Title Page

Running head: STRESS AND HEAVY DRINKERS' DECISION-MAKING

Anticipatory stress restores decision-making deficits in heavy drinkers by increasing sensitivity to losses

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Abstract

Background: Substance abusers are characterized by hypersensitivity to reward. This leads to maladaptive decisions generally, as well as those on laboratory-based decision-making tasks, such as the Iowa Gambling Task (IGT). Negative affect has also been shown to disrupt the decision-making of healthy individuals, particularly decisions made under uncertainty. Neuropsychological theories of learning, including the Somatic Marker Hypothesis (SMH), argue this occurs by amplifying affective responses to punishment. In substance abusers, this might serve to rebalance their sensitivity to reward with punishment, and improve decision-making. **Methods:** Before completing the IGT, 45 heavy and 47 light drinkers were randomly assigned to a control condition, or led to believe they had to give a stressful public speech. IGT performance was analyzed with the Expectancy-Valence (EV) learning model. Working memory and IQ were also assessed. **Results:** Heavy drinkers made more disadvantageous decisions than light drinkers, due to higher attention to gains (versus losses) on the IGT. Anticipatory stress increased participants' attention to losses, significantly improving heavy drinker's decision-making. **Conclusions:** Anticipatory stress increased attention to losses, effectively restoring decision-making deficits in heavy drinkers by rebalancing their reward sensitivity with punishment sensitivity.

Keywords: alcohol; addiction; decision-making; IGT; stress; reward sensitivity; punishment sensitivity; behavioral inhibition

1. Introduction

There is a large body of evidence linking heavy alcohol use with deficits in adaptive decision-making under uncertainty; that is, decision-making when the contingencies are not fully known (Bechara, 2005; Bechara et al., 2001; Johnson et al., 2008; Yechiam et al., 2005). Much of this research has been conducted using the Iowa Gambling Task (IGT), a laboratory-based decision-making task involving decisions under ambiguity, thereby mirroring "real-life" decisions (Bechara et al., 1994). Negative affect has also been shown to disrupt IGT decision-making in healthy individuals, but this effect has yet to be investigated in heavy drinkers (de Vries et al., 2008; Heilman et al., 2010; Preston et al., 2007). Given the key role of negative affect (particularly stress) in promoting alcohol abuse and abstinence violation (King et al., 2009; Witkiewitz and Villarroel, 2009), this is an important area of study. This is particularly so, given that certain theoretical models predict stress/negative affect should actually enhance decision-making (Bechara and Damasio, 2005; Gray and McNaughton, 2000); therefore, the impact of stress on decision-making requires clarification. The purpose of the present study was to investigate the effect of anticipatory stress on decision-making in heavy compared to light alcohol users.

Deficits in adaptive decision-making have been linked to problem alcohol use at various points in the "addiction cycle". Poor IGT performance has been shown to predict later binge-drinking in adolescents (Xiao et al., 2009), as well as treatment outcome in alcohol-dependent patients (Bowden-Jones et al., 2005). Detailed investigation into the cognitive mechanisms underlying poor decision-making in substance users has implicated hypersensitivity to reward coupled with insensitivity to future punishment (Bechara et al., 2002; Johnson et al., 2008; Lovallo et al., 2006). A similar conclusion has emerged from neuroimaging, psychopharmacological, and self-report studies (Christakou et al., 2009; Dawe et al., 2004; de Wit and Richards, 2004; Li et al., 2010). On the IGT, hypersensitivity to reward is observed as enhanced affective responses (i.e., skin conductance responses) to anticipated and received monetary gains (Bechara et al., 2002). The processing of rewards during the IGT has been localized to brain activity within the orbitofrontal, dorsomedial, cingulate, and insular cortices (Christakou et al., 2009; Li et al., 2010). Furthermore, insensitivity to future punishment is observed by the absence of affective responses prior to making a poor decision resulting in a large monetary loss (i.e., absence of "warning signals"; Bechara et al., 2002). There is compelling evidence implicating the ventromedial prefrontal cortex (vmPFC) in this (in)sensitivity to punishment (Bechara et al., 2001; Bechara et al., 2002; Christakou et al., 2009; Fellows and Farah, 2005). This has led to the proposition that addiction is caused (and maintained), in part, by maladaptive decision-making resulting from aberrant processing in these brain regions (Bechara, 2005).

Recently, a number of studies have explored the role of background negative emotion in decision-making under uncertainty. It should be noted first that the general term *negative affect* here refers to any aversive/unpleasant emotional state, including anxiety, anger, stress, or disgust (Watson et al., 1988). We use the term *stress* to refer to a specific negative affective state originating from a threat/harm facing the organism that is appraised to be insurmountable or challenging (Lazarus, 1993). *Anticipatory stress* refers to stress originating from an upcoming stressor.

de Vries et al. (2008) found that experimentally-induced negative affect (i.e., watching a distressing film) increased the number of disadvantageous decisions made during the early stages of the IGT. Similarly, Preston et al. (2007) reported poorer decision-making in those experiencing anticipatory stress. Again, this was only detected within the early stages of the IGT when participants were still making choices under ambiguity. In this study, anticipatory stress was induced by leading participants to believe they were about to give a public speech on what they disliked about themselves. More recently, Heilman et al. (2010)

found that the detrimental effect of negative affect on decision-making could be restored through the use of appropriate emotion regulation strategies (e.g., cognitive reappraisal). Consistent with this, van den Boss et al. (2009) reported that acute stress only disrupted IGT decision-making in those evidencing a high cortisol response to the stressor.

Theoretical explanations for these disruptive effects on decision-making have tended to focus around two themes. The first explains the effect of stress in terms of the distraction it may cause in the decision-maker (Miu et al., 2008; Preston et al., 2007). That is, stressed participants perform more poorly on the IGT because they are worrying about the upcoming aversive event, which taxes working memory resources that would otherwise be devoted to the task. This is a plausible explanation given optimal performance on the IGT requires adequate working memory resources (Pecchinenda et al., 2006), and worrying does tax these resources (Hayes et al., 2008). The second explanation is more biologically-focused. Stress produces high background emotion that may consequently "drown out" task-related affective responses, particularly aversive responses, processed in the vmPFC to guide decision-making under uncertainty (Christakou et al., 2009; Heilman et al., 2010; Preston et al., 2007; van den Bos et al., 2009). This supposition is also plausible given that glucocorticoids and other neurochemicals released during high stress have been linked to increased reward sensitivity and disruption of prefrontal functioning (Liston et al., 2009; Piazza et al., 1991).

Such findings appear to contradict predictions made by Bechara and Damasio (2005). According to their Somatic Marker Hypothesis (SMH), background emotion should enhance decision-making under certain circumstances. Specifically, background emotion states should "amplify" subsequent emotional responses that are consistent with it, i.e., of similar valence (Bechara and Damasio, 2005). In this way, background negative affect caused by stress would facilitate the processing of losses during the IGT due to their aversive nature. Interestingly, this view is also consistent with Gray's (1987; Gray and McNaughton, 2000) neuropsychological model of anxiety, which has recently been incorporated into models of substance use (Gullo and Dawe, 2008). According to Gray (1987; Gray and McNaughton, 2000), anticipating a future threat would sensitize the brain's defense system, increasing vigilance and sensitivity to punishments generally. That is, anticipatory stress would be expected to increase sensitivity to losses on the IGT. While the available evidence appears inconsistent with these theories, due consideration of individual differences in baseline reward/punishment sensitivity may resolve this conflict.

Whether stress-induced increases in punishment sensitivity would enhance, rather than impair, decision-making likely depends on an individual's baseline sensitivity to reward and punishment. In healthy individuals, a stress-induced increase in punishment sensitivity could overly bias responding such that decisions are driven solely by avoidance of punishments/losses, causing an overall maladaptive response pattern (Busemeyer and Stout, 2002). This could explain the detrimental effects of negative affect reported in healthy individuals (de Vries et al., 2008; Heilman et al., 2010; Preston et al., 2007; van den Bos et al., 2009). By contrast, in substance abusers, who are characterized by hypersensitivity to reward, a stress-induced increase in punishment sensitivity may restore this motivational imbalance and improve decision-making, as predicted by Bechara and Damasio (2005), and Gray (1987).

The aim of the present study was to examine the effect of anticipatory stress on the underlying mechanisms involved in the decision-making of heavy versus light alcohol users. By analyzing IGT response patterns with the Expectancy-Valence (EV) learning model (Busemeyer and Stout, 2002), different explanations for the effect of stress on decision-making could be compared. The EV model decomposes IGT decision-making into the component processes of attention to gains versus losses, attention to recent versus past choice outcomes, and the consistency with which future choices are based on past outcomes. The EV model has been particularly useful in exploring the specific cognitive processes disrupted in various neuropsychological disorders (Yechiam et al., 2005). No study has yet explored how stress affects these component processes.

According to Bechara and Damasio (2005), and Gray (1987; Gray and McNaughton, 2000), anticipatory stress will increase attention to losses; thereby, improving the decision-making of heavy drinkers (who have low baseline attention to losses), but impair that of light drinkers (who have more balanced attention to gains and losses). Specifically, non-stressed heavy drinkers were hypothesized to attain significantly lower IGT scores than non-stressed light drinkers, and this effect would be fully mediated by their lower attention to losses. However, there will be no difference in IGT scores or attention to losses between stressed heavy and light drinkers. By contrast, if stress “drowns out” IGT affective responses or “distracts” participants, this will impair decision-making in heavy and light drinkers alike, most likely by way of decreasing attention to losses. Specifically, these models hypothesize that stressed participants will attain significantly lower IGT scores and attention to losses than non-stressed participants, regardless of drinking status. Additionally, the distraction model predicts stressed participants will have lower choice consistency and attention to past outcomes scores.

2. Methods

2.1. Participants

Ninety-two first-year undergraduates were recruited for the present study and offered partial course credit. Sixty-seven (72.8%) were female (M = 21.43 years, SD = 7.42) and 25 (27.2%) were male (M = 21.49 years, SD = 6.31). Exclusion criteria included a history of diagnosed organic brain disease, neurosurgery, psychosis, Attention Deficit-Hyperactivity Disorder (ADHD), or head injury resulting in loss of consciousness. All participants were pre-screened with the Alcohol Use Disorders Identification Test (AUDIT; Saunders et al., 1993) to determine drinking status. Male and female heavy drinkers were operationalized as scoring ≥8 and ≥7 on the AUDIT, respectively, indicating the presence of hazardous/harmful alcohol use (Babor et al., 2001; Roche and Watt, 1999). Light drinkers were operationalized as scoring ≤6, indicating an absence of hazardous/harmful alcohol use. Thus, males with AUDIT scores of 7 were not eligible to participate. However, no screened male scored a 7. Nearly all light drinkers (95.7%) reported no binge-drinking over the past three months, or less-than-monthly binge-drinking. By contrast, the majority of heavy drinkers reported monthly (55.6%) or weekly (26.7%) binge-drinking. All participants provided informed consent before taking part in the study.

2.2. Measures

2.2.1. Decision-making. The Iowa Gambling Task (IGT; Bechara et al., 2001) is a computerized task containing four decks of cards (A', B', C', D') in which there are 60 cards in each deck. All participants make 100 card selections (5 blocks of 20 trials). Participants are not aware in advance how many cards are in each deck or how many selections they will have to make. Each deck of cards has a certain overall ratio of reward to punishment in terms of "play" money. Decks A' and B' generally deliver high immediate gains ($100 on average) but larger delayed losses (i.e., result in a net loss). In contrast, decks C' and D' generally deliver small immediate gains ($50 on average), but lower overall losses (i.e., result in a net gain). Additionally, the magnitude of net gains/losses across the decks increases over the course of the task. In the long run, decks A' and B' are disadvantageous whereas decks C' and D' are advantageous. Again, participants are not aware of these contingencies before commencing the task, but are informed that "some decks were worse than others" (Bechara et al., 2000). Decision-making quality is typically operationalized as a net-score of (C'+D' selections) – (A'+B' selections). Further details are reported in Bechara et al. (2001).

2.2.2. Working memory. Previous studies suggest that working memory capacity influences IGT performance (Pecchinenda et al., 2006). Therefore, backward digit span was assessed as a brief measure of working memory capacity. A computer-administered task (Mueller, 2007) was employed that involved the presentation of a random series of single-digit numbers, 1 second apart, after which the participant had to recall the sequence in reverse order.

2.2.3. Intelligence may also influence IGT performance (Fishbein et al., 2005). Therefore, the National Adult Reading Test: Second Edition (NART) was administered as a brief measure of IQ (Nelson and Willison, 1991). This test required participants to pronounce 50 irregular English words that cannot be pronounced correctly by following conventional phonetic structure. The NART has excellent test-retest (.98) and inter-rater reliability (.99), and performance is a strong indicator of IQ (Blair and Spreen, 1989; Crawford et al., 1989).

2.2.4. Negative Affect. The Negative Affect (NA) scale of the Positive and Negative Affect Schedule (PANAS; Watson et al., 1988) was used as a manipulation check to determine whether the stressor increased negative affect, as intended. The PANAS assesses the degree to which participants are currently experiencing 10 negative and 10 positive emotions. A high NA score reflects a state of distress and anxiousness. The PANAS was developed and validated on a large US college sample (Watson et al., 1988). Both scales have been shown to have good reliability (NA: $\alpha = .87$; PA: $\alpha = .88$), and NA correlates highly with measures of anxiety and depression (Watson et al., 1988).

2.2.5. Drinking Status. The AUDIT (Saunders et al., 1993) is a 10-item self-report inventory developed by the World Health Organization. It is more sensitive to hazardous/harmful drinking than other commonly used screening tools (Aertgeerts et al., 2001; Dawe et al., 2002). The AUDIT was found to have a 6-week test-retest reliability of .88 in a sample of 332 primary care patients (Daeppen et al., 2000), and internal reliability of .83 in a sample of 327 Australian college students (Gullo et al., 2010).

2.3. Procedure

All participants were pre-screened with the AUDIT in order to assess drinking status (i.e., heavy or light drinker). Upon arrival, participants were asked to read briefing material that led them to believe the study was investigating the interaction between self-perception, alcohol use, and decision-making. After providing informed consent, participants were administered the PANAS (Time 1) and NART. Participants were then administered the PANAS again (Time 2). Upon completion of the PANAS, the backward digit-span task was administered.

While completing the computer-administered digit-span task, participants were randomly assigned to the Stress or Control Condition. Two separate random allocation sequences were generated for heavy and light drinkers with random allocation sequence software (Saghaei, 2004) by an independent person (MJG) who had no role in the recruitment, enrolment, or testing of participants. Random assignment to the Stress/Control Condition was indicated by random permuted blocks of eight (1:1 allocation ratio; Schulz and Grimes, 2002b). Sequentially Numbered Opaque Sealed Envelopes (SNOSE) were used to ensure allocation concealment (Schulz and Grimes, 2002a). This led to four distinct groups: stressed heavy drinkers (n = 23), stressed light drinkers (n = 25), heavy drinker controls (n = 22), and light drinkers controls (n = 22).

After completing the backward digit-span, participants allocated to the Stress Condition were told that after completing the IGT they would have to give a speech on *what I dislike about my body and physical appearance* (Preston et al., 2007). The speech had to go for at least 5 minutes, would be recorded, and then rated by a clinical psychologist for organization, articulation, openness, and defensiveness to gauge their personality. The experimenter simultaneously presented a previously obscured video camera on a tripod, plugged the camera into the wall, and activated it in front of the participant. The experimenter also tested a stopwatch before putting it down on the table in front of the participant. This procedure was similar to Preston et al. (2007) and has been shown to reliably increase physiological arousal and cortisol levels (Dickerson and Kemeny, 2004). Control participants were simply administered the next measure on completion of the backward digit-span.

All participants completed another PANAS (Time 3), before being administered the IGT. When participants in the Stress Condition had completed the IGT, they were informed they were not required to give a speech, but they could if they wished to. No participant elected to give the speech. Participants were then debriefed as to the true nature of the experiment.

2.4. Data Analysis

As in previous studies, separate analyses were conducted on the learning (block 1 – 3) and performance (block 4 – 5) phases of the IGT (de Vries et al., 2008; Heilman et al., 2010; Preston et al., 2007). This distinction is consistent with Bechara et al.'s (1997) report that, on average, participants do not develop a conceptual understanding of deck contingencies until the 80th trial (range: 60th – 90th; i.e., block 4 – 5). That is, they are making decisions under ambiguity up until this point. Similarly, neuroimaging findings suggest it is during the learning phase that the somatic marker circuitry is most active (Li et al., 2010). In addition to this, separate ANOVAs were conducted on EV cognitive parameters in order to explore how stress affected decision-making.

Expectancy-valence (EV) learning model. The EV model derives three separate parameters based on participants' trial-by-trial choices/feedback considered crucial to decision-making (for details, see Supplementary Material, and Busemeyer and Stout, 2002). The *attention weight parameter*, calculates the degree to which attention to gains or losses influence card selection. Scores range from 0 to 1. A score of 0.5 indicates deck selections are made considering both losses and gains equally. Values less than 0.5 signify more attention to losses than gains. Values greater than 0.5 reflect greater attention to gains than losses (Yechiam et al., 2005).

The *updating rate parameter* reflects the degree to which recent versus past information influences deck selection (Busemeyer and Stout, 2002; Yechiam et al., 2005). Values range between 0 and 1. Small values indicate the participant takes into consideration past outcomes for long periods of time when making deck selections. In contrast, large values indicate past outcomes are quickly disregarded, and more recent deck experiences weigh strongly on decisions (Yechiam et al., 2007).

The *choice consistency parameter* ranges between -5 and 5. A positive score indicates increasing choice consistency over time (i.e., choices rely more on expectancies derived from past outcomes). Negative scores indicate choice consistency lowering over time, often a sign of non-attendance, boredom, or fatigue (Busemeyer and Stout, 2002). Parameters were calculated in MATLAB (MathWorks Inc., 2009) using maximum-likelihood estimation (Busemeyer and Stout, 2002).

3. Results

3.1. Manipulation Check

A 3 (Time) x 2 (Stress Condition) mixed within-between factorial ANOVA was conducted to investigate whether the stress task increased NA. This revealed a significant main effect for Time ($F[2, 180] = 35.16$, $p < .001$, $\eta^2 = .28$) and Stress Condition ($F[1, 90] = 5.64$, $p = .02$, $\eta^2 = .06$), which were qualified by a significant interaction, $F(2, 180) = 22.46$, $p < .001$, $\eta^2 = .20$. Post-hoc comparisons revealed, as intended, a significant increase in NA from before being told of the upcoming speech (*M* = 12.52, *SD* = 3.43) to after (*M* = 17.19, *SD* = 5.36) for the Stress group only, $t(47) = 7.89$, $p < .001$, $d_z = 1.14$. Furthermore, just before starting the IGT (Time 3), stressed participants (*M* = 17.19, *SD* = 5.36) reported significantly higher NA than controls (*M* = 12.89, *SD* = 3.22), $t(90) = 4.62$, $p < .001$, $d = 1.00$. Eight participants in the Stress Condition (four heavy drinkers, four light drinkers) reported no increase in NA after being told of the speech. Therefore, these participants were excluded from further analyses (van den Bos et al., 2009).

3.2. Evaluation of Covariates

Table 1 shows baseline characteristics of light and heavy drinkers. Heavy drinkers engaged in significantly more hazardous drinking, but did not differ from light drinkers in age, gender composition, IQ, working memory, or baseline affect. Similarly, there were no differences between the Stress and Control groups on these variables (*p*s > .05). Furthermore, their inclusion as covariates in main analyses did not affect the results, except baseline NA when examining IGT learning phase performance. Therefore, it was included as a covariate for this analysis.

3.3. Main Analyses

Analyses were performed in SPSS (version 14.0.2, SPSS Inc., Chicago, IL). A 2 x 2 x 3 (Drinking Status x Stress Condition x IGT Block) ANCOVA was conducted on IGT net-scores for the learning phase, with baseline negative affect included as a covariate. This revealed a significant Block x Baseline NA interaction whereby participants with higher baseline NA showed a steeper learning curve, $F(2, 164) = 4.13$, $p = .02$, partial $\eta^2 = .05$. This suggests learning did take place. There was also a significant main effect of Drinker Status, with light drinkers making more advantageous decisions than heavy drinkers, $F(1, 79) = 5.11$, $p = .03$, partial $\eta^2 = .06$. However, these effects were qualified by a significant three-way interaction, $F(2, 158) = 3.40$, $p = .036$, partial $\eta^2 = .04$. Closer examination revealed stress improved the learning of heavy drinkers, in that they made more advantageous decisions during Block 2 than heavy drinkers in the Control Condition, $F(2, 38) = 6.04$, $p = .02$, partial $\eta^2 = .14$. As shown in Figure 1, while the decision-making of heavy drinkers was significantly poorer than light drinkers in the Control Condition during Block 2 ($F(2, 41) = 7.40$, $p = .01$, partial $\eta^2 = .15$) and Block 3 ($F(2, 41) = 5.70$, $p = .02$, partial $\eta^2 = .12$), these differences disappeared under stress. The ANOVA for the performance phase revealed no significant effects.

To investigate how stress improved heavy drinkers' decision-making during the learning phase, 2 x 2 (Drinker Status x Stress Condition) ANOVAs were conducted on the EV cognitive parameters. For the attention weight parameter, there was a significant main effect of stress ($F[1, 80] = 7.63$, $p = .01$, partial $\eta^2 = .09$), whereby stress increased attention to losses. There was also a main effect of Drinking Status ($F[1, 80] = 7.44$, $p = .01$, partial $\eta^2 = .09$), in which heavy drinkers showed more attention to gains (and less attention to losses) than light drinkers. The interaction was not significant, $F(1, 80) = 0.14$, $p = .71$, partial $\eta^2 = .002$. As shown in Figure 2, heavy drinkers displayed significantly more attention to gains versus losses than light drinkers in the Control condition, $t(42) = 2.58$, $p = .01$, $d = 0.79$. However, stress increased heavy drinkers' attention to losses such that equal attention was now being paid to gains and losses, similar to non-stressed light drinkers, $t(39) = 0.02$, $p = .98$, $d = 0.00$. Path analysis was used to test for mediation, in accordance with the *joint significance* test (MacKinnon et al., 2007). This revealed the effects of heavy drinking and stress on decision-making were fully-mediated by changes in attention to gains/losses (see Figure 3). The ANOVAs conducted on the updating rate and choice consistence parameters revealed no significant effects of Stress Condition or Drinker Status (ps > .05).

4. Discussion

The present study investigated the effect of anticipatory stress on decision-making in heavy and light alcohol users, and employed cognitive modeling of decisions to explore the nature of this effect. The main finding was that stress restored the decision-making deficits of heavy drinkers by increasing attention to losses. In fact, anticipatory stress increased both heavy and light drinkers' attention to losses, consistent with Bechara and Damasio (2005), and Gray (1987; Gray and McNaughton, 2000). This is the first study to investigate the impact of anticipatory stress on the decision-making of substance abusers, and the first to demonstrate that experimentally increasing punishment sensitivity leads to improved decision-making.

Numerous studies have demonstrated that poor decision-making in substance abusing populations is related to reward hypersensitivity (Bechara et al., 2002; Johnson et al., 2008; Lovallo et al., 2006). Given that IGT decisions involve the consideration of potential reward and punishment, that nature of the task is such that hypersensitivity to one of these outcomes comes at the expense of *hypo*sensitivity to the other. This differential sensitivity is reflected in the attention weight parameter of the EV model (Busemeyer and Stout, 2002), and studies have shown substance abusers score higher on this parameter (Lovallo et al., 2006; Yechiam et al., 2005). Our results show that for heavy drinkers characterized by hypersensitivity to reward, anticipatory stress rebalances their attention to punishments with attention to rewards. For light drinkers, who already possess a balanced sensitivity to rewards and punishments, this biases their attention toward losses (at the expense of gains).

Previous studies with healthy controls have consistently reported a detrimental effect of negative affect on IGT decision-making, particularly during the learning phase of the task when decisions are being made under uncertainty (de Vries et al., 2008; Heilman et al., 2010; Preston et al., 2007; van den Bos et al., 2009). Consistent with this, our results showed the same increase in loss sensitivity observed in heavy drinkers. Assuming that our light drinkers are comparable to the "healthy individuals" recruited in previous studies, our findings suggest this detrimental effect may occur by over-sensitizing them to losses.

While of clear theoretical importance, the extent to which these findings have implications for intervention is less clear. At the suggestion of an anonymous reviewer, we added self-reported negative affect to the model as a mediator of the effect of stress induction on attention to gains/losses. This revealed that while stress did predict increased negative affect ($\beta = .42$, $p < .001$), affect itself did not predict attention to gains/losses ($\beta = .07$, $p = .45$). Rather, it was an additional outcome of the stress induction. This suggests the effect of stress on punishment sensitivity was not a result of the conscious experience of negative emotion, but rather the underlying neurobehavioral mechanisms proposed by Gray (1987; Gray and McNaughton, 2000) and the SMH (Bechara and Damasio, 2005). These results are consistent with studies implicating the importance of the vmPFC to learning from punishment (Christakou et al., 2009), and theories linking vmPFC hypofunctioning to substance abuse (Bechara, 2005; Dawe et al., 2004; Rogers et al., 1999). Based on such findings, any intervention that improves vmPFC functioning and/or the processing of punishments in those hypersensitive to reward would be expected to improve decision-making deficits seen in substance abusers.

A question for future research is whether the effect observed here can be replicated in an alcohol-dependent population, in which general cognitive deficits and comorbid psychopathology are common, and may differentially affect stress reactivity and decision-making (Fishbein et al., 2007; Tiet and Mausbach, 2007). More broadly, the fact that a (predominantly female) college sample was recruited should also be taken into account when considering the generalizability of our findings. It is also important to emphasize that the beneficial effects of stress observed here were confined to decision-making when outcomes are not fully known which, while consistent with theory, is somewhat counter-intuitive when viewed in the context of general models of stress and addiction (King et al., 2009; Piazza et al., 1991; Witkiewitz and Villarroel, 2009). The effect of stress on decision-making when contingencies are explicit may differ. Additionally, whether the same effects would be observed in those who have consumed alcohol (or intoxicated) is another important question for future research. Future research could also explore IGT decision-making during anticipation of the stressful speech versus after having actually confronted the stressor.

In summary, this is the first study to investigate the effects of anticipatory stress on heavy drinkers' decision-making. Anticipatory stress improved the IGT performance of heavy drinkers by increasing their sensitivity to losses, effectively rebalancing their sensitivity to reward and punishment. Stress also affected light drinkers' attention to gains versus losses, biasing it toward losses. However, this did not affect their overall decision-making quality.

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Figure Legends

Figure 1. Mean net-scores on the Iowa Gambling Task for heavy and light drinkers in the Control and Stress conditions. Errors bars represent standard errors. Blocks 1 – 3 comprise the Learning Phase; Blocks 4 – 5 comprise the Performance Phase. Unadjusted Learning Phase means are reported for consistency. An asterisk (*) indicates a significant difference between heavy and light drinkers ($p < .05$).

Figure 2. Mean attention weight scores on the Iowa Gambling Task for heavy and light drinkers in the Control and Stress conditions. Scores above 0.5 indicate relatively greater attention to gains; scores below 0.5 indicate relatively greater attention to losses. Errors bars represent standard errors. An asterisk (*) indicates a significant difference between heavy and light drinkers ($p < .05$).

Figure 3. Path model of attention to gains/losses as mediator of heavy drinking and stress effects on Iowa Gambling Task (IGT) learning phase performance. Maximum-Likelihood estimation with bias-corrected bootstrap (2000 samples) confidence intervals was employed. Attention to gains/losses significantly, and fully, mediated the effect of heavy drinking (standardized indirect effect = -.10; CI_{95}: -.20 – -.03) and stress (standardized indirect effect = .09; CI_{95}: .02 – .19) on IGT net-scores. Model showed very good fit to the data, χ^2 (5) = 5.10, p = .41, CFI = .998, RMSEA = .015. Standardized path coefficients are presented. Residuals, and covariances between Expectancy-Valence parameters, are not shown for clarity of exposition. Analysis was performed in AMOS 6.0 (SPSS Inc., Chicago, IL).

**$p \leq .01$.

***$p < .001$.

Table 1

Descriptive data for light (n =43) and heavy (n = 41) drinkers

	Light Drinkers	Heavy Drinkers	*t* (*df*)	*p*
Age	22.58 (8.86)	20.76 (5.36)	1.14 (82)	.26
Gender[a]	33 F / 10 M	31 F / 10 M	.02 (1)	.90
AUDIT	2.67 (2.24)	12.66 (4.72)	12.47 (82)	**< .001**
NART FSIQ	105.82 (5.13)	106.60 (4.43)	0.74 (82)	.46
Backward Digitspan	5.14 (1.34)	5.29 (1.49)	0.50 (82)	.62
Baseline Positive Affect	28.93 (7.80)	26.34 (6.55)	1.64 (82)	.10
Baseline Negative Affect	12.56 (3.07)	12.71 (3.21)	0.22 (82)	.83

Note. AUDIT = Alcohol Use Disorders Identification Test; NART FSIQ = National Adult Reading Test Full-Scale IQ.

[a]Group differences tested with chi-square test.

Table 2

Unadjusted Means (Standard Deviations) for Iowa Gambling Task (IGT) Net-Score by Drinker Status and Stress Condition

		Block				
Drinker Status	Stress Condition	1	2	3	4	5
Light Drinkers	Control	-4.91 (6.98)	4.27 (9.45)	6.64 (8.95)	4.00 (9.24)	5.45 (11.70)
	Stress	-1.81 (5.40)	2.76 (6.24)	3.81 (8.96)	4.19 (9.05)	2.10 (11.00)
Heavy Drinkers	Control	-4.27 (7.74)	-2.36 (7.08)	1.18 (9.17)	1.91 (12.09)	-0.18 (9.64)
	Stress	-4.32 (4.02)	2.74 (6.23)	2.21 (8.97)	1.47 (10.47)	2.00 (12.93)

Note. Net-scores are calculated as number of advantageous decisions – number of disadvantageous decisions.

Figure 1
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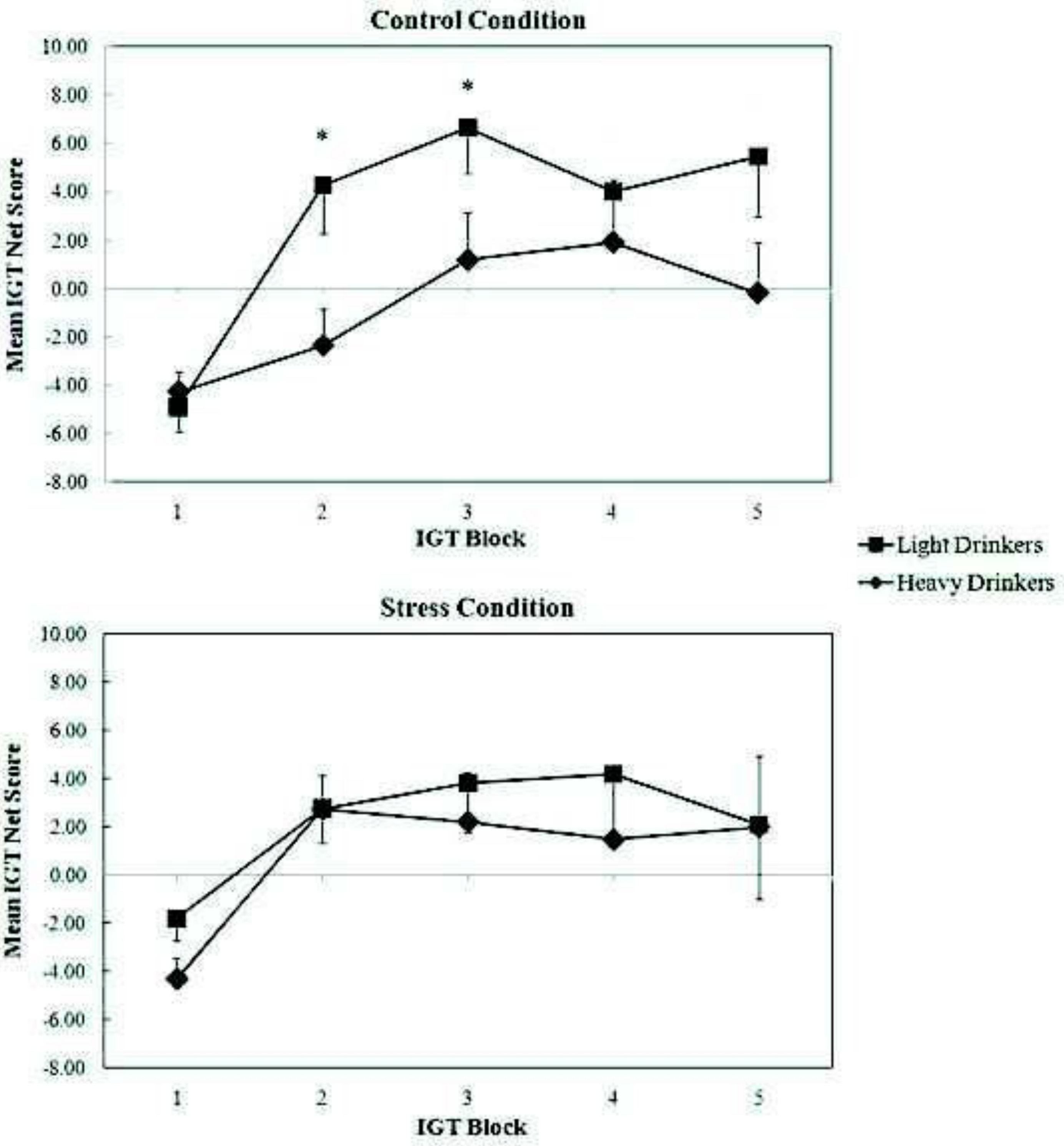

Figure 2
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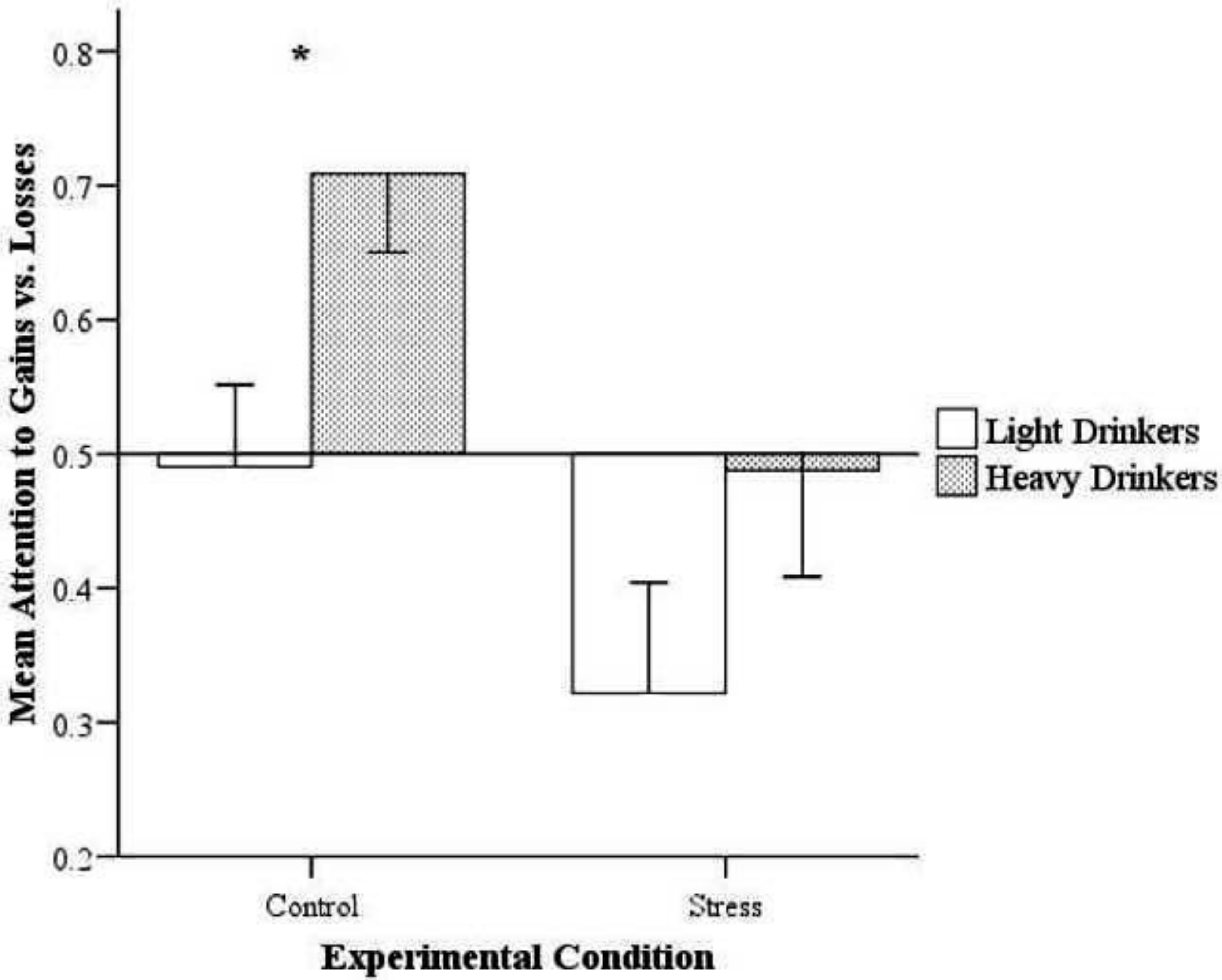
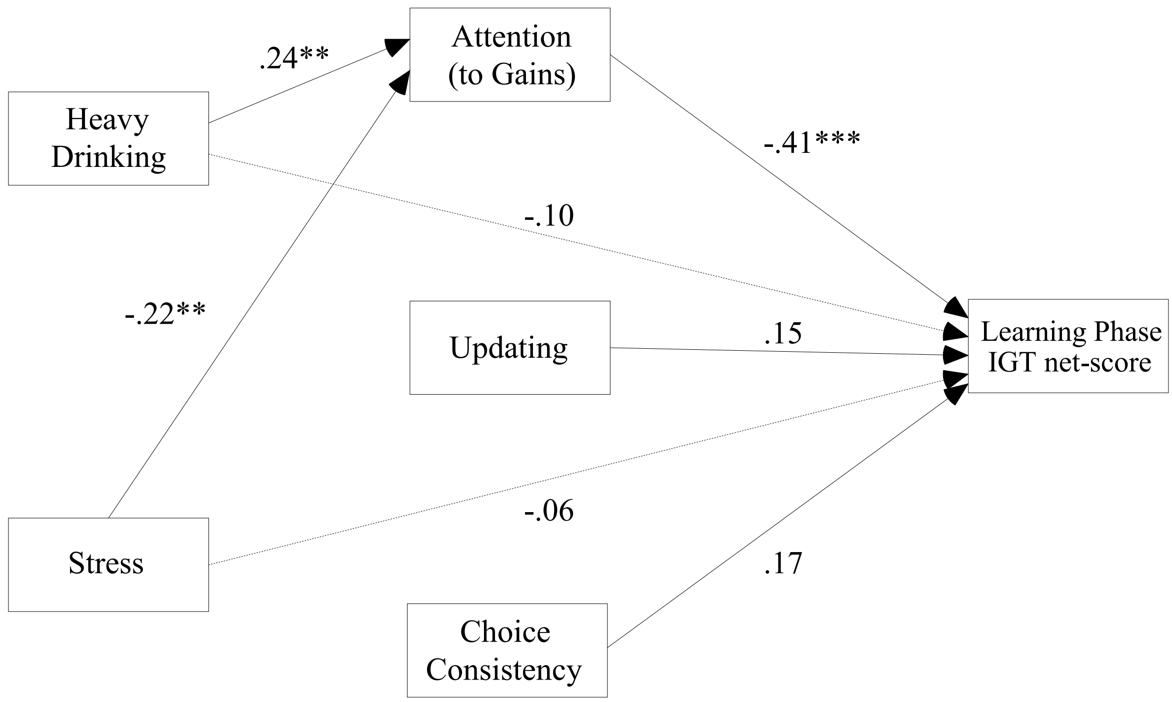


Figure 3



Attention
(to Gains)
.24**
Heavy
Drinking
-.41***
-.10
-.22**
Updating
.15
Learning Phase
IGT net-score
-.06
Stress
.17
Choice
Consistency

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Contributors
Both authors designed the study, wrote the protocol, and managed the literature searches and summaries of previous related work. Dr. Gullo undertook the statistical analyses and wrote the first draft of the manuscript. Both authors contributed to and have approved the final manuscript.

Conflict of Interest
No conflict declared.

Supplementary material for *Anticipatory stress restores decision-making deficits in heavy drinkers by increasing sensitivity to losses* by Matthew J. Gullo and Adam Stieger. This material supplements but does not replace the content of the peer-reviewed paper published in *Drug and Alcohol Dependence*.

Expectancy-valence (EV) learning model.

The EV model derives three separate parameters thought to be crucial to decision-making based on participants' trial-by-trial feedback (Busemeyer and Stout, 2002).

The *attention weight parameter* (*W*), calculates the degree to which attention to gains or losses influence card selection. The model assumes that after each deck choice a valence of overall gains (or losses) is experienced from that selection; represented *v*(*t)*. The valence of outcome is the weighted average of winnings (*win*) and losses (*loss*) on a specific trial (*t)*. Formally:

$$v(t) = Wwin(t) - (1 - W)loss(t) .$$

Each participant scores between 0 and 1 on the attention weight parameter (*W*). A score of 0.5 indicates deck selections are made considering both losses and gains equally. Values less than 0.5 signify more attention to losses than gains. Finally, values greater than 0.5 reflect greater attention to gains than losses (Yechiam et al., 2005).

The EV model also assumes that participants generate expectancies of future consequences from each deck throughout the IGT. The *updating rate parameter*, denoted Φ, examines the degree to which recent versus past information influences deck selection (Busemeyer and Stout, 2002; Yechiam et al., 2005). When a deck choice is made, the expectancy for that deck, E_j, is updated as a function of past valences experienced for that specific deck. The recently experienced valence is also updated. The updating rate parameter calculates the degree to which attention to past or recent outcomes are considered when making choices. Formally:

$$E_j(t) = E_j(t-1) + \phi[v(t) - E_j(t-1)].$$

Values for Φ range between 0 and 1. Small values indicate the participant takes into consideration past outcomes for long periods of time when making deck selections. That is, they remember previous deck experiences which guide their decisions. In contrast, large values indicate past outcomes are quickly disregarded, and more recent deck experiences weigh strongly on decisions (Yechiam et al., 2007).

The EV model postulates that a deck is selected when the expectancy for that deck is deemed more advantageous than all others (Busemeyer and Stout, 2002; Yechiam et al., 2005). Formally:

$$\Pr\left[G_j(t+1)\right] = \frac{e^{\theta(t)\cdot E_j(t)}}{\sum_k e^{\theta(t)\cdot E_k(t)}}.$$

The variable $\theta(t)$ denotes how consistently participants follow expectancies with actual selections. As more deck selections are made, choice consistency is expected to increase (i.e., choices rely more on expectancies). A power function formalizes this assumption (Busemeyer and Stout, 2002):

$$\theta(t) = (t/10)^c.$$

Values for c, the *choice consistency parameter*, range between -5 and 5. A positive score indicates increasing choice consistency over time. Negative scores indicate choice consistency lowering over time. This is often a sign of non-attendance, boredom, or fatigue (Busemeyer and Stout, 2002).

Evaluation of Expectancy Valence (EV) Parameters

The fit of the EV model to actual IGT decisions, from which the cognitive parameters were derived, was evaluated prior to the main analyses. Specifically, the EV model was compared to a baseline statistical model in which deck choices on the IGT were assumed to be independently and identically distributed across trials (Busemeyer and Stout, 2002) :

$$p_4 = 1 - (p_1 + p_2 + p_3),$$

where p_1 is the probability of selecting deck A, p_2 is the probability of selecting deck B, and so on. The baseline model perfectly reproduces the marginal choice probabilities, pooled across trials. Thus, the EV model would only perform better if it can explain how deck choices are influenced, over time, by the sequence of trial-by-trial feedback (Busemeyer and Stout, 2002).

The models were compared using the G^2 statistic, which is the log-likelihood difference between the fit of the two models:

$$G^2 = 2(L_{EV} - L_{baseline}).$$

Positive values of G^2 indicate the EV model provides a better fit to the data than the baseline model. In this study, the EV model was found to provide a better fit than the baseline model in 72.6% of cases (mean $G^2 = 13.92$, $SD = 25.78$), supporting the use of EV cognitive parameters (Busemeyer and Stout, 2002).