both IQ and mood disorder history.

Executive Function

The overall multivariate effect for EF was statistically significant ($F(8,81) = 2.69$, $P < .05$, $\eta^2 = .21$). PGs scored significantly higher on the TOL total move score and TOL rule breaks. They also completed fewer categories on the WCST (see Table 2).

Because full scale IQ differed between PGs and controls, we conducted the same analysis using IQ as a covariate. The results were essentially unchanged. The overall multivariate effect for EF was still significant ($F(8,80) = 2.18$, $P < .05$, $\eta^2 = .18$). Controls scored better than PGs on the TOL total move ($F(1,87) = 6.32$, $P < .05$, $\eta^2 = .07$)

Table 2 Raw mean and standard deviation on executive function measures

Variable	Pathological gamblers ($n = 45$)	Controls ($n = 45$)	$F(1,88)$	$P<$	η^2
WMS working memory	101.0(14.2)	105.8(15.1)	2.39	.13	.03
Stroop interference	48.9(9.9)	51.3(7.8)	1.71	.20	.02
COWAT total correct	37.9(9.9)	39.3(9.5)	.50	.48	.01
COWAT rule break	1.8(1.6)	1.5(1.6)	.74	.39	.01
TOL total moves	40.7(18.4)	30.4(14.4)	8.75	.01	.09
TOL rule breaks	.64(1.2)	.17(.52)	7.09	.01	.08
WCST perseverative responses	22.6(23.4)	16.3(12.7)	1.33	.25	.02
WCST categories	4.2(2.2)	5.0(1.7)	4.02	.05	.04

WMS Wechsler Memory Scale, *COWAT* Controlled Oral Word Association Test, *TOL* tower of London, *WCST* Wisconsin Card Sort Test

Table 3 Correlations between executive function variables and intelligence

Variable	2	3	4	5	6	7	8	9
1. WMS working memory	.15	.29**	.01	−.28**	−.03	−.37***	.23*	.52***
2. Stroop interference		.14	.18	−.13	−.15	−.20	.19	.07
3. COWAT total correct			.32**	−.03	.08	−.11	.09	.24*
4. COWAT rule break				−.13	−.08	−.06	.03	−.01
5. TOL total moves					.34***	.27**	−.15	−.22*
6. TOL rule breaks						.22*	−.21	−.09
7. WCST perseverative Responses							−.79***	−.35***
8. WCST categories								.27**
9. WASI full scale IQ								

1 Wechsler Memory Scale Working Memory, *2* Stroop interference, *3* Controlled Oral Word Association Test total correct, *4* Controlled Oral Word Association Test rule break, *5* Tower of London total moves, *6* Tower of London rule breaks, *7* Wisconsin Card Sort Test perseverative responses, *8* Wisconsin Card Sort Test categories, *9* Wechsler Abbreviated Intelligence Scale full scale IQ

* $P < .05$

** $P < .01$

*** $P < .001$

and rule break ($F(1,87) = 6.28$, $P < .05$, $\eta^2 = .07$) measures, but the groups no longer differed on the WCST categories scale ($F(1,87) = 2.04$, $P = .16$, $\eta^2 = .02$). The multivariate effect for IQ was also significant ($F(8,80) = 4.16$, $P < .001$, $\eta^2 = .29$). As is also indicated in Table 3, higher IQ was associated with higher letter number sequencing scores ($F(1,87) = 29.68$, $P < .001$, $\eta^2 = .25$), higher total FAS score ($F(1,87) = 4.70$, $P < .05$, $\eta^2 = .05$), completion of more WCST categories ($F(1,87) = 4.96$, $P < .05$, $\eta^2 = .05$) and fewer WCST perseverative responses ($F(1,87) = 10.96$, $P < .001$, $\eta^2 = .11$).

When controlling for history of mood disorder, the multivariate analysis of mood history was not significant ($F(8,79) = 1.87$, $P = .08$, $\eta^2 = .16$). Multivariate effects were otherwise unchanged from prior analyses. After controlling for mood history, in addition to the previously identified differences on the TOL, WCST categories was again significant ($F(1,86) = 6.34$, $P = .01$, $\eta^2 = .07$) (other data not presented).

We considered that PGs recruited from treatment samples ($n = 23$) may present with more severe problems than those recruited from the community ($n = 22$). To determine whether treatment-recruited PGs exhibited more severe EF deficits than community-recruited PGs, we conducted a series of independent sample t-tests on the same variables examined in the MANOVA. Although no group differences were found on IQ ($P > .05$), these two groups of PGs differed on three EF variables. Specifically, PGs recruited from the community performed significantly better than those recruited from treatment on the COWAT total correct ($t(43) = -2.08$, $P < .05$) and completed more categories on the WCST ($t(43) = -2.02$, $P < .05$), but committed significantly more rule breaks on the COWAT ($t(43) = -2.07$, $P < .05$).

Response Inhibition

Results of the GoStop response inhibition task are presented in Fig. 2. Data from 12 participants (9 PGs, 3 controls) whose data suggested they did not understand the task were excluded, leaving a total of 78 responses. A significant main effect for delay to stop signal was identified ($F(3,73) = 3.05$, $P < .05$, $\eta^2 = .11$), with length of latency time being associated with greater difficulty inhibiting responses. The gambling group x latency ($F(3,73) = 1.00$, $P = .40$, $\eta^2 = .04$) and full scale IQ x latency ($F(3,73) = .50$, $P = .71$, $\eta^2 = .02$) interactions, as well as the main effects for gambling group ($F(1,75) = .33$, $P = .57$, $\eta^2 = .00$) and full scale IQ ($F(1,75) = 3.45$, $P = .07$, $\eta^2 = .04$) were not

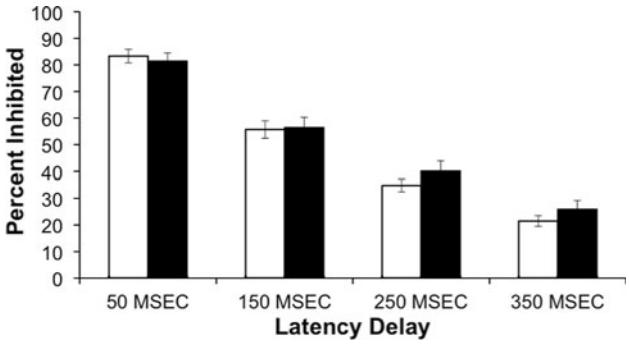

Fig. 2 Estimated marginal means for response inhibition (GoStop) score at 50, 150, 250 and 350 MSEC delay for pathological gamblers (PGs; *Black bars*) and controls (*White bars*). Error bars are standard error of the mean

statistically significant. When mood disorder history was included, however, the gambling group x latency interaction was statistically significant ($F(3,222) = 2.65$, $P < .05$) with controls appearing to perform slightly better at 50 ms and PGs performing slightly better at 250 and 350 ms latencies.

Decision-Making

Data from four participants were excluded from the analysis of the IGT due to technical problems. The within subjects analysis of the Iowa Gambling Task revealed a significant group x time-block interaction ($F(4,332) = 2.86$, $P < .05$). Figure 3 illustrates that control participants increasingly made more advantageous choices from one time block to the next, while the responding of PGs was more variable. The main effects for time block ($F(4,332) = .43$, $P = .79$), gambler group ($F(1,83) = .01$, $P = .91$), full scale IQ ($F(1,83) = .85$, $P = .36$) and the time block x full scale IQ interaction ($F(4,332) = .41$, $P = .80$) were not statistically significant. When we re-analyzed the data including history of mood disorder, the group x time block interaction was no longer significant ($F(4,328) = 1.53$, $P = .21$).

Memory

The overall multivariate test comparing PGs and controls on memory measures from the WMS-III and controlling for IQ was not statistically significant ($F(7,81) = 1.34$, $P < .24$, $\eta^2 = .10$). The overall multivariate effect for IQ was statistically significant ($F(7,81) = 6.21$, $P < .001$, $\eta^2 = .35$). In addition, higher IQ scores were shown to be significantly associated with higher scores on the Logical Memory I ($r = .43$, $P < .001$), Verbal Paired Associates ($r = .51$, $P < .001$), Logical Memory II ($r = .37$, $P < .001$), Verbal Paired Associates II ($r = .34$, $P < .001$) and Auditory Recognition ($r = .32$, $P < .01$) scales (Table 4).

Discussion

Consistent with our initial hypothesis, PGs appear to exhibit EF deficits relative to control participants, although these deficits were more specific than we had originally predicted.

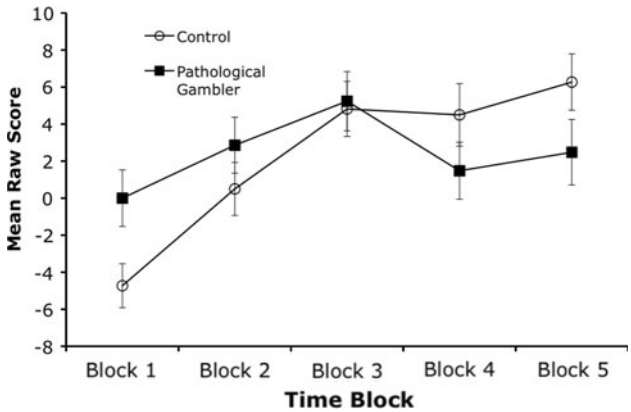

Fig. 3 Mean Iowa Gambling Task raw scores for pathological gamblers (*closed square*) and controls (*open diamonds*). Error bars are standard error of the mean

Table 4 Raw mean scores and standard deviations for memory scale scores

Variable	Pathological gamblers ($n = 45$)	Controls ($n = 45$)
WMS-III logical memory I	9.8(2.6)	11.2(2.9)
WMS-III faces I	8.6(2.3)	9.2(2.9)
WMS-III verbal paired associates I	10.1(2.1)	10.9(2.8)
WMS-III logical memory II	10.4(2.4)	11.6(2.8)
WMS-III faces II	9.1(2.1)	9.8(2.4)
WMS-III verbal paired associates II	10.9(2.2)	11.3(2.9)
WMS-III auditory recognition	10.7(2.9)	11.0(2.5)

WMS Wechsler Memory Scale

Planning, in particular, appears to be an area of marked deficit among PGs, relative to control participants. Goudriaan et al. (2006) similarly found that PGs performed more poorly on the TOL than did normal controls and individuals with Tourette Syndrome. Impulsivity studies have also found that PGs experience planning difficulties. In a recently published study, significant differences were noted between PGs and controls on the non-planning scale of the Barratt Impulsiveness Scale (Ledgerwood et al. 2009), which is a self-report measure reflecting impairments in planning. Other studies have also found PG to be associated with deficits on impulsivity planning scale responses (e.g., Fischer and Smith 2008; Voon et al. 2007). Thus, the current results, in conjunction with past research, indicate that impaired planning may be the most consistently observed EF deficit in PG.

The impaired decision-making observed in PGs in our sample is consistent with past research examining potential decision-making deficits in PGs relative to healthy controls. For example, Cavedini et al. (2002) found significant differences between PGs and controls on the Iowa Gambling Task. However, their study may have been confounded by age and/or gender differences between their groups. Brand et al. (2005) found that PGs exhibited more disadvantageous risk taking, which was also associated with categorization, cognitive flexibility and set-shifting measures of EF.

Perseveration, as measured by the WCST categories scale, also was identified as a potential deficit among PGs. However, once the variance from full scale IQ was removed this deficit no longer reached statistical significance. Similarly, Goudriaan et al. (2006) found that PGs evidenced no significant differences in percentage of perseverative errors, although PGs completed fewer categories than healthy controls. Conversely, although Cavedini et al. (2002) found significant differences between PGs and controls on a decision-making task, the groups did not differ significantly in the WCST categories or perseverative errors. Our study differed from Cavedini's in that our sample size was substantially larger, which may account for our identification of significant findings on the categories measure before controlling statistically for IQ. Thus, these findings suggest that PGs may experience elevated cognitive perseveration relative to healthy control participants. However, interpretation of this finding should be made with caution as controlling for IQ resulted in this difference to no longer be significant.

Performance on the remaining EF variables examined in the current study (i.e., working memory, Stroop Interference, COWAT and GoStop) did not differ significantly as a function of gambling status, and results from past studies have been inconsistent on the extent to which PGs exhibit deficits on these EF traits. For example, Goudriaan et al. (2006) found that PGs performed significantly worse than controls on measures of response inhibition, time estimation, cognitive flexibility and planning tasks. Although the current

study had a similar sample size, participants from both treatment and community sources were included whereas Goudriaan's study included only treatment-recruited participants. Thus, our more specific EF findings may reflect sampling differences between the two studies. Nevertheless, it is notable that we found few differences between PGs recruited from treatment and community on EF measures.

Lawrence et al. (2009) noted that PGs performed similarly to healthy controls on a measure of response inhibition despite scoring higher on impulsivity measures, a finding that recently was reported by Ledgerwood et al. (2009), and found again in the current investigation. However, Lawrence et al. (2009) also found that alcohol dependent individuals experienced significant impairment in response inhibition relative to controls, suggesting that PGs and individuals with alcohol dependence may differ in the extent to which they have disinhibition deficits. A study of risk behaviors in preadolescents similarly found that problematic gambling behaviors were associated with impulsivity and sensation seeking, but not with working memory and only very modestly correlated with the Stroop task ($r = -.11$; Romer et al. 2009). Gambling was reported at a relatively high prevalence rate in Romer's study (27.6%). Thus, our findings are relatively consistent with prior investigations that suggest focal deficits in certain types of EF (i.e., planning) and perhaps subtle deficits in other forms of EF that are not always detectable in relatively smaller and varied (e.g., by age, or gender) samples.

Although PGs and controls may not differ substantially across all measures of EF, they may evidence differential brain activation. For example, Potenza et al. (2003a, b) found that PGs performed similarly to controls on the Stroop, and fMRI revealed activation in the same areas as controls (i.e., dorsal anterior cingulate, right middle and inferior frontal gyri, bilateral inferior frontal gyri, right insula, and right thalamus). However, PGs also demonstrated decreased activity in a region of the ventromedial prefrontal cortex that involves the left middle and superior frontal gyri, an area of the brain associated with decision-making, reward processing and expectancy. As explained above, we also observed differences between PGs and controls on decision-making. These findings are important because some forms of EF dysfunction (e.g., disinhibition) may place PGs at risk for relapse (Goudriaan et al. 2008).

Controlling for history of mood disorder had mixed effects on our findings. It is important to include individuals with mood disorder histories in studies of PG because up to 37% of individuals with PG also have a history of major depression and up to 17% have a history of dysthymic disorder (Petry et al. 2005). When we included this variable in our analysis of EF, the results were largely unchanged. Thus, EF differences appear to be relatively independent of mood history. However, when mood disorder history was included in the analysis of decision-making, the interaction between problem gambling group and time block was no longer significant. Thus, it appears that depression may partially mediate the relationship between decision-making and PG.

The present study has limitations. First, we are limited by our sampling method as our PGs were recruited from both treatment and community sources. Although it could be argued that treatment-recruited PGs may experience greater and more severe difficulties, we found few significant differences between treatment and community PGs on EF measures. Interestingly, the few tests on which differences were found did not necessarily favor one particular group. Another limitation is that we conducted assessments at only one time point, in a cross-sectional design, rather than examining possible changes in EF over time. Future studies may examine changes in EF prospectively as problem gambling symptoms remit or worsen. Our study sample size also was somewhat small. However, it is notable that our sample was consistent with other PG and EF studies (e.g., Goudriaan et al.

2006). Finally, we did not thoroughly assess psychotropic medication use, which may influence executive function. Further studies should more thoroughly assess potential effects of medication use on EF in PGs.

This study also had several notable strengths. We were able to recruit roughly equal numbers of men and women in each group, while many past studies have oversampled PG men. Our PG and control groups were well-matched on age, gender and other important demographic variables. Among the PGs, we were able to recruit equal numbers of participants both from outpatient treatment and community sources. Thus, our study is inclusive, resulting in strong external validity. Further, our sampling method allowed us to conduct preliminary analyses to determine whether these two types of research participants differed substantially. Finally, our test battery was a comprehensive assessment of EF and other discriminating cognitive processes, and it consisted solely of measures that have established norms. Thus, our investigation is a particularly strong test of the hypothesis that PGs experience EF dysfunction.

Overall, findings from the current study demonstrate that PGs appear to have EF deficits in comparison to healthy controls. Specifically, PGs evidence impairments in planning ability and decision-making, and show subtle signs of cognitive perseveration. This study has implications for our understanding of co-occurring conditions that may contribute to the development of and perhaps the long-term maintenance of PG (in this case, neurological dysfunction). Our findings could also be used to guide the development of efficacious treatments for PG that target interventions to address specific cognitive difficulties. That is, interventions involving higher level cognition and psychological mindedness may not be a good fit for PGs with EF dysfunction, and treatment techniques that focus more on specific impulsive behaviors, planning and decision-making-deficits may be more appropriate. Thus, our study lays the scientific groundwork for future development of interventions for PG that specifically target EF, decision-making and problems with impulsivity.

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