Diurnal Cortisol and Decision Making Under Risk in Problem Gambling

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Abstract

The aim of this study was to assess the influence of diurnal cortisol profile on decision making under risk in individuals with problem gambling and a healthy control group. We examined the relationship between diurnal cortisol, assessed over the course of two days, and a battery of tasks that assessed decision making under risk, including the Columbia Card Task and the Cups Task. Thirty individuals with problem gambling and 29 healthy individuals took part in the study. Those with problem gambling showed blunted diurnal cortisol and more risk taking behavior compared to those in the healthy control group. Blunted cortisol profile was associated with more risky behavior and less sensitivity to losing money in problem gambling. These findings suggest that blunted stress physiology plays a role in specific parameters of risky decision making in problem gambling.

Keywords: Gambling Disorder, Stress Physiology, Columbia Card Task, Cups Task

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Gambling disorder is the most common behavioral addiction and frequently co-occurs with other psychiatric disorders, damaging health and financial stability (Petry, Stinson, & Grant, 2005; Potenza, 2015). Abnormal stress physiology serves as a risk factor for the development of other addictions such as substance use disorders (Biback & Zack, 2015; Lovallo, 2006) and is related to greater addiction severity, cravings, and poor treatment outcomes (Buchanan & Lovallo, 2018; Lovallo, 2006). The little work done on stress physiology in gambling disorder suggests abnormal stress responses that are similar to other addictions (Geisel, Panneck, Hellweg, Wiedemann, & Muller, 2015; Paris, Franco, Sodano, Frye, & Wulfert, 2010), suggesting that a pattern of blunted stress reactivity may play a role in the behavioral changes that accompany gambling disorder. This work has not yet examined the mechanisms that link abnormal stress physiology with the behavioral disturbances of gambling disorder: namely the pattern of risky decision making that facilitates the development and maintenance of the disorder (van Holst, van den Brink, Veltman, & Goudriaan, 2010).

Stress and Gambling Disorder. Exaggerated cardiovascular and neuroendocrine reactivity has well-documented negative health consequences (Chida & Steptoe, 2009; Lovallo & Gerin, 2003). Recent work suggests that *reduced* reactivity to stress may also serve as a marker for negative health outcomes, including addiction (Carroll, Ginty, Whittaker, Lovallo, & de Rooij, 2017; Miller, Chen, & Zhou, 2007; Phillips, Ginty, & Hughes, 2013). A vigorous stress response may serve as a marker of a healthy, adaptive physiological system, which may serve as a protective factor against the development of addictions (al'Absi, 2018). The stress-related biological and behavioral characteristics of substance use disorders suggest an addiction phenotype that includes a blunted hormonal and cardiovascular response to stress and altered

diurnal dynamics of the hypothalamic pituitary adrenocortical (HPA) axis (al'Absi, 2018; Carroll et al., 2017; Lovallo, 2006; Meyer et al., 2004; Sinha, 2011).

Gambling disorder is now classified in the DSM-5 as a 'Substance-Related and Addictive Disorder' (American Psychiatric Association, 2013). This reflects an evolving understanding of the disorder, but a great deal remains unknown about gambling disorder. During a gambling episode, healthy individuals typically show a physiological response characterized by increased activity of the sympathetic nervous system (SNS) and HPA axis (Krueger, Schedlowski, & Meyer, 2005; Meyer et al., 2000; Meyer et al., 2004). These findings suggest that SNS and HPA physiology during gambling episodes reflect the arousing, but also potentially stressful, aspects of gambling. Such physiological activity may provide a bodily signal of stress that normally triggers cognitive and emotional regulatory processes to stop gambling upon reaching a threshold of physiological response. This normal pattern may be disrupted in gambling disorder, such that these bodily signals are dampened or absent, resulting in a lack of recognition of the stress of the gambling situation and financial losses that inevitably occur. In support of this idea, individuals with gambling disorder showed a blunted cortisol response to watching gambling-related videos compared to recreational gamblers (Paris et al., 2010). Similarly, lower resting heart rate (Schmidt, Mussel, & Hewig, 2013) and lower resting cortisol (van Honk, Schutter, Hermans, & Putman, 2003) in healthy populations are associated with more risky decision making, suggesting a relationship between blunted stress physiology and increased risk taking that may extend to the general population.

In addition to the acute effects of stress physiology on decision making, diurnal patterns of the hormone cortisol may also influence addictive decision making. The diurnal dynamics of cortisol include the awakening response, an increase in cortisol secretion that peaks 30-60

minutes after awakening (Pruessner et al., 1997) and the diurnal fall, a reduction in cortisol secretion from the morning to the evening (Evans et al., 2011). Alterations in these dynamics are associated with higher self-reported stress, as well as poorer mental, physical, and cognitive outcomes (Adam et al., 2017; Chida & Steptoe, 2009; Evans et al., 2011). In particular, a flatter slope of the cortisol fall is associated with negative health outcomes, including cancer, cardiovascular disease, depression, and obesity, among other disorders (Adam et al., 2017). Research has also shown associations between diurnal cortisol patterns and addictive behavior. Adolescents who started drinking at an earlier age showed lower levels of cortisol *before and during* a laboratory stressor (Evans, Greaves-Lord, Euser, Franken, & Huizink, 2012). Since adolescents who start drinking earlier are more likely to develop alcohol use disorder, these findings, among others (Moss, Vanyukov, Yao, & Kirillova, 1999; Moss, Vanyukov, & Martin, 1995; Sorocco, Lovallo, Vincent, & Collins, 2006), suggest that lower diurnal cortisol levels may serve as a physiological marker for the development of addiction.

The relation between diurnal cortisol and decision making extends to financial decisions. Older adults (age range: 55-82) showing a flatter slope of cortisol fall made more risky choices in the gain domain in a financial decision making task; an effect found in both men and women (Weller et al., 2014). Also, men (but not women) with a flatter slope of cortisol made more risky choices in the loss domain compared to men and women with a steeper cortisol fall. These findings demonstrate that older adults with a steeper, more healthy, diurnal cortisol profile were more likely to avoid risks compared to those with a flatter, less healthy, profile. Therefore, altered HPA dynamics may play a role in the risky decision making of people with gambling disorder. The relationship between cortisol dynamics and risky decision making has never been addressed in gambling disorder, however.

Decision Making in Gambling Disorder. The types of decisions involved in gambling can be characterized as occurring under risk or under uncertainty (see De Groot & Thurik, 2018 for review). An example of decision making under risk is betting on a coin flip, in which the outcome is unknown (heads or tails), but the probability of winning is known (50%). By contrast, decision making under uncertainty (sometimes termed 'ambiguity') is more akin to betting on a slot machine in which neither the outcome nor the probability of winning is known. People with gambling disorder perform worse on decision making under both risk and uncertainty compared to a control group (Brevers et al., 2012).

In both types of decision making, the term 'risk perception' is used to characterize the evaluation of risk parameters of the decision, including possible rewards, possible losses, and their respective probabilities. People with gambling disorder show poor risk perception, expecting better outcomes associated with gambling compared to non-gamblers (Spurrier & Blaszczynski, 2014). For example, individuals with gambling disorder are less attentive to monetary losses, but are highly responsive to greater monetary gains, suggesting heightened reward sensitivity (Boog, Höppener, Goudriaan, Boog, & Franken, 2014; Brevers, Koritzky, Bechara, & Noël, 2014; Marmurek, Switzer, & D'alvise, 2014). Poor risk perception among those with gambling disorder may lead to higher levels of risk taking behavior (e.g., greater impulsivity, steeper discounting rates, poor time perception, chasing propensity), all of which are associated with gambling severity (Ciccarelli, Griffiths, Nigro, & Cosenza, 2017; Madden, Petry, & Johnson, 2009; Nigro, Ciccarelli, & Cosenza, 2018).

Research to date has left unclear the specific parameters of the decision making situation that differentiates those with gambling disorder from recreational gamblers. The current study set

out to examine these parameters in individuals with problem gambling[1] compared to a healthy control group, and to assess how stress physiology may impact decision making under risk. We hypothesized that those with problem gambling would show a blunted cortisol awakening response and a flatter diurnal cortisol slope than the control group. In a set of exploratory analyses, we examined the relation between diurnal cortisol parameters and decision making under risk in a battery of gambling-type tasks that assess sensitivity to gains, losses, and expected value, both in terms of gambling behavior and self-reports of risk perception behind such behavior.

Methods

Participants

Community dwelling participants were recruited via advertisements in local newspapers, via Facebook, and flyers placed in community centers and retail establishments. Two groups of participants were recruited: (a) non-treatment seeking individuals with problem gambling (n = 30) and (b) healthy control participants (n = 29). Additional demographic data are provided in Table 1.

Inclusion criteria for all participants were being 21 years of age or older and English speaking. Exclusion criteria for all participants included uncontrolled serious psychiatric disorders (e.g., schizophrenia, manic episodes), current use of corticosteroid medications,

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[1] Note that we use the term 'problem gambling' to refer to our sample, which is comprised of individuals with 3 or more symptoms of gambling disorder, rather than the 4 or more symptoms that are required for diagnosis with gambling disorder.

hormonal contraceptive use or current breastfeeding in women, positive breathalyzer test for alcohol intoxication, and positive urine toxicology tests for recent cocaine, opiates, or amphetamines use. Inclusion criteria for the problem gambling group included report of at least four gambling episodes in the past 60 days, wagering at least $100 total, and reporting no recent treatment for gambling disorder. Inclusion criteria for healthy controls included no lifetime history of gambling disorder or substance dependence and no past-year history of mood or anxiety disorder.

An *a priori* power analysis was conducted based on previous data collected by our group. This analysis showed a difference in decision making on a probability discounting task between a group with gambling disorder and a control group of $d = .75$. A sample size of at least n = 23 per group is required to detect a statistically reliable group difference at 80% power. Our sample size of $n = 30$ was chosen to ensure adequate statistical power in detecting group differences in decision making.

Procedure

The study was approved by Saint Louis University's Institutional Review Board. The study consisted of three phases: (a) Day 1: initial drug and alcohol screening, (b) Days 2 & 3: diurnal salivary cortisol collection over two consecutive days, and (c) Day 4: behavioral assessment in the laboratory. Participants were given a $100 ClinCard (Greenphire, King of Prussia, PA) for completing participation.

Drug and Alcohol Screening

Participants provided informed consent and confirmed the absence of recent alcohol use via breathalyzer (Alco-sensor IV Alcometer; Intoximeters, St. Louis, MO). Next, participants provided a urine sample to confirm the absence of recent drug use (iCup A.D. 5 Panel Urine

Drug Test; Instant Technologies, Norfolk, VA). The drug and alcohol screenings were repeated before the behavioral assessments, two days later (see below), to confirm compliance with inclusion criteria. Participants who tested positive for alcohol intoxication, cocaine, opiates, or amphetamines on either day were excluded from the study; two participants were excluded and replaced for testing positive for drugs.

Gambling Severity

The following measures were used to determine whether a person met the clinical threshold for problem gambling.

The National Opinion Research Center DSM Screen for Gambling Problems (NODS) (Gerstein et al., 1999). The NODS is a structured interview used to determine past-year and lifetime problem gambling. This measure consists of 17 questions reflecting the DSM-IV criteria and was devised by the National Opinion Research Center for the 1999 National Survey of Gambling Behavior; scoring for this measure was changed to reflect the new DSM-5 criteria. This measure has good internal consistency ($\alpha = .88$; (Wickwire, Burke, Brown, Parker, & May, 2008). The problem gambling group in this study included individuals who scored a three or higher on the NODS; the healthy controls all scored zero on the screen. Although the threshold for problem gambling is lower than previously proposed for gambling disorder (i.e., four criteria), recent research suggests significant psychosocial impairment among subclinical gamblers who endorse fewer gambling disorder criteria (Weinstock, April, & Kallmi, 2017).

Gambling Timeline Followback (GTLFB). The GTLFB assesses the dollar amount wagered and frequency of gambling behavior over the past 60 days using calendar prompts (Weinstock, Whelan, & Meyers, 2004). This measure was used as an indicator of gambling severity and to determine eligibility as part of the inclusion criteria, requiring participants with problem

gambling to spend at least $100 on 4 occasions over the previous 60 days. As reported by Weinstock and colleagues (2004), the GTLFB had good test-retest reliability among frequent (r = .75 - .96) and disordered gamblers (r = .73 - .93) as well as validity due to strong correlations between the measure and daily self-monitoring of gambling behavior.

Salivary Cortisol Collection

Participants collected saliva samples using Salivette collection devices (Sarstedt, Nümbrecht, Germany) at 10 time points over two consecutive weekdays outside the laboratory to reliably assess the cortisol awakening response and the post-awakening diurnal fall of cortisol (Hellhammer et al., 2007; Smyth, Thorn, Hucklebridge, Evans, & Clow, 2015). Sampling times included (a) awakening; (b) thirty minutes after awakening; (c) forty-five minutes after awakening; (d) three hours after awakening; and (e) bedtime. For each participant, samples at each time point from day 1 were averaged with samples from the same time point on day 2. Cortisol awakening response was measured by calculating the area under the curve with respect to increase (AUCi; Pruessner, Kirschbaum, Meinlschmid, & Hellhammer, 2003) for the first three samples of the day. Diurnal cortisol slope was assessed by calculating the difference between cortisol at bedtime and the morning peak (i.e., 45 minutes after waking) and dividing by the time awake (i.e., bedtime – peak / hours awake; Adam et al., 2017).

Recent work has shown that non-compliance with sampling instructions reduces reliability of diurnal cortisol dynamics measures; objective documentation of wake time using actigraphy and exact sampling time using objective monitoring are required for reliable assessment of cortisol dynamics (Smyth et al., 2015; Stalder et al., 2016). To document compliance, we used the Medication Event Monitoring System (MEMS; MWV Switzerland Ltd., Sion, Switzerland) caps on containers with Salivette swabs stored inside that recorded the time

when caps were removed. The cotton pledgets, normally stored in the Salivette device, were stored in the MEMS device to provide an objective time stamp of each sample. Also, FitBit activity monitors (FitBit Inc., San Francisco, California) were used to document wake times. The FitBit device shows high reliability and consistency with more traditional research-grade activity monitoring devices (Gusmer, Bosch, Watkins, Ostrem, & Dengel, 2014).

Participants were shown exactly how to complete saliva collection, and a research assistant was available via SMS messaging if participants had questions during the two days of sampling. Participants also received written instructions detailing the process, including: (a) instructions to wear the FitBit to bed the night after the first lab visit to objectively document sleep and wake time; (b) instructions on the exact times to collect saliva samples on both subsequent days; (c) instructions to collect saliva by opening the MEMS cap to remove one Salivette pledget at the time of each saliva sample; and (d) instructions to place the pledget in the Salivette device and stored it in participants' home freezers prior to returning them to the laboratory.

After the sampling days, participants returned the Salivette tubes, MEMS cap, and FitBit during the second laboratory visit. Saliva samples were stored at −20◦C until assayed. Measurement of salivary cortisol was conducted via chemiluminescence assay (CLIA; IBL Hamburg, Germany) in the laboratory of Dr. Clemens Kirschbaum, Technical University of Dresden, Germany. Intraassay coefficients of variation were less than 10%. The lower sensitivity for cortisol is 0.5 nmol/l.

Behavioral Assessment

Participants returned to the lab on Day 4 to complete the behavioral assessment described below. Participants repeated the alcohol and drug screening; those who showed evidence of

intoxication or recent drug use were excluded from further participation. Monetary incentives for all decision making tasks were hypothetical.

The Cups Task (Levin & Hart, 2003; Weller, Levin, Shiv, & Bechara, 2007). In the Cups Task, participants made 54 choices between a certain and uncertain option, comprised of gain trials (in which money can be won) and loss trials (in which money can be lost). For gain trials, choosing a cup (displayed on a computer screen) from the "certain side" always results in the gain of a dollar. The alternative is the "risky side" in which participants are presented with the possibility to win more money – or win nothing. For each trial, they were informed whether two, three, or five dollars may be gained by choosing the "winning" cup from a risky side array of two (50% chance to win), three (33%) or five (20%) cups. The three outcome magnitudes (i.e., number of dollars at stake) and three probabilities levels (i.e., number of cups) yield nine combinations, each iteration repeated three times in a random order, for a total of 27 reward trials.

Participants also completed 27 loss trials. In this version, participants began each trial with a bank filled with the number of dollars that they could potentially lose on each trial. Choosing the "certain side" will always result in the loss of one dollar. Like the gain trials, participants saw an array of either 2, 3, or 5 cups. Selecting the "incorrect" cup from the array will result in the money disappearing from the bank. The blocks of gain and loss trials were counterbalanced. Outcome variables include number of risky choices overall, risky choices to achieve a gain or avoid a loss, separately. Additionally, because of the independent manipulation of probability and outcome magnitude, we can derive, for both risky gains and losses, individual estimates of participants' sensitivity to expected value, which serves as an index of advantageous

decision-making (i.e., the tendency to make choices that have a more favorable long-term expected payout).

The Columbia Card Task (Figner, Mackinlay, Wilkening, & Weber, 2009) is a dynamic computerized card game that assesses risk taking levels and information use strategies. Participants completed both the Hot, affective, and the Cold, deliberative versions of the task. In both versions, participants are told that the objective is to earn the most points possible for each trial. In each of the 24 rounds, participants are shown a display of 32 cards face-down. The top of the screen shows information about the array of cards, including the number of points that one may earn for selecting a gain card (i.e., 10 or 30 points), the number of loss cards that are present (i.e., 1 or 3 cards), and its corresponding loss value if selected (i.e., 250 or 750 points). In the 'hot' version of the task, participants can choose any card to begin, and may continue making selections until either a loss card appears or they choose to terminate the round (by selecting the 'next round' button). If a loss card is encountered, the loss amount for the round is subtracted from the point total and the round is over. Since the likelihood of a loss increases continuously as more cards are turned over, continued selection of cards becomes an increasingly risky strategy. The 'cold' version of this task uses the same risk factors as the 'hot' version (i.e., number of loss cards, points for each gain card, points for each loss card) but cards are not selected individually in turn. Instead, participants indicate the total number of cards they would select based only on the information about the array of cards at the top of the screen; they are provided with no feedback on the wins or losses of each round. The average number of cards selected in each version of the task thus serve as an indicator for each participant's level of risk taking, under different conditions. The two versions of the task were counterbalanced in order of presentation.

At the end of each version of the CCT, participants were asked to report what decision strategy they used to make their choices, with their responses to the following items: (a) I mainly focused on the number of loss cards; (b) I mainly focused on the gain amount; and (c) I mainly focused on the loss amount. Participants rated each of these options using a visual analogue scale (scored 0-100). These ratings were used to assess risk perception and whether those with problem gambling used different information in making their choices than did the control group.

Statistical Analyses

Demographic characteristics (age, education, income, etc.) were analyzed between groups using t-tests for continuous data and chi-square for categorical data (see Table 1). Descriptions of analyses of cortisol and behavioral data are described in detail in the respective results sections.

Data Availability

Our data, as well as our code for statistical analyses, are publicly accessible at https://osf.io/73h8q/. The stimulus materials may be obtained from the authors of the original tasks (the Cups Task: Levin & Hart, 2003 and the Columbia Card Task: Figner et al., 2009)).

Results

Diurnal Cortisol

Saliva Sampling Compliance. Missing samples were replaced with the value of the sample on the other day. For example, if an individual was missing Sample 3 from Day 2, we replaced that value with the value from Sample 3 on Day 1. Such cases were rare; we were only missing 14 samples total (or 2.3% out of 590 samples). No participants were excluded due to noncompliance with the sampling protocol. To assess compliance in saliva sampling timing, we

followed the guidelines from Smyth and colleagues (2015), which indicate that cortisol data collected greater than 5 minutes outside of the expected sample times may result in inaccurate assessment of the cortisol awakening response. Compliance for these samples were measured by comparing the time from awakening (assessed via actigraphy) to the first opening of the MEMS cap. Based on this five-minute cut-off, 75% of gamblers were compliant and 77% of controls were compliant in their first saliva samples on each day; an independent t-test indicated no significant difference in compliance for the first sample between problem gambling (M[SD] = 6.41 [8.13] minutes from wake time) and control groups (M[SD] = 3.89 [4.74] minutes from wake time; $t = 1.203$, $p = .237$, $d = 0.38$). However, there were significant differences between groups for compliance on the 30-minute sample with higher non-compliance in the problem gambling (M[SD] = 16.09 [18.53] minutes from 30 min sample) compared to the control group (M[SD] = 4.50 [4.28] minutes from 30 min sample; $t = 2.846$, $p = .026$, $d = 0.86$). Despite this difference, the magnitude of the cortisol awakening response was not related to compliance of the wake ($r = -.088$, $p > .05$) nor the 30-minute sample ($r = -.197$, $p > .05$) among the problem gambling group, nor in the control group (wake: $r = -.401$, $p > .05$; 30-minute sample: $r = -.279$, $p > .05$).

Cortisol Levels between Groups. A repeated measures ANOVA examining the time course of the diurnal cycle between groups indicated a significant main effect of Group ($F(1,57) = 5.392$, $p = .024$, $\eta^2 = .086$), and a Group × Time interaction ($F(2.86, 162.77) = 5.81$; $p = .001$; $\eta^2 = .092$) demonstrating reduced cortisol levels in the problem gambling group, especially at the 30-minute ($t[57] = -3.361$, $p = .001$) and 45-minute ($t[57] = -3.165$, $p = .002$) post-wake samples. There was also a main effect of Time indicating significant changes over the day in both groups,

($F(2.86, 162.77) = 120.39$; $p < .001$; $\eta^2 = .68$; see Figure 1). Mauchly's test of sphericity was significant and therefore a Greenhouse-Geisser correction was used.

Next, we assessed individual components of the diurnal cycle between groups, the cortisol awakening response (CAR) and the diurnal slope. An independent samples *t*-test indicated no significant differences in the CAR between the problem gambling (M[SD] = 3.39 [6.61]) and control group (M[SD] = 6.62 [7.13]; *t[57]* = -1.81; $p = .076$; $d = .47$; 95% CI: -6.81 - .35). However, there was a significant group difference in diurnal cortisol slope (*t[57]* = 3.12; $p = .003$; $d = .86$; 95% CI: .008 - .035) such that those with problem gambling had a flatter slope (M[SD] = -.036 [.028]) than the control group (M[SD] = -.058 [.023]). Levene's tests indicated no issues of heterogeneity of variance for CAR or diurnal cortisol slope.

Correlation analyses were conducted to examine the relation between problem gambling severity and diurnal cortisol patterns, including only participants in the problem gambling group. Lower CAR was associated with higher NODS scores, $r = -.396$, $p = .015$; CAR was not associated with any GTLFB variables. We found no significant relations between cortisol slope and gambling severity indices (i.e., NODS, GTLFB). Altogether, these data demonstrate blunted cortisol levels throughout the morning, which translates to a flatter diurnal cortisol slope in those with problem gambling. Further, within the problem gambling group, lower CAR was associated with greater gambling severity, as assessed with the NODS, suggesting that these alterations are related to problem gambling pathology.

Behavioral Data

Columbia Card Task (CCT). For the CCT analyses, we used a linear mixed-effects model approach using SPSS Version 24. For the CCT, the main omnibus model included a fixed

intercept, a fixed effect for the "hot" versus "cold" CCT factor (all factors were coded using sum-to-zero contrasts), fixed effects for the group factor, the three card game factors probability, gain amount, and loss amount, as well as a standardized (i.e., centered and scaled) continuous predictor for Block (indicating the three blocks of eight trials each). Additionally, we included fixed effects for the two-way interaction terms involving condition by task factors, as well as those involving group by task factors. We also included the three-way interactions among condition, group, and each of the card game factors.

We followed Barr, Levy, Scheepers, and Tily's (2013) recommendation to use a maximal random-effects structure: The repeated-measures nature of the data was accordingly modeled by including a per-participant random adjustment to the fixed intercept ("random intercept"), as well as per-participant random adjustments to all within-subject predictors (i.e., condition, probability, gain, loss, block, and the two-way interactions between condition and each of the card game factors) (Barr, Levy, Scheepers, & Tily, 2013). The random covariance terms were modeled with an autoregressive structure among the random effects. Significance was determined by calculating 95% confidence intervals for the parameter estimates using bootstrapping with 2000 resamples.

Table 2 displays the parameter estimates for the CCT mixed-effects models analysis. At the task level, we found a main effect for task version; thus, participants were more likely to turn over more cards on the CCT-Cold version than for the CCT-Hot. Additionally, we found main effects for the probability, gain magnitude, and loss magnitude CCT primitive factors. Participants selected more cards when (a) 1 loss card was present (compared to 3 loss cards), and (b) when the loss amount was 250 (compared to 750) points. We also observed a main effect for trial block, indicating that as the tasks progressed, participants turned over fewer cards, on

average. As they learn to reduce this number, they typically will earn more points. Central to our hypotheses, we found that the problem gambling group turned over more cards on the CCT than did the control group, regardless of condition.

These effects were conditional on several interaction effects. We found significant two-way interactions at the task level. Specifically, CCT Condition interacted with (a) loss magnitude and (b) gain magnitude, with each effect suggesting greater information use (i.e., sensitivity to changes in magnitude) in the Cold version. Central to our study, we also observed significant two-way interactions between group and the task characteristics, holding other variables constant. Though the problem gambling group took more risks overall, they were especially apt to do so in the Cold condition (see Figure 2). Additionally, they were less sensitive to changes in number of loss cards from 1 to 3 (i.e., probability level). Further, the gambling group was less likely to adjust to a more risk-averse strategy like the control group did, evidenced by a significant Group by Block interaction. The tested three-way interactions were not significant.

CCT Strategy Use. The problem gambling group indicated paying more attention to the gain points than did the healthy controls on both the CCT-Hot (t[57] = 2.55, p = .017, 95% CI: 4.20 – 35.21, d = .68) and CCT-Cold (t[57] = 2.38, p = .021, 95% CI: 2.89 – 33.65, d = .63; see Table 3). There were no significant differences between groups on self-reported attention paid to number of loss cards or loss amount. Combined, these results from behavior and self-reported strategy use on the CCT, indicate that those with problem gambling made more risky choices, did not alter their behavior over the course of the task, and reported focusing more on gains than did the control group.

Cups Task. Analyses for the Cups Task were similar to those for the CCT, with the following exceptions: First, because responses for each trial of the Cups Task are binary, we

used a logit-link function for a generalized linear mixed model analysis framework. The main omnibus model included a fixed intercept, a fixed effect for domain (gain/loss; all factors were coded using sum-to-zero contrasts), fixed effects for the problem gambling group factor, and the two task factors: probability and outcome magnitude. Additionally, we included fixed effects for the two-way interactions between group and each of the task factors, as well as domain and the task factors. Finally, we included, the three-way interactions among condition, group, and each of the card game factors. The repeated-measures nature of the data was accordingly modeled by including a random intercept, as well as per-participant random adjustments to all within-subject predictors (i.e., domain, probability, outcome, and the two-way interactions between domain and both the task factors). The random covariance terms were modeled with an autoregressive structure among the random effects.

Consistent with expectations due to the Cups Task payout structure, we found significant domain by probability and domain by outcome interactions (see Table 4). Specifically, individuals took fewer risks as the number of Cups changed from 2 (50% probability) to 5 (20%) cups for the gain domain, and took fewer risks as the number of cups decreased in the loss domain. Similarly, this pattern was apparent for outcome magnitude; increases in the potential risky gain related to greater risk-taking, whereas increases in the amount that one could lose related to less risk-taking. Holding these effects constant, though, we also found an effect for group, in which the problem gambling group made more risky choices than did the control group, regardless of whether or not the decision was presented as a potential gain or potential loss.

Influence of Diurnal Cortisol on Decision Making

Given the robust findings suggesting differences between the problem gambling and control groups, we tested the degree to which diurnal cortisol dynamics were associated with performance on the CCT and Cups task in the problem gambling group. To do this, we modified the mixed models described above to include gamblers' CAR and diurnal slope as fixed effects, also allowing these variables to interact with task factors.

CCT. As shown in Table 5, we found that a more blunted CAR was associated with increased risk-taking on the CCT. This effect, however, is conditional on a CAR by Condition interaction. As shown in Figure 3, although lower CAR was associated with increased overall risk taking, this effect was most pronounced on the Hot version of the CCT. We did not find any significant effects with respect to the diurnal fall indicator.

Cups Task. Table 6 reports the parameter estimates for the generalized linear mixed model analysis for the Cups task. In contrast to the CCT, we did not find any significant effects for either CAR or diurnal fall, either in terms of main effects or their interactions with the task factors.

Findings from these analyses demonstrate a potential influence of blunted morning cortisol on specific aspects of decision making among individuals with problem gambling.

Discussion

The aims of this study were to examine whether diurnal cortisol patterns differ between those with problem gambling and a healthy control group and to determine the degree to which cortisol dynamics relate to specific aspects of decision making under risk. Consistent with our predictions, we first found that individuals with problem gambling demonstrated altered cortisol dynamics, including blunted morning cortisol levels and a flatter diurnal slope across the day.

Second, compared to control individuals, participants with problem gambling showed elevated risk-taking preferences on two often-used risky decision-making tasks. We found evidence that this elevated pattern was due to the problem gambling group showing lower sensitivity to changes in probability across trials, showing more optimism than controls when there was a low probability for a loss, and paying more attention to gains than either losses or probabilities. Third, we observed that for the problem gambling group, lower cortisol was associated with more risk taking, especially when the decision context was more affective in nature (in the Hot versus the Cold CCT).

Compared to an age- and sex-matched control group, individuals with problem gambling showed lower cortisol levels at both 30 and 45 minutes after awakening, resulting in a flatter cortisol slope. The groups did not differ in cortisol levels at wake time, in the afternoon, nor at bedtime. These findings are consistent with studies demonstrating a blunted stress response in addiction populations (Lovallo, 2006). Such blunted responsivity may reflect a physiological phenotype of addiction, such that individuals with lowered physiological reactivity to stress, and in this case, to awakening, may be more likely to engage in addictive behaviors or show blunted reactivity due to the addictive behavior. No matter the pathway, these reduced bodily signals may lead to greater sensation seeking among at-risk populations that ultimately play a role in addiction development (al'Absi, 2018; Carroll et al., 2017). These findings are, however, counter to a previous report, which showed that ‘pathological’ gamblers (N = 8, reporting greater than 5 criteria for problem gambling on the DSM-IV checklist) showed a larger cortisol awakening response than did ‘problem’ gamblers (N = 51, who reported between 1 to 4 criteria for gambling disorder) and ‘recreational’ gamblers (N = 66, reporting 0 criteria for gambling disorder; Wohl, Matheson, Young, & Anisman, 2008). There are a number of methodological differences

between the current study and that of Wohl and colleagues (2008). First, our problem gambling population was considerably older and reported more severe problem gambling than the first-year college student population assessed in the previous study. Second, in the previous study, saliva samples were collected on only one day and did not include objective measures to determine the timing of awakening or saliva sampling, which may have resulted in imprecise measures of the cortisol awakening response. These relations between diurnal cortisol and gambling behavior should be examined in more problem gambling populations to more fully examine the relationship between these variables.

People in the problem gambling group made more risky choices in both the hot and the cold versions of the CCT. These results are in line with our hypothesis and previous work documenting increased risk preferences among those with problem gambling (Giorgetta et al., 2014; Ring et al., 2018; Takeuchi et al., 2016). Previous research showed that adolescents performing better on a measure of inhibitory control (Go/No-Go task) took fewer risks on the CCT-hot (Figner & Weber, 2011). We did not assess inhibitory control in our participants, but previous work with gambling disorder populations shows impaired inhibition performance (Grant & Chamberlain, 2014). These findings, coupled with the relationship between adolescent inhibitory control and CCT-hot performance, suggest that inhibitory control may play a role in the increased risk taking behavior observed in our sample.

Among those with problem gambling, lower cortisol was associated with more risky decisions in the hot, but not the cold version of the CCT. The specific relation between lower cortisol and increased risky decisions in the CCT-hot suggests further that blunted cortisol is indicative of more severe risk taking behavior among those with problem gambling. Future work should address the time course of this relationship to determine whether blunted cortisol levels

and/or responses to stress pre-date the elevated risk taking in this population. Among those with problem gambling, lower cortisol was also associated with more optimistic choices in decision making under risk, both on the hot and cold versions of the CCT, regardless of whether the risk was presented as a potential gain or loss. When presented with trials with a high loss amount (750 points), most participants turn over fewer cards, compared to trials with a low loss amount (250 points). Those problem gambling participants with lower cortisol were less likely to change their behavior based on potential loss amount. This finding is consistent with recent work showing that problem gamblers (who fulfilled at least three of the DSM-IV criteria for pathological gambling) were not sensitive to changes in the loss domain, but focused on changes in the gain domain only (Ring et al., 2018). These findings are consistent with the probability distortion hypothesis, the idea that problem gambling is related to an overweighting of small probabilities of winning, as well as the probability elevation hypothesis, or a general overweighting of gain probabilities (Ligneul, Sescousse, Barbalat, Domenech, & Dreher, 2013). It also ties into maladaptive cognitive distortions endorsed by individuals with problem gambling. One cognitive distortion frequently endorsed by gamblers is the "availability illusion", in which an individual more easily recalls times when they won versus the much more common experience of losing (Ciccarelli et al., 2017). Severity of gambling disorder, assessed with the South Oaks Gambling Screen is positively correlated with a measure of 'risk attractiveness' in a gambling disorder population (Ligneul et al., 2013). Our results demonstrating a relation between blunted CAR, higher problem gambling severity assessed with the NODS, and more optimistic choices in the CCT leads to the speculation that lower cortisol levels may serve as a marker for gambling severity, which may be addressed in future prospective research. Current evidence suggests altered cortisol reactivity in those at high-risk

for substance use disorders, such as individuals with a family history of the disorder (see Lovallo, 2006 for review). The similarities between gambling disorder and other addictions further support speculation about the relationship between blunted cortisol and gambling disorder.

Analysis of self-reported decision strategy about what information participants attended to in the CCT showed that individuals with problem gambling reported paying more attention to gain information (i.e., number of points gained per gain card) compared to the control group. These findings extend previous work on behavioral choice to subjective report and demonstrate that those with problem gambling have some insight into the motivation behind their behavior. The groups did not differ on attention paid to loss information (i.e., number of points lost when a loss card was chosen) or the probability of picking a loss card. This finding is consistent with our behavioral results and previous work demonstrating a biased focus on gains in problem gambling (Ring et al., 2018).

In contrast to group differences in the CCT, Cups Task performance did not differ between the problem gambling group and the control group. Both groups showed the typical changes in behavioral responses based on whether the choices were framed in the gain or the loss domain and the expected value of each gamble. Differences in the probabilities of the gambles in the Cups versus the CCT may have resulted in these differences. The probabilities of winning in the CCT (1 or 3 out of 32 cards) is much lower than the probabilities of winning in the Cups task (20, 33, and 50%). The weighting function of Prospect Theory suggests greater distortions of probability the closer you get to the extremes (sure wins and sure losses; (Tversky & Kahneman, 1983)). Probabilities in the CCT, then, are closer to the extremes, perhaps allowing for greater sensitivity to detect group differences based on decision biases. Nonetheless, past research has

shown that the Cups Task is sensitive to group-level differences between vulnerable groups that have been associated with greater levels of psychological dysregulation (Weller et al., 2007; Weller, Levin, & Bechara, 2010; Weller, Kim, Leve, Bhimji, & Fisher, 2015). Thus, future research with a larger sample is warranted.

A few limitations of our study should be noted. We classified our participants in a binary, rather than a dimensional approach that takes problem gambling severity into account (e.g., Canadian Problem Gambling Severity Index classifications; (Holtgraves, 2009)). This classification scheme does not allow for detailed problem gambling severity to be accounted for in our statistical models. Despite this, severity of problem gambling in our sample, assessed with the NODS, was associated with lower cortisol levels. Our relatively low sample size (another limitation of the study) precluded further subdividing participants along a severity scale for the modeling analyses. Another limitation of the study is the use of laboratory tasks without real financial risks or real financial gains. Although performance on these tasks differentiated the problem gambling group from the control group, these tasks may not reflect real-world decision making.

Results from this study show an altered diurnal cycle of cortisol in problem gambling, characterized by lower cortisol in the morning and a flatter diurnal slope. This altered pattern was related to risky decision making; those individuals with problem gambling with the lowest cortisol awakening response made the most risky decisions in an affective decision making task. Results also demonstrated a risk preference toward gains among those with problem gambling, similar to previous results (Ligneul et al., 2013; Ring et al., 2018). These results suggest that policies and interventions aimed at redirecting attention from potential gains may be useful in addressing the risk biases of people with problem gambling. Further, these results highlight the

potential role of stress physiology in the risky decision making associated with problem gambling.

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Table 1. Demographic characteristics by group

Variable	Problem Gambling (n = 30)	Healthy Control (n = 29)	Statistic (df), p-value
Gender			$\chi^2(1) = 3.30$, $p = .069$
Male	17 (56.7%)	10 (33.3%)	
Female	13 (43.3%)	20 (66.7%)	
Marital Status			$\chi^2(4) = 2.81$, $p = .591$
Single	19 (63.3%)	15 (51.7%)	
Married	7 (23.3%)	8 (27.6%)	
Divorced/Separated	3 (10.0%)	6 (20.6%)	
Widower/Other	1 (3.3%)	0 (0.0%)	
Race			$\chi^2(3) = 5.77$, $p = .124$
Caucasian	17 (56.7%)	23 (79.3%)	
African American	12 (40.0%)	5 (17.2%)	
Other	1 (3.3%)	1 (3.4%)	
Ethnicity			$\chi^2(1) = 1.05$, $p = .305$
Hispanic	0 (0.0%)	1 (3.4%)	
Non-Hispanic	30 (100%)	28 (96.60%)	
Employment Status			$\chi^2(5) = 6.69$, $p = .245$
Full Time	16 (53.3%)	16 (55.2%)	
Part Time	3 (10.0%)	2 (6.9%)	
Retired	3 (10.0%)	6 (20.7%)	
Disability	3 (10.0%)	0 (0.0%)	
Student	0 (0.0%)	2 (6.9%)	
Other	5 (16.7%)	3 (10.3%)	
	M (SD)	*M (SD)*	
Age (years)	45.63 (12.75)	42.70 (13.81)	$t(52) = .809$, $p = .422$
Education (years)	14.10 (2.04)	16.07 (4.23)	$t(57) = -2.29$, $p = .026$
Annual Income ($ in thousands)	34.07 (24.14)	45.34 (34.32)	$t(56) = -1.45$, $p = .154$

Table 2 *Linear Mixed Models Analysis for CCT Performance in All Participants*

Fixed Effects	Parameter estimate	Std. Error	95% Confidence Interval	
			Low	High
(intercept)	10.81	0.125	10.56	11.04
Group	-1.61*	0.129	-1.85	-1.34
Condition (Hot/Cold)	1.84*	0.124	1.60	2.10
Block	-0.30*	0.121	-0.54	-0.06
Probability	-2.63*	0.122	-2.86	-2.40
Gain	0.25*	0.120	0.01	0.49
Loss	-0.49*	0.120	-0.72	-0.26
Group X Condition	-0.51*	0.126	-0.76	-0.27
Group X Block	-0.30*	0.118	-0.54	-0.07
Group X Probability	0.34*	0.119	0.11	0.57
Group X Gain	-0.11	0.120	-0.34	0.13
Group X Loss	-0.14	0.122	-0.37	0.11
Condition X Block	0.03	0.121	-0.21	0.27
Condition X Probability	0.03	0.119	-0.20	0.27
Condition X Gain	0.28*	0.120	0.05	0.52
Condition X Loss	-0.38*	0.120	-0.62	-0.15
Block X Condition X Group	0.08	0.119	-0.16	0.31
Probability X Condition X Group	-0.20	0.120	-0.43	0.04
Gain X Condition X Group	-0.15	0.120	-0.38	0.09
Loss X Condition X Group	0.09	0.119	-0.13	0.33

* Indicates significance based on the 95% confidence intervals for the obtained parameter estimate.

Table 3. Ratings of Strategy Use During CCT Between Groups							
	Means (SD)						
	Problem Gambling	Control	*t*	df	*p*		*95% CI*
CCT-Hot							
Probability	57.07 (31.42)	48.46 (28.28)	1.14	54	.259	.305	-6.91 – 25.13
Gain	57.11 (28.96)	35.75 (28.23)	2.79	54	.007	.747	6.04 – 36.68
Loss	49.89 (32.44)	54.75 (32.37)	.56	54	.577	.149	-22.22 – 12.51
CCT-Cold							
Probability	65.55 (27.87)	68.36 (31.79)	-.35	55	.724	.094	-18.66 – 13.05
Gain	56.66 (32.01)	39.39 (26.55)	2.21	55	.031	.586	1.62 – 32.90
Loss	48.03 (33.37)	51.36 (32.97)	-.38	55	.707	.100	-20.94 – 14.29

Note: Probability strategy item: “I mainly focused on the number of loss cards”; Gain strategy item: “I mainly focused on the gain amount”; and Loss strategy item: “I mainly focused on the loss amount”

Table 4 *Linear Mixed Models Analysis for Cups Task Performance in All Participants*

Fixed Effects	Parameter estimate	Std. Error	95% Confidence Interval	
			Low	High
(intercept)	.52	.166	.19	.84
Group	-.34	.166	-.66	-.01
Domain (Gain/Loss)	.04	.127	-.21	.29
Probability	-.07	.063	-.20	.06
Outcome	.17*	.074	.02	.32
Group X Domain	.09	.127	-.16	.34
Group X Probability	.02	.063	-.11	.15
Group X Outcome	-.11	.074	-.22	.08
Domain X Probability	-.37*	.071	-.52	-.23
Domain X Outcome	-.45*	.077	-.60	-.29
Group X Domain X Probability	-.14	.071	-.28	.01
Group X Domain X Outcome	-.04	.077	-.19	.12

* Indicates significance based on the 95% confidence intervals for the obtained parameter estimate.

Table 5 *Linear Mixed Models Analysis: Cortisol Indicators Moderate CCT Task Performance in Problem Gambling Group*

			95% CI	
	Estimate	Std. Error	Lower Bound	Upper Bound
Intercept	12.27	0.184	11.8749	12.60
CAR	-0.51*	0.223	-0.94	-0.07
Diurnal Fall	0.17	0.226	-0.27	0.63
Condition	2.36*	0.177	2.00	2.71
Block	0.01	0.175	-0.34	0.35
Probability	-3.09*	0.169	-3.4	-2.76
Gain	0.35	0.178	-0.01	0.70
Loss	-0.51*	0.171	-0.86	-0.18
CAR X Condition	0.53*	0.220	0.10	0.98
CAR X Block	0.26	0.210	-0.16	0.70
CAR X Probability	0.06	0.205	-0.33	0.47
CAR X Gain	-0.21	0.207	-0.63	0.21
CAR X Loss	-0.32	0.208	-0.74	0.09
Diurnal Fall X Condition	0.21	0.224	-0.21	0.66
Diurnal Fall X Block	0.10	0.210	-0.31	0.50
Diurnal Fall X Probability	0.38	0.208	-0.02	0.79
Diurnal Fall X Gain	-0.06	0.213	-0.49	0.38
Diurnal Fall X Loss	0.30	0.205	-0.10	0.71
Condition X Block	-0.07	0.176	-0.41	0.27
Condition X Probability	0.15	0.168	-0.16	0.49
Condition X Gain	0.47*	0.171	0.13	0.82
Condition X Loss	-0.61*	0.175	-0.96	-0.26
CAR X Condition X Block	-0.26	0.218	-0.70	0.18
CAR X Condition X Probability	-0.35	0.210	-0.76	0.06
CAR X Condition X Gain	-0.25	0.214	-0.67	0.17
CAR X Condition X Loss	-0.18	0.212	-0.59	0.24
Diurnal Fall X Condition X Block	-0.06	0.210	-0.47	0.33
Diurnal Fall X Condition X Probability	0.04	0.210	-0.38	0.43
Diurnal Fall X Condition X Gain	-0.25	0.204	-0.66	0.16
Diurnal Fall X Condition X Loss	0.31	0.209	-0.09	0.72

* Indicates significance based on the 95% confidence intervals for the obtained parameter estimate.

Table 6: *Linear Mixed Models Analysis: Cortisol Indicators and Cups Task Performance in Problem Gambling Group*

			95% CI	
	Estimate	Std. Error	Lower Bound	Upper Bound
Intercept	0.84	0.142	0.56	1.13
CAR	0.06	0.147	-0.24	0.35
Diurnal Fall	0.02	0.140	-0.26	0.30
Domain	0.04	0.142	-0.24	0.32
Probability	-0.15	0.150	-0.44	0.15
Outcome	0.24	0.151	-0.06	0.54
CAR X Domain	0.00	0.147	-0.29	0.30
CAR X Probability	-0.09	0.155	-0.40	0.22
CAR X Outcome	-0.04	0.156	-0.35	0.27
Diurnal Fall X Domain	-0.18	0.140	-0.46	0.10
Diurnal Fall X Probability	0.09	0.149	-0.21	0.38
Diurnal Fall X Outcome	-0.08	0.149	-0.38	0.22
Domain X Probability	-0.20	0.150	-0.50	0.10
Domain X Outcome	-0.43*	0.151	-0.73	-0.13
CAR X Domain X Probability	-0.02	0.155	-0.29	0.33
CAR X Domain X Outcome	0.02	0.156	-0.29	0.33
Diurnal Fall X Domain X Probability	-0.06	0.149	-0.36	0.23
Diurnal Fall X Domain X Outcome	0.10	0.149	-0.19	0.40

* Indicates significance based on the 95% confidence intervals for the obtained parameter estimate.

Figure Legends

Figure 1: Mean cortisol levels (± SEM) after awakening across groups. The problem gambling group showed blunted cortisol levels at 30 and 45 min after awakening and a flatter diurnal slope; W = wake.

Figure 2. Mean (± SEM) number of cards turned in the Columbia Card Task across groups. The problem gambling group showed greater risk taking across both the hot and the cold versions of the CCT.

Figure 3. CAR moderates the association between CCT condition and risk taking for individuals with problem gambling. Model-based estimates are presented.