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Individual Differences in Decision-Making and Reward Processing: An Event-Related Potential Investigation

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ABSTRACT

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Gambling paradigms tapping both reward processing and decision-making tasks in control and patient populations have found differences in behavior based on individual differences in immediate reward representation. The current investigation examined decision-making in individuals who differed on self-reported measures of impulsivity and used event-related potentials (ERPs) to examine the network dynamics of reward and decision-making circuitry among low and high impulsive participants. An inferior frontal component, the anterior P2 (P2a), indexing orbitofrontal cortex (OFC) activity, and a medial frontal negativity (MFN), indexing anterior cingulate cortex (ACC) activity, were measured related to choices made from high-risk and low-risk decks of cards in two modified versions of the Iowa Gambling Task. Results indicated that the P2a indexed reward expectation in a single-presentation version of the Iowa Gambling Task and the MFN indexed evaluation of decisions in a dual-presentation version of the Iowa Gambling Task.
Acknowledgements

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INTRODUCTION

Decisions are made everyday, ranging from what to eat for breakfast to what career path to follow. The decision-making process consists of three main components; the presence of one or more courses of action, expectations about possible outcomes, and the evaluation of consequences of these outcomes (Hastie & Dawes, 2001). Deficits in decision-making among clinical populations illustrate where problems can arise in the decision-making process and what types of behavior can lead to decisions that are not advantageous to the decision-maker. Neuroimaging and neuropsychological studies of decision-making provide insights about the neural networks involved in decision-making and their relationship to reward processing circuitry.

Reward processing is involved in decision-making at both the expectation and evaluation stages. A common approach to studying reward processing in decision-making involves the use of gambling paradigms in which decisions result in some form of monetary reward or punishment. These paradigms have been used in both behavioral and neuroimaging studies of normal participants and neuropsychological and psychiatric patients. However, little research has been done on decision-making and reward-processing using event-related potentials (ERPs). The advantage of ERPs lies in their temporal resolution. Studying decision-making and reward processing using ERPs may provide insight into the time-course of decision-making as well as the neuronal response to rewards resulting from a given decision.
Neural Systems of Reward

Animal models of the neural systems of reward have identified the mesotelencephalic dopamine system, originating in the VTA and projecting widely throughout the limbic system, basal ganglia, and neocortex, as important for processing rewarding properties of stimuli. In particular, the projections to the ventral striatum, including the nucleus accumbens, and ventromedial prefrontal/orbitofrontal cortex are critically involved in reward processing (Cardinal, Parkinson, Hall, & Everitt, 2002; Duffy, 1997; Kalivas & Nakamura, 1999; Rolls, 1999). The ventral striatum represents goals based on input from dopaminergic VTA cells and limbic structures (Robbins & Everitt, 1996; Williams, Rolls, Leonard, & Stern, 1993). The orbitofrontal cortex (OFC) monitors the reward values by representing rewards, updating reward values, and assigning behaviors in response to rewards (Rolls, 2000). Moreover, the medial and lateral OFC differentiate between rewards and punishments in that the medial OFC is more influenced by the receipt of rewards and the lateral OFC is more influenced by the receipt of punishments (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001).

Hemodynamic studies in humans reveal that different brain areas appear to respond differentially to reward properties; some areas merely respond to the presence of reward while other areas index the degree of reward value. In an fMRI study using a rewarding target detection task, the amygdala, striatum and dopaminergic midbrain responded to the presence of reward while the OFC
responded more to minimum and maximum reward values than to midrange reward values and the premotor cortex responded more as reward values increased (Elliott, Newman, Longe, & Deakin, 2003).

Additional animal research has demonstrated that reward processing structures are not only sensitive to reward delivery but also to reward prediction (Schultz, Dayan, & Montague, 1997; Tremblay & Schultz, 1999, 2000). For instance, Schultz et al. (1997) found that when monkeys received an unexpected squirt of juice, dopaminergic activity of the VTA increased to reward delivery. However, after the animals were trained that a cue (such as a light or sound) predicted a reward, the VTA activity increased to the presentation of the predictive cue rather than to the reward itself. In contrast on trials when the expected reward was withheld following a reward-predicting cue, the VTA activity increased at the time of the cue but then decreased below baseline at the time of the expected reward, suggesting that predictability plays an important role in the evaluation of reward and influences dopaminergic activity in the reward system (Schultz et al., 1997).

Further studies have found that OFC neurons in monkeys are also activated in response to reward prediction (Tremblay & Schultz, 1999, 2000). When macaques received rewards for correctly responding in a delayed–response task, activation of OFC neurons was sustained before presentation of the rewards, presumably due to reward expectation. Activation of the OFC neurons appeared to be more sensitive to reward properties, such as
the predictability of reward, than to stimulus properties, such as spatial or visual-feature information (Tremblay & Schultz, 1999).

Predictability of rewards also relates to increased activation of the ventral striatum and OFC in humans. An fMRI study similar to Schultz et al.’s (1997) monkey experiment showed that humans given predictable or unpredictable squirts of juice or water showed larger increases in activation of the NA, thalamus, and medial OFC when the reward was unpredictable than when the reward was predictable (Berns, McClure, Pagnoni, & Montague, 2001). These increases in activity were attributed to the projection of dopamine from the VTA to the activated reward processing regions in ventral striatum and OFC. Further evidence for the release of dopamine to reward processing regions was found in a PET study of humans playing video games in which playing the game activated the release of dopamine to the striatum (Koepp et al., 1998).

Decision-Making and Rewards

Decision-making research offers a unique insight into reward processing by examining outcomes resulting from a participant’s decision. Neural systems involved in decision-making include reward processing areas such as OFC as well as areas involved in emotional coding, working memory, conflict monitoring and response inhibition (Ernst et al., 2002). The majority of the research cited thus far has focused on animal models and studies in which participants received rewards but had little control over their delivery. Research on decision-making
often employs gambling paradigms to simulate the types of complex decisions individuals must make outside the laboratory setting.

*Computerized Gambling Task*

Using a computerized gambling task, R. D. Rogers, Everitt et al. (1999) assessed decision-making by having participants guess whether a token was under a blue or red box on the computer screen. The goal of the task was to earn as many points as possible by choosing correctly and placing bets after each choice. The ratio of blue to red boxes changed from trial to trial allowing for the quality of the decision to be evaluated based on whether participants chose the red boxes, for example, because the red to blue ratio was higher on a given trial. A poor decision on this task occurred when participants chose the color with the lower ratio of boxes. Participants placed bets indicating how confident they were about their decision. Bets were offered in ascending and descending orders allowing for isolation of impulsive behavior (occurring if the first bets offered were consistently chosen regardless of value) from risk taking behavior (occurring if high bets were consistently chosen regardless of whether they were offered first or last). In a PET study, increased cerebral blood flow in the right inferior and orbital prefrontal cortex was found when participants received rewards for choosing correctly, demonstrating that reward processing areas may also be linked to areas important for decision-making (R. D. Rogers, Everitt et al., 1999).
Iowa Gambling Task

Another gambling task, the Iowa Gambling Task developed by Bechara, Damasio, Damasio, and Anderson (1994), involved choosing cards from four decks. Two decks of cards contained high reward/high penalty values whereas the other two decks contained low reward/low penalty values. Choosing primarily from the high reward/high penalty decks resulted in net loss while choosing primarily from the low reward/low penalty decks resulted in net gain. Thus the high reward/high penalty decks were considered disadvantageous whereas the low reward/low penalty decks were considered advantageous. In addition, one of the high reward/high penalty decks and one of the low reward/low penalty decks contained more frequent punishments than the other two decks. Participants were told that the goal of the task was to earn as much money as possible and that they could switch decks as often as they wished, however they were not told how many card selections would be made (1994).

Modifications have been made to the Iowa Gambling Task for implementation in different research paradigms. For instance, the Iowa Gambling Task was modified to investigate differences between guessing and learned performance on a computerized version of the gambling task in a PET study (Ernst et al., 2002). In this study, two experimental and two control blocks were presented in alternation. The first experimental block was considered the guessing task since participants had not yet developed a strategy of card selection, and the second experimental block was considered the learned block
because the participants had performed the task previously and were presumably utilizing knowledge gained from their previous experience with the task. On the control tasks participants chose decks in a fixed sequential order. Results showed activation of decision-making in areas associated with reward such as OFC and prefrontal cortex, as well as, areas involved in emotional coding, working memory, conflict monitoring, and response inhibition. Activation was found predominantly over the right-hemisphere. Moreover differences between the guessing and the learned task included left-lateralized activation of the emotional and sensory processing structures whereas the learned task engaged bilateral activation of memory and motor areas (Ernst et al., 2002).

Other modifications of the Iowa Gambling Task have been made to study affect and approach versus avoidance behaviors in response to each deck by using a single-presentation version of the gambling task. Differences in performance using single-presentation compared to the original task in which all four decks were presented simultaneously included a tendency to choose each card that was presented. Despite high acceptance rates overall, results supported the authors hypotheses regarding individual differences in decision-making showing that participants who demonstrated greater reactivity to negative events based on self-report measures made fewer choices from high-loss decks whereas participants who demonstrated greater reactivity to positive events made more choices from high-gain decks (Peters & Slovic, 2000). These results are encouraging for implementation in the ERP environment because they show
that single-presentation of cards can be employed to study individual differences in decision-making.

Impairments in Decision-Making

Decision-making is thought to be impaired when individuals take a long time to make a decision, do not allocate the proper resources to make the decision, or make decisions that fail to meet their desired goals (Rahman, Sahakian, Cardinal, Rogers, & Robbins, 2001). Decision-making impairments have been studied in frontal lesion patients (Bechara et al., 1994; Bechara, Damasio, Tranel, & Damasio, 1997; Bechara, Tranel, Damasio, & Damasio, 1996; R. D. Rogers, Everitt et al., 1999) and substance dependant patients (Bechara & Damasio, 2002; Grant, Contoreggi, & London, 2000; Kirby, Petry, & Bickel, 1999; Petry, 2001; R. D. Rogers, Everitt et al., 1999). Moreover, impairments in decision-making have also been examined among individuals with no history of neurological or substance abuse problems yet are self-described risk-takers (Bechara & Damasio, 2002).

Frontal Lesions

Decision-making in patients with orbital prefrontal lesions and dorsolateral and dorsomedial prefrontal lesions has been examined using R. D. Rogers, Everitt et al.'s (1999) computerized gambling task. Orbital prefrontal patients showed slower deliberation times and made poor decisions more often compared to controls and to patients with dorsolateral or dorsomedial prefrontal lesions.
However, both patient groups showed a conservative betting pattern indicating little confidence in their decisions (R. D. Rogers, Owen et al., 1999).

Studies using the Iowa Gambling Task have shown that ventromedial prefrontal patients consistently chose cards from the high reward/high punishment decks whereas normal controls and brain injured controls appeared to learn that the low reward/low punishment decks were better in the long run and consistently chose cards from the low reward/low punishment decks (Bechara et al., 1994; Bechara et al., 1997; Bechara et al., 1996). Further investigations revealed that ventromedial prefrontal patients chose more from the high reward/high punishment, disadvantageous decks not due to a hypersensitivity to rewards or a insensitivity to punishments, rather ventromedial prefrontal patients were insensitive to future outcomes (Bechara et al., 1994; Bechara, Tranel, & Damasio, 2000).

Insensitivity to future outcomes among ventromedial prefrontal patients was illustrated by incorporating varying levels of immediate rewards and punishments in each deck of the Iowa Gambling Task. For instance, the advantageous deck was altered to have high immediate punishments but still contained a higher net value whereas the disadvantageous decks contained low immediate punishment values and a lower net value. Despite changes in the immediate and delayed reward and punishment values of both decks ventromedial prefrontal patients primarily chose cards from the disadvantageous decks indicating a decision-making impairment in which patients base decisions
on immediate prospects as oppose to future consequences (Bechara et al., 1994; Bechara, Tranel et al., 2000).

Electrophysiological data demonstrated that ventromedial prefrontal patients like controls produced anticipatory skin conductance responses (SCRs) when rewards or punishments were received suggesting that patients respond in the same way controls did to rewarding and punishing situations (Bechara et al., 1997; Bechara et al., 1996). However, controls began to produce anticipatory SCRs before choosing a card, whereas patients with ventromedial prefrontal damage failed to show any anticipatory SCRs when deciding which deck to choose. Anticipatory SCRs produced among normal controls occurred prior to conscious awareness of which decks yielded higher net gains and indicated a possible unconscious bias towards certain decks (Bechara et al., 1997; Bechara et al., 1996). The absence of such biasing signals among ventromedial prefrontal patients further indicated that these patients may be more sensitive to immediate prospects rather than future outcomes of decisions (Anderson, Bechara, Tranel, Damasio, & Damasio, 1996). This failure to produce a biasing signal may explain the occurrence of inappropriate social behaviors displayed by patients with frontal lobe damage as resulting from an inability to evaluate the goals of a given situation and respond appropriately (Bechara, Damasio, & Damasio, 2000; Damasio, 1998).

Furthermore, poor performance among patients on the Iowa Gambling Task was not a result of working memory impairments (Bechara, Damasio,
Tranel, & Anderson, 1998). A comparison of patients with ventromedial prefrontal lesions to those with dorsolateral/high mesial prefrontal lesions showed that individuals with right dorsolateral mesial lesions were not impaired on the gambling task but were impaired on delay tasks whereas individuals with left dorsolateral mesial lesions were not impaired on either task. In contrast anterior ventromedial lesions resulted in impairment on the gambling task and posterior ventromedial lesions resulted in impairment on both tasks. The presence of impairment on one task but not the other in these patient groups showed a dissociation between working memory and decision-making (Bechara et al., 1998).

**Substance Abuse**

Substance abuse has been defined as persistent drug use regardless of adverse long-term consequences and may be due to decision-making deficits that involve the impairment of advantageous evaluation of future outcomes (Grant et al., 2000). Performance on R. D. Rogers, Everitt et al.’s (1999) computerized gambling task among amphetamine and opiate abusers was marked by increased deliberation times due to altered neuromodulation of the prefrontal circuitry related to substance abuse. In addition, amphetamine abusers performed similarly to patients with orbitofrontal damage by guessing that the token was behind the colored box with the lower ratio of boxes (R. D. Rogers, Everitt et al., 1999).
On the Iowa Gambling Task, some drug abusers performed similarly to ventromedial patients and chose from the high reward/high punishment decks more often than from the low reward/low punishment decks (Bechara & Damasio, 2002; Grant et al., 2000). The poor performance of these subjects, who continue to select cards from disadvantageous decks containing the high-reward “lures”, indicates an overvaluation of immediate reward and a lack of forethought towards future consequences. This pattern of behavior is thought to be due to an impairment in the ventromedial circuitry that is essential to the decision-making process. In addition, substance dependant individuals failed to generate an anticipatory SCR when choosing cards in the Iowa Gambling Task yet did generate SCRs in response to punishment, whereas normal controls generated both anticipatory SCRs and SCRs in response to punishment (Bechara & Damasio, 2002). Studies such as these show that like ventromedial prefrontal patients, drug abusers seem to be enticed by the prospect of a high immediate reward in contrast to looking at long-term outcomes. Similarly, heroin addicts show higher discount rates to delayed rewards, meaning that they prefer a smaller immediate reward as opposed to waiting a week to six months for a larger reward (Kirby et al., 1999).

*Impulsivity*

Described as “acting without thinking” and characterized by rapid responding, reduced sensitivity to punishment, and enhanced sensitivity to immediate rewards (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001),
impulsivity impacts decision-making in both clinical and non-clinical populations. Impulsivity is a personality dimension associated with several psychiatric and personality disorders, including mania and substance abuse (Moeller et al., 2001). Research indicates that individual differences, such as risk-taking and impulsivity, may influence decision-making and has focused on patient populations such as substance dependent individuals who have exhibited high levels of impulsivity (Bechara & Damasio, 2002; Grant et al., 2000) and have scored higher than undergraduate controls on self-report impulsivity measures (Patton, Stanford, & Barratt, 1995; Petry, 2001). Moreover, substance dependant individuals who were also pathological gamblers not only scored higher on impulsivity measures compared to substance dependent individuals who were not pathological gamblers, but also performed more impulsively on the Iowa Gambling Task (Petry, 2001). This result illustrated that individual differences such as impulsivity play an important role in decision-making.

Impulsive and risk taking behaviors can also lead to impaired decision-making among individuals with no history of substance abuse. For instance, individuals who describe themselves as high-risk takers or thrill-seekers performed poorly on the Iowa Gambling Task (Bechara & Damasio, 2002). Thus far, impulsivity and decision-making have been examined predominantly among substance dependant individuals. However, little research has examined decision-making in impulsive individuals with no history of substance dependence. Therefore, the current studies focus on both behavioral and
electrophysiological differences in decision-making among individuals with no history of neurological or substance abuse disorders but who score high or low on a self-report measure of impulsivity.

**ERP Indices of Rewards**

In general, positive feedback has been found to elicit larger P300 amplitudes than negative feedback (Johnson & Donchin, 1985). Previous ERP studies on reward processing and monetary incentives indicate that P300 amplitudes to incentives may index the motivational properties of stimuli (Begleiter, Porjesz, Chou, & Aunon, 1983; Ramsey & Finn, 1997). Specifically, large rewards elicited larger P300 amplitudes than small rewards (Begleiter et al., 1983; Ramsey & Finn, 1997). In addition, individuals with a no family history of alcoholism produced enhanced P300 amplitudes to incentive properties whereas individuals with a family history of alcoholism did not show this enhancement due perhaps to deficits in neural systems of motivation (Ramsey & Finn, 1997).

However, the P300 is modulated by numerous stimulus and task attributes other than task-relevance (Wijers, Mulder, Gunter, & Smid, 1996) and appears to emanate from a variety of different brain structures, not including the OFC (Halgren, Marinkovic, & Chauvel, 1998; Johnson, 1993; R. L. Rogers et al., 1991; Ruchkin, Johnson Jr., Canoune, Ritter, & Hammer, 1990; Tarkka & Stokic, 1998).

A prefrontal positivity, prior to the P300, has recently been described, variously called the anterior P2 (P2a) (Potts & Tucker, 2001), frontal P3 (P3f) (Makeig et al., 1999), and Frontal Selection Positivity (FSP) (Anillo-Vento, Luck, &
Hillyard, 1998; Kenemans, Kok, & Smulders, 1993). The frontal positivity is enhanced if the presented stimulus meets criterion for a target, based on a single feature (Anllo-Vento et al., 1998; Potts & Tucker, 2001) or a conjunction of features (Kenemans et al., 1993). Unlike the P300, the P2a is responsive to task-relevant stimuli only, not to relatively rare but irrelevant items (Potts, Liotti, Tucker, & Posner, 1996). Makeig et al. (1999) hypothesized that the frontal positivity indexes activity in a frontal-parietal network involved in the organization of a motor response. However, the frontal positivity has also been observed in silent count tasks, where there is no overt motor response (Potts et al., 1996). Dipole modeling has localized the P2a to medial orbitofrontal cortex (Potts, Patel, & Azzam, 2004). Given the localization and psychological responsiveness of the P2a, we hypothesize that it indexes activity in the orbitofrontal target of the VTA dopaminergic reward system, and activity is related to the integration of motivational information, including expected reward value, with perceptual representations to identify task-relevant items (Potts et al., 1996; Potts et al., 2004; Potts & Tucker, 2001). Moreover, the P2a has been found to show differential activity to rewarding stimuli among high and low impulsive participants. Specifically, the P2a is more responsive to reward prediction among high impulsive individuals than among low impulsive individuals (Martin & Potts, submitted).

The error-related negativity (ERN) is also responsive to rewards. The response-locked ERN or NE occurs about 100 ms after a response execution
and is marked by a negative deflection. ERN amplitudes are larger during error trials than correct trials (Gehring, Goss, Coles, Meyer, & et al., 1993) and are attributed to cognitive operations of detecting errors (Scheffers, Coles, Bernstein, Gehring, & Donchin, 1996). Dipole models have localized the ERN to the anterior cingulate cortex (ACC) in both its electroencephalographic and magnetoencephalographic forms (Dehaene, Posner, & Tucker, 1994; Gehring & Knight, 2000; van Veen & Carter, 2002). Holroyd and Coles (2002) have presented a model that explicitly links the ERN to the action of the mesencephalic dopamine system on the ACC in comparing the expected reinforcing value of an action with the reward actually acquired so that ongoing behavior can be modified.

The ERN may not be responding simply to the detection of error, but instead may assess the motivational impact of a response. In particular, a component in the same location as the ERN known was the medial frontal negativity (MFN) showed a greater sensitivity to errors on trials resulting in monetary loss as oppose to errors on trials that would have resulted in monetary gain if correct and has been dipole-modeled to the ACC. Moreover, the MFN can occur in the absence of an error when participants receive losses as oppose to gains in an incentive paradigm (Gehring & Willoughby, 2002). Few studies have examined how impulsivity affects neural measures of reward processing.
ERP Indices of Impulsivity

The most common ERP finding in impulsivity is a reduction in the P300 (Moeller et al., 2001). For instance, increases in impulsivity are accompanied by decreases P300 amplitudes (Harmon-Jones, Barratt, & Wigg, 1997). These amplitude changes are thought to reflect a deficit in general cognitive efficiency. Furthermore, the ERN responds differentially to signals of reward and punishment and varies with impulsivity in that high impulsive individuals produced larger ERNs when errors were made to rewarding trials whereas low impulsive individuals produced larger ERNs when errors were made to punishing trials during an incentive flanker task (Potts, George, Martin, & Barratt, submitted). These results demonstrated that high impulsive individuals are more sensitive to errors resulting in lack of reward compared to errors resulting in punishment.

Current Studies

The current experiments used modified versions of the Iowa Gambling Task to present alternative choices that differed in immediate and long-term reward value. The experiments used ERPs to assess the expectation and evaluation stages of decision-making in high and low impulsive participants. The P2a component was expected to serve as the index of OFC networks of expectation, and the MFN was expected to serve as the index of ACC networks of evaluation. The P300 was examined as an index of the motivational properties of stimuli. Impulsivity differences were expected to reflect an
enhanced sensitivity to immediate reward among high impulsive participants compared to low impulsive participants.

Specifically, the P2a was expected to show larger amplitudes to cards from low-risk decks for low impulsive participants, due to the net gain associated with these decks, and to cards from the high-risk deck for high impulsive participants, due to the immediate reward values associated with these decks. Moreover, the P2a was expected to show larger amplitudes to rewarding feedback among both low and high impulsive participants, however this difference between rewarding and punishing feedback was expected to be larger for high impulsive participants. Increases in P2a amplitudes associated with deck and feedback presentation were expected to become more pronounced as trials progressed in that P2a amplitudes were expected to be larger on later trials compared to early trials within blocks. For example, the P2a was expected to be largest among low impulsive participants when the low-risk deck was presented on the final trials in a block compared to the first trials in a block. In contrast, the P2a was expected to be largest among high impulsive participants when the high-risk deck was presented on the final trials in a block compared to the first trials in a block.

Low impulsive, but not high impulsive, participants were expected to show larger MFN amplitudes when choices were made from the high-risk deck compared to the low-risk deck. Moreover, the MFN was expected to show larger differentiation between decks among low impulsive participants as they learned
that net loss was associated with choosing primarily from the high-risk deck. This learning pattern was expected to produce the largest MFN amplitudes for low impulsive participants when cards were chosen from the high-risk deck on the final trials within any given block. MFN amplitudes for high impulsive participants were expected to show little, if any, differentiation between decks. Moreover, if MFN amplitudes were different to choices made from the high-risk compared to low-risk deck, they were expected to be larger when choices were made from the low risk deck due to relatively low immediate reward values.

The P300 was expected to produce larger amplitudes among low impulsive participants compared to high impulsive participants. Moreover, the P300 was expected to respond to the motivational properties of the decks in that amplitudes were expected to be largest to low-risk deck presentation among low impulsive participants and high-risk deck presentation among high impulsive participants. Overall, P300 amplitudes were expected to be larger to rewarding than punishing feedback. In addition, rewarding feedback was expected to produce larger P300 amplitudes for high impulsive participants compared to low impulsive participants due to increased sensitivity to reward among high impulsive individuals.
EXPERIMENT 1

The current design utilized a single-presentation version of the Iowa Gambling Task to reduce lateral eye-movements that could contaminate the EEG data. Before implementing the paradigm in the ERP environment, Experiment 1 was run to verify that the modifications described in detail below yielded similar behavioral patterns to those of the original gambling task. Expected behavioral patterns included more choices from low-risk than high-risk decks as well as interactions between choices and levels of self-reported impulsivity.

Method

Participants

Thirty-eight Rice University undergraduate psychology students (ages 18-24) participated for course credit and were divided into high and low impulsive groups based on a median split of Barratt Impulsivity Scale scores (BIS-11) (Patton et al., 1995) (median BIS = 64.5; high group: mean BIS = 71.58, SD = 4.30; low group: mean BIS = 58.37, SD = 4.64). The BIS-11 is a 30-item self-report scale in which participants rate statements such as “I do things without thinking” and “I am restless at lectures and talks” on a 4-point scale ranging from 1 = “Rarely/Never” and 4 = “Almost Always”. Scores were calculated by summing all responses. Scores could range from 30-120 with high scores indicating high levels of impulsivity. Comparisons of the BIS-11 scores between groups revealed that the groups were significantly different, t (36) = 9.098, p < .0001. Participants were run in groups of up to 15 participants at a time. All
participants gave informed consent prior to participation and were debriefed on the nature of the experiment following completion of the task.

Task

The current study utilized a single-card presentation version of the Iowa Gambling Task in which a card back from one of two decks was presented during each trial. Participants were informed that the goal of the task was to earn as much money as possible during each experimental block. A total of five blocks were presented in which the two decks varied in color and design in an attempt to minimize expectations of the reward and loss values associated with any given deck from one block to the next. In each block one deck was considered low-risk containing a relatively low reward value ($0.75) and small to moderate loss values ($0.05-1.00) and the other deck was considered high-risk containing a higher reward value ($1.25) and moderate to large loss values ($0.75-2.25). Each deck contained equal numbers of reward and loss cards, which had a constant reward value and five levels of loss increasing in $0.25 increments for the low-risk deck and $0.50 increments for the high-risk deck. The deck values were based on the frequent loss decks of the original Iowa Gambling Task.

Participants were presented with the back of one card on each trial and were asked to accept or decline the presented card by pressing a key on the response pad. Response keys were counterbalanced across participants. If participants accepted the card a screen followed stating how much they won or lost on that trial as well as their current total. However, if the participant declined
the card a screen followed showing that no reward or punishment had been added or subtracted to his/her total. Fifty cards from each deck were presented randomly in all five blocks. Participants were told that 100 cards would be presented per block and their goal was to maximize their earnings during each block. Participants began with $10 in their bank and their total was reset to $10 at the beginning of each block. No real money was given in the behavioral pilot.

During each trial the card presented stayed on the screen until the participant made a decision, then a fixation appeared for 1000 ms followed by a feedback screen. Feedback consisted of the current trial’s winnings plus the participant’s current total for the block. The feedback screen stayed on until the participant pressed a key to initiate the next trial. Figure 1 illustrates an example trial. A total of ten decks of cards were developed for the task and varied in one of five designs and shades of green, blue, purple, orange and red. The decks were counterbalanced so that no two decks of the same color were advantageous or disadvantageous in more than one block of the task. Card designs and colors are shown in Appendix A.

*Individual Differences Measure*

After completing the computerized gambling task, participants filled-out the BIS-11 (Patton et al., 1995) to assess levels of impulsivity.

*Stimulus Presentation and Response Collection*

All stimulus presentation and behavioral response collection was controlled by a Dell Pentium III computer running E-Prime 1.0 (PST, Pittsburgh)
Figure 1. Example trial for single-presentation version of the Iowa Gambling Task used in Experiments 1 and 2.
<table>
<thead>
<tr>
<th>Display</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>1000 ms</td>
</tr>
</tbody>
</table>

Collects Response

| +       | 1000 ms  |

+0.75 \( \text{$5.75$} \)

Participant Initiates Next Trial
in Windows 98. Stimuli were presented on a Dell 17-inch monitor. Data were collected at Rice University’s Behavioral Research Lab.

Data Analysis

A repeated-measures ANOVA with Deck (low-risk, high-risk) and Choice (accept, decline) as within factors and Impulsivity (low, high) as a between factor was used to assess the behavioral patterns of low and high impulsive participants. A second repeated-measures ANOVA added trial (early, late) as a within subject factor in which the first 50 trials were compared to the last 50 trials to examine learning patterns within blocks. A final repeated-measures ANOVA examined learning across blocks by adding block (block 1, block 2, block 3, block 4, block 5) as a within subject factor to the first ANOVA.

Results

Experiment 1 results did not show significant differences in card choice between high and low impulsive participants. However, a main effect of choice showed that participants accepted more cards than they declined, $F (1, 36) = 20.519, p < .001$ (Figure 2a). A Choice x Deck interaction, $F (1, 36) = 8.120, p < .01$ (Figure 2b), showed that participants accepted more cards from the low-risk than the high-risk deck. The additional ANOVAs examining learning patterns revealed that a greater percentage of cards were accepted on early trials within each block compared to late trials, $F (1, 36) = 12.253, p < .01$ (Figure 2c), and as the blocks progressed fewer cards were accepted per block, $F (4, 144) = 8.403, p < .001$ (Figure 2d).
Figure 2. Experiment 1 behavioral results: a) main effect of Choice showing more cards accepted than declined, b) Choice x Deck interaction showing that more cards accepted from the low-risk deck compared to the high-risk deck, c) Choice x Trial interaction showing that a larger percentage of cards accepted on early compared to late trials within blocks, and d) Choice x Block interaction showing that more cards accepted on early blocks compared to late blocks.
Discussion

The results showed participants chose more from low-risk decks than the high-risk decks, as did control subjects in the original Iowa Gambling Task (Bechara et al., 1994). In addition the results were similar to the previous single-presentation version of the Iowa Gambling Task in which participants accepted more cards than they declined (Peters & Slovic, 2000). The current version of the task also elicited a behavioral strategy in which participants accepted more cards overall on early trials within each block and on early blocks. This strategy indicated that as the trials progressed participants accepted fewer cards in order to avoid frequent punishments associated with cards from both the high- and low-risk decks. Interactions between decisions and impulsivity were not present perhaps due to the way groups were separated using a median split in which some individuals in the low impulsive group scored only 1-2 points below those in the high impulsive group. Moreover, the lack of real money earned during the task may have dampened possible impulsivity differences.
EXPERIMENT 2

Despite the lack of significant behavioral impulsivity differences in the Experiment 1 an ERP version of the experiment was run to see if significant differences in EEG signals, which may be more sensitive, were present regardless of the presence of behavioral differences. Modifications made to the ERP version of the task are discussed below.

Method

Participants

Twenty Rice University undergraduate psychology students (ages 18-22) participated for course credit and were divided into high and low impulsive groups based on a median split of BIS-11 scores (Patton et al., 1995) (median BIS = 65; high group: 6 female, mean age = 20.2, SD = 1.32, mean BIS = 72.9, SD = 5.86; low group: 3 female, mean age = 19.8, SD = 1.03, mean BIS = 59.4, SD = 7.04). The groups were significantly different based on BIS-11 score, t(18) = 4.6601, p < .001. Six participants (4 low impulsive, 2 high impulsive) were excluded from the ERP analysis to feedback presentation due to eye movement and eye blink artifact in the EEG signal. All participants were briefed on the nature of EEG acquisition and provided informed consent prior to participation.

Task

The task described for the Experiment 1 was implemented in the ERP environment with a few minor changes. In the ERP task participants played for real money. Specifically participants were informed at the beginning of the task
that they would be rewarded the highest amount won on an individual block at the end of the experiment. For example, if a participant earned $20 on Block 3 and less than $20 on all other blocks, the participant was given $20 at the end of the experiment. If a participant's total on all blocks was less than the $5 participants started with in their bank at the beginning of each block, then they were given $5 at the end of the experiment.

Other modifications included the addition of five neutral cards to each deck, as well as an additional block of trials. The neutral cards were added as catch trials that yielded neither reward nor punishment when chosen. The extra block was added due to the addition of two decks that were black in color. These decks were added so that the color combinations of decks and designs could be counterbalanced across subjects. See Appendix B for color combinations and designs used in Experiment 2.

*Individual Differences Measure*

As in the Experiment 1, impulsivity was measured using the BIS-11 (Patton et al., 1995).

*Stimulus presentation and behavioral response collection*

All stimulus presentation and behavioral response collection was controlled by E-Prime 1.0 (PST, Pittsburgh). Visual stimuli were presented on an Apple 15" flat-panel active matrix Studio display to reduce 60 - 75 Hz monitor refresh electrical noise associated with CRT displays. Manual responses were
collected with a 4-key microswitch keypad (Electrical Geodesics, Inc., Eugene, OR).

Subjects sat in an adjustable chair with their chin in a chinrest. The chinrest was placed so that subjects' eyes were 50 cm from the center of the flatpanel screen. The chair was adjusted for comfort. Subjects were instructed to remain as still as possible, with their eyes on the fixation mark, throughout the experimental trials. Subjects were asked to refrain from blinking as much as possible while the stimuli appeared. Breaks were provided after each block so that participants could rest their eyes.

*Behavioral Data Analysis*

Behavioral analysis for Experiment 2 was the same as that described for the Experiment 1.

*EEG Data Acquisition and ERP Data Analyses*

EEG data was acquired with a 128 channel Electrical Geodesics system (Electrical Geodesics, Inc., Eugene) and continuously referenced to the vertex with .1 - 100 Hz analog filtering and digitized at 250 Hz. The EGI Geodesic Sensor Net is a lightweight elastic thread structure containing plastic pedestals. Each pedestal contains a silver/silver chloride electrode housed in a synthetic sponge. The sponges were soaked in a saline solution to render them conductive. Application of all 128 channels took approximately 15 minutes.

EEG data was digitally filtered at 20 Hz lowpass to remove residual high-frequency noise and segmented off-line into 1000 ms epochs spanning 200 ms
before the stimulus to 800 ms after the stimulus for comparisons of the stimulus-
locked P2a and P300 to the presentation of the card as well as the presentation
of the feedback. In addition, EEG data was segmented off-line in 1000 ms
epochs spanning 500 ms before and after the response for analysis of the
response-locked MFN. Data was digitally screened for artifact (eye blinks or
movements, subject movement, or transient electronic artifact) and contaminated
trials were removed. Remaining data was sorted by response, deck, and/or
reward value and averaged to create the ERPs. Averaged ERP data was
baseline corrected over the 200 ms prestimulus period and re-referenced into an
average reference frame to remove topographic bias due to choice of reference
site (Dien, 1998). The subject-averaged ERPs were averaged together to
produce mean waveforms across subjects.

Visual inspection of the waveforms identified the temporal windows (See
Table 1) and region of interest (ROI) groupings of left/right pairs of electrodes
(See Appendix C). The mean amplitudes within each temporal window from the
appropriate ROI (inferior prefrontal for the P2a, centroparietal for the P300,
medial frontal for the MFN) were extracted from the subject-average ERPs and
cast into repeated-measures ANOVAs with Deck (high-risk, low-risk) as a within
factor and Group (high impulsive, low impulsive) as a between factor for analysis
to the presentation of the card and response. Outcome (reward, punish) was
added as a within factor for analysis to the presentation of the feedback (the
neutral condition was not included in analysis due to low trial counts). ERP
analysis was done only on cards accepted in each condition due to the small number of declined cards. Learning patterns were not examined due to low trial counts of accepted cards on late trials. Waveform plots were created from the grandaverage of the ROI averaged channels.

Table 1

*ERP Temporal Windows for Experiment 2*

<table>
<thead>
<tr>
<th>ERP Component</th>
<th>Card</th>
<th>Feedback</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2a</td>
<td>250-350 ms</td>
<td>300-375 ms</td>
<td>N/A</td>
</tr>
<tr>
<td>P300</td>
<td>300-370 ms</td>
<td>300-500 ms</td>
<td>N/A</td>
</tr>
<tr>
<td>MFN</td>
<td>N/A</td>
<td>N/A</td>
<td>135-179 ms</td>
</tr>
</tbody>
</table>

Results

*Behavioral Results*

The behavioral results showed the same pattern as the Pilot results with a greater number of cards accepted than declined, F (1, 17) = 47.247, p < .001 (Figure 3a), and Choice x Deck interaction, F (1, 17) = 5.988, p < .05, revealed that more cards were chosen from the low-risk deck than the high-risk deck (Figure 3b). In addition an interaction of Choice x Trial x Impulsivity was found, F (1, 17) = 4.932, p < .05, demonstrating that low impulsive individuals accepted fewer cards on late trials (trials 56-110) than on early trials (trials 1-55), t (9) =
Figure 3. Experiment 2 behavioral results: a) main effect of Choice showing that more cards accepted than declined, b) Choice x Deck interaction showing that more cards accepted from the low-risk deck compared to the high-risk deck, and c) Choice x Trial x Impulsivity showing that low impulsive participants accepted more cards on early trials compared to late trials within blocks.
2.602, p < .05, whereas high impulsive individuals chose similarly on early and late trials (Figure 3c). No significant differences were found across blocks.

**ERP Results**

*Card Presentation*

*P2a.* Segmentation of the EEG data around the presentation of the card resulted in significant differences of the P2a. A Deck x Laterality x Impulsivity interaction revealed the expected pattern over the left hemisphere with a larger P2a amplitude to the high-risk deck among high impulsive individuals and a larger P2a amplitude to the low-risk deck among low impulsive individuals, $F(1, 18) = 5.242, p < .05$ (Figures 4 and 5).

*P300.* The P300 resulted in a trend towards lower amplitudes for high impulsive compared to low impulsive participants, $F(1, 18) = 4.137, p = .06$ (Figure 6), however, no significant differences were found based on deck type.

*Feedback Presentation*

*P2a.* No significant differences were found in analysis of the P2a to the delivery of feedback.

*P300.* Feedback presentation resulted in a trend towards an Outcome x Impulsivity interaction in which P300 amplitudes for high impulsive participants were larger to rewarding feedback than punishing feedback and showed little differentiation between type of feedback for low impulsive participants, $F(1, 15) = 4.179, p = .06$ (Figure 7).
Figure 4. Experiment 2 P2a to card presentation; a) P2a waveform stimulus-locked to card presentation and averaged over inferior frontal left and right ROIs for low and high impulsive participants.
Figure 5. P2a interaction plot showing predicted pattern over the left ROI with largest P2a amplitude to the high-risk deck presentation for high-impulsive participants and to the low-risk deck presentation for low-impulsive participants.
Figure 6. Experiment 2 P300 to card presentation: a) P300 waveform stimulus-locked to card presentation and averaged over central parietal ROI for low and high impulsive participants, b) P300 interaction plot showing trend towards a main effect of impulsivity with larger P300 amplitudes among low impulsive compared to high impulsive participants.
a) P300 waveforms to card presentation

Low Impulsive

High Impulsive

μV

ms

High-Risk

Low-Risk

b) P300 interaction to card presentation

μV

Low Impulsive

High Impulsive
Figure 7. Experiment 2 P300 to feedback presentation: a) P300 waveform stimulus-locked to feedback presentation and averaged over central parietal ROI for low and high impulsive participants, b) P300 interaction plot showing larger P300 amplitudes to rewarding compared to punishing feedback among high impulsive participants and little differentiation between rewarding and punishing feedback among low impulsive participants.
a) P300 waveforms to feedback presentation

**Low Impulsive**

![Graph showing P300 waveforms for Low Impulsive subjects with different feedback presentations.]

**High Impulsive**

![Graph showing P300 waveforms for High Impulsive subjects with different feedback presentations.]

b) P300 interaction to feedback presentation

![Bar graph showing the interaction of P300 with feedback presentation for Low and High Impulsive subjects.]

- Low-Risk Punish
- Low-Risk Reward
- High-Risk Punish
- High-Risk Reward
Response

MFN. No significant effects of impulsivity or deck were found for the MFN.

Discussion

Behavioral results of the ERP version demonstrated that, overall, participants accepted more cards than they declined. In addition, the strategy of accepting fewer cards as trials progressed was present only among the low impulsive participants illustrating that the low impulsive individuals made attempts to change their responses to increase earnings on each block by accepting fewer cards on later trials, thus avoiding punishment from either the low or high-risk deck.

As predicted, ERP results demonstrated that the P2a did differentiate between impulsivity in a decision-making task in that P2a amplitudes increased to high-risk deck presentation among high impulsive participants and increased to the low-risk deck presentation among low impulsive participants. However, this P2a response pattern was present only over the left hemisphere. The left lateralization of the P2a is consistent with group analyses of neuroimaging studies showing left-lateralized activity in reward processing areas when monetary rewards are involved (Delgado, Nystrom, Fissell, Noll, & Fiez, 2000; Koepp et al., 1998; O'Doherty et al., 2001; Thut et al., 1997; Warren et al., 1984). Therefore, the laterality effect in the current study was likely due to the presence of monetary rewards, however further examination of this effect in ERPs is needed to draw firm conclusions.
A trend in the P300 amplitude was consistent with previous research showing a reduction in P300 amplitude among individuals rated as high impulsive based on self-report measures (Harmon-Jones et al., 1997). This reduction was thought to demonstrate an overall reduction in efficiency of cognitive processing among highly impulsive individuals. Moreover, the P300 to feedback resulted in a trend illustrating larger P300 amplitudes to rewarding compared to punishing feedback for high impulsive but not low impulsive participants. This trend was consistent with previous research showing increased P300 amplitudes to motivational properties of stimuli (Begleiter et al., 1983; Ramsey & Finn, 1997) and that high impulsive participants have an enhanced sensitivity to reward and reduced sensitivity to punishment.

The current study, however, failed to produce the expected enhanced MFN among low-impulsive participants to choices made from the high-risk deck. The lack of an MFN effect in the current study may be due to the nature of the decisions made in the single-presentation version of the Iowa Gambling Task in which participants are deciding whether to accept or decline the presented card. The decision in the single-presentation version of the Iowa Gambling Task was different than that in the original task in which participants had to choose a card from low-risk versus high-risk decks. The absence of MFN differences to deck presentation indicated that the MFN was responding not to the quality of decision made, tapped by the net gains and losses associated with each deck, rather the MFN was responding to the decision-making process associated with the current
task, accept versus decline. Therefore MFN predictions should have been made in regards to accepting and declining cards rather than whether the cards come from the low- or high-risk decks. However, the behavioral results of the current study demonstrated that participants accepted more cards than they declined. Due to this acceptance bias few decline trials were present to compare decisions to accept versus decline cards and an adequate decision evaluation, indexed by the MFN, could not be examined.

Despite promising P2a results to the presentation of cards, the single-presentation methodology used in Experiment 2 produced problems in analyzing the ERP data. Individual variation in response patterns made some comparisons difficult due to a lack of trials in all the conditions. For instance, only accepted trials could be analyzed due to low rates of declined cards. In addition, the behavioral strategy used by the low impulsive participants, who declined more cards as trials progressed, made comparisons of ERP components on early versus late trials difficult due to low trial counts. Therefore, further modifications were made and a follow-up ERP study attempted to sort out the laterality interactions of the single-presentation version and increase trial counts for each condition allowing for comparisons of early and late trials. Furthermore, the decision was changed from accept/decline to a forced choice between decks to elicit an MFN response to the decision.
EXPERIMENT 3

A dual card presentation version of the Iowa Gambling Task, in which both decks were presented simultaneously, was used in Experiment 3 yielding a forced choice between decks. This design was avoided originally due to the possibility of lateral eye movements, to minimize lateral eye movements a fixation cross was placed between the two decks and participants were instructed to keep their eyes on the fixation throughout the experiment.

Method

Participants

Twenty-nine Rice University undergraduate psychology students (ages 18-21) participated for course credit. One participant was excluded from analysis due to familiarity with the Iowa Gambling Task, which resulted in selections primarily from the low-risk deck on all trials. In addition, two participants were excluded from all analyses, one participant (1 low impulsive) was excluded from the ERP response-locked analysis, and two participants (1 low impulsive, 1 high impulsive) were excluded from feedback-locked analyses due to eye movement and eye blink artifact in the EEG signal. The remaining participants were divided into high and low impulsive groups based on a median split of BIS-11 scores (Patton et al., 1995) (median BIS = 60.5; high group: 8 female, mean age = 19.0, SD = 1.08, mean BIS = 71.6, SD = 7.11; low group: 3 female, mean age = 19.3, SD = 1.03, mean BIS = 55.3, SD = 2.59). The groups were significantly different based on BIS-11 scores, t (24) = 7.7662, p < .0001. All participants were briefed
on the nature of EEG acquisition and provided informed consent prior to participation.

*Task Modification*

During the task, cards from each deck were presented simultaneously to the right and left of a fixation mark. Presentation of cards within each deck and position of each deck to the left or right of the fixation mark was randomized across trials. Participants chose cards by pressing the corresponding left or right key on the response pad. Both decks were presented and stayed on the screen until the participant made a decision, then a fixation appeared for 1000 ms followed by a feedback screen. The feedback screen for Experiment 3 was the same as in Experiments 1 and 2 and stayed on until the participant pressed a key to initiate the next trial. Figure 8 illustrates an example trial. Six blocks of 100 trials were presented to participants. Payoff rates and card colors and designs were the same as in Experiment 2 (Appendix B).

*Individual Difference Measure*

As in the Experiment 1 and Experiment 2 impulsivity was measured using the BIS-11 (Patton et al., 1995).

*Stimulus Presentation and Behavioral Response Collection*

Stimulus presentation and response collection was the same as that described for Experiment 2.
Figure 8. Example trial for dual-presentation version of the Iowa Gambling Task used in Experiment 3.
<table>
<thead>
<tr>
<th>Display</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>1000 ms</td>
</tr>
</tbody>
</table>

Collects Response

+0.75  
($5.75)$  
Participant Initiates Next Trial
Behavioral Data Analysis

Choice patterns were analyzed in a repeated measures ANOVA with deck (low-risk, high-risk) as the within factor and Impulsivity (low, high) as the between factor. A second repeated-measures ANOVA added trial (early, late) as a within subject factor in which the first 50 trials were compared to the last 50 trials to examine learning patterns within blocks. A final repeated-measures ANOVA examined learning across blocks by adding block (block 1, block 2, block 3, block 4, block 5) as a within subject factor to the first ANOVA.

EEG Data Acquisition and ERP Data Analyses

EEG acquisition was identical to that used in Experiment 2. Visual inspection of the waveforms identified the temporal windows (See Table 2) and region of interest (ROI) groupings of left/right pairs of electrodes (See Appendix D). The mean amplitudes within each temporal window from the appropriate ROI (inferior prefrontal for the P2a, centroparietal for the P300, medial frontal for the MFN) were extracted from the subject-averaged ERPs and cast into repeated-measures ANOVAs with Deck (high-risk, low-risk) as a within factor and Group (high impulsive, low impulsive) as the between factor for analysis to card presentation and response. Outcome (reward, punish) was added as a within factor for analysis to the presentation of feedback (the neutral condition was not included in analysis due to low trial counts). Additional ANOVAs were run to examine learning patterns within blocks by adding Trial (early trials 1-50, late trials 51-100) and to examine learning patterns across blocks by adding block
(early blocks 1-3, late blocks 4-6) as within factors. Waveform plots were created from the grandaverage of the ROI averaged channels.

Table 2

**ERP Temporal Windows for Experiment 3**

<table>
<thead>
<tr>
<th>ERP Component</th>
<th>Card</th>
<th>Feedback</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>P2a</td>
<td>220-270 ms</td>
<td>255-320 ms</td>
<td>N/A</td>
</tr>
<tr>
<td>P300</td>
<td>240-430 ms</td>
<td>250-400 ms</td>
<td>N/A</td>
</tr>
<tr>
<td>MFN</td>
<td>N/A</td>
<td>N/A</td>
<td>80-125 ms</td>
</tr>
</tbody>
</table>

Results

**Behavioral Results**

No significant behavioral effects were found. However, the pattern of deck choices was similar to that in both the Experiment 1 and Experiment 2 showing that the low-risk deck was chosen more often than the high-risk deck, \( F(1, 24) = 2.116, p = .16 \).

**ERP Results**

**Card Presentation**

\( P2a \). No significant main effects of deck or interactions with impulsivity were found for the \( P2a \). However, the \( P2a \) was larger overall when cards were chosen from the high-risk deck on early trials and larger when cards were chosen from the low-risk deck on late trials, \( F(1, 26) = 7.640, p < .05 \) (Figure 9).
Figure 9. Experiment 3 P2a to card presentation: a) P2a waveform stimulus-locked to card presentation and averaged over inferior frontal ROI for low and high impulsive participants, b) P2a interaction plot showing larger P2a amplitude to card presentation when cards were chosen from the high-risk compared to the low-risk deck on early trials.
a) P2a waveforms to card presentation

Low Impulsive

High Impulsive

b) P2a interaction to card presentation
**P300.** The P300 did not show a main effect of impulsivity. However, the P300 did show a Deck x Impulsivity interaction in which the P300 was greater for high-risk choices made by low impulsive participants and low-risk choices made by high impulsive participants, \( F(1, 26) = 7.6, p < .05 \) (Figure 10). Further analysis revealed that the P300 was significantly larger when cards were chosen from the low-risk deck compared to when cards were chosen from the high-risk deck among high impulsive individuals, \( t(13) = 2.270, p < .05 \), however significant differences were not found between the low-risk and high-risk deck choices among the low impulsive individuals.

**Feedback Presentation**

**P2a.** Segmentation around the feedback resulted in larger P2a amplitudes to feedback from the high-risk deck compared to feedback from the low-risk deck, \( F(1, 17) = 7.323, p < .05 \) (Figure 11), and to rewarding compared to punishing feedback, \( F(1, 17) = 5.388, p < .05 \) (Figure 11).

**P300.** The P300 was greater to rewarding compared to punishing feedback, \( F(1, 17) = 11.163, p < .01 \) (Figure 12).

**Response**

**MFN.** A trend towards a main effect of Impulsivity was found for the MFN in which low-impulsive participants produced and enhanced MFN, \( F(1, 23) = 3.695, p = .07 \). Moreover, a Deck x Impulsivity interaction showed that the MFN for low impulsive participants differentiated between decks with a larger MFN
Figure 10. Experiment 3 P300 to card presentation: a) P300 waveform stimulus-locked to card presentation and averaged over central parietal ROI for low and high impulsive participants, b) P300 interaction plot showing larger amplitudes of card presentation when cards were chosen from the high-risk compared to low-risk deck among low impulsive participants and when cards were chosen from the low-risk compared to high-risk deck among high impulsive participants.
a) P300 waveforms to card presentation

**Low Impulsive**

![Graph showing P300 waveforms for Low Impulsive individuals with Low-Risk and High-Risk groups.

**High Impulsive**

![Graph showing P300 waveforms for High Impulsive individuals with Low-Risk and High-Risk groups.

b) P300 interaction to card presentation

![Bar graph showing P300 responses for Low-Risk and High-Risk groups in Low Impulsive and High Impulsive conditions.](image)
Figure 11. Experiment 3 P2a to feedback presentation: a) P2a waveform stimulus-locked to feedback presentation and averaged over inferior frontal ROI for low and high impulsive participants, b) P2a interaction plot showing main effect of Deck in which P2a amplitudes are larger to feedback from the high-risk compared to low-risk deck and a main effect of Outcome in which P2a amplitudes are larger to rewarding compared to punishing feedback.
a) P2a waveforms to feedback presentation

Low Impulsive

High Impulsive

b) P2a interaction to feedback presentation

Deck Main Effect

Outcome Main Effect
Figure 12. Experiment 3 P300 to feedback presentation: a) P300 waveform stimulus-locked to feedback presentation and averaged central parietal ROI for low and high impulsive participants, b) P300 interaction plot showing a main effect of Outcome in which P300 amplitudes are larger to rewarding than punishing feedback.
a) P300 waveforms to feedback presentation

Low Impulsive

High Impulsive

μV

-300 0 200 400 600 800

Low-RiskPunish
Low-RiskReward
High-RiskPunish
High-RiskReward

b) P300 interaction to feedback presentation
when cards were chosen from the high-risk deck compared to when cards were chosen from the low-risk deck, $F(1, 23) = 5.474, p < .05$ (Figure 13).

Discussion

The results from Experiment 3 showed no behavioral effects and did not show the expected interactions of a P2a differentiation of deck and impulsivity to card presentation. Main effects of deck and outcome to feedback presentation showed significant P2a differences. P2a amplitudes were larger to rewarding feedback, as well as, feedback from high-risk deck selections. These results support findings that the P2a indexes task relevance (Martin & Potts, submitted; Potts et al., 1996; Potts et al., 2004; Potts & Tucker, 2001) in that rewards were relevant in maximizing wins throughout the task and feedback to high-risk cards was relevant due to high reward possibilities associated with this deck. Note, however, interpretations of amplitude differences of the P2a to card presentation should be taken cautiously. As seen in Figure 6, the amplitude differences among low impulsive participants on early presentations of the low-risk deck are not specific to the P2a temporal window and may be due to artifact.

The P300 also showed a main effect of outcome with larger amplitudes to rewarding than punishing feedback which supported the role of the P300 as an index of motivational properties of stimuli (Begleiter et al., 1983; Ramsey & Finn, 1997). However to card presentation, the P300 interaction of Deck x Impulsivity was in the opposite direction of the original predictions of P300 responsiveness to card presentation. The prediction that the P300 would be larger to the low-risk
Figure 13. Experiment 3 MFN to response: a) MFN waveform response-locked and averaged over medial frontal ROI for low and high impulsive participants, b) MFN interaction plot showing the largest MFN amplitude to the when cards are chosen from the high-risk deck for low impulsive participants.
a) MFN waveforms

Low Impulsive

High Impulsive

- High-Risk
- Low-Risk

b) MFN interaction

Low-Risk
High-Risk
Low Impulsive
High Impulsive
deck for low impulsive individuals, due to the net gain associated with the low-risk deck, and larger to the high-risk deck for high impulsive individuals, due to the larger reward values associated with the high-risk deck, was based on findings that the P300 indexed motivational properties of stimuli (Begleiter et al., 1983; Ramsey & Finn, 1997). The present P300 results fit Donchin’s context updating hypothesis in which the P300 is associated with updating one’s model of the environment. Predictions of this theory suggest that P300 amplitudes should be influenced by the amount of adjustment that must be made to one’s model (Donchin & Coles, 1988).

In the present experiment participants had to update their model of decision-making based on feedback to choices made from each deck. The P300 results indicated that low-impulsive participants must update their decision-making model more when cards are chosen from the high-risk deck than the low-risk deck whereas high-impulsive individuals must update their model more when cards are chosen from the low-risk deck than the high-risk deck. Therefore, the P300 in the dual-presentation deck indexed the decision-making model that was operating when decisions must be made to card presentation. Low impulsive individuals had to make larger adjustments to their decision-making models when cards are chosen from the high-risk deck due to the net loss associated with this deck, whereas high impulsive individuals had to make larger adjustments to their decision-making models when cards are chosen from the low-risk deck due to the lower reward value associated with this deck.
The MFN on the other hand indexed the predicted motivational values of the stimuli in that low impulsive individuals showed enhanced MFN amplitudes when choosing cards from the high-risk deck compared to the low-risk deck. MFN differentiation of the decks however was not present among high impulsive individuals. These results support accounts that the MFN or ERN reflects not merely error-processing but also motivational aspects related to response (Bush, Luu, & Posner, 2000; Gehring & Willoughby, 2002). Moreover, the present MFN results among low impulsive individuals is reminiscent of the SCR findings on the original Iowa Gambling Task in which control subjects produced SCRs prior to choosing cards from the disadvantageous deck (Bechara et al., 1997). Thus the MFN may index somatic markers related to deciding advantageously among low impulsive individuals and indicate that these biasing signals may not be present during the decision-making process for high impulsive individuals.
GENERAL DISCUSSION

Animal models of reward processing and human neuroimaging studies indicate that reward processing involves the release of dopamine and activation of the OFC to rewards as well as reward prediction. Few studies however have examined differential activations of reward systems due to individual differences in a normal population. The current group of exploratory studies investigated reward processing and decision-making in modified versions of the Iowa Gambling Task utilizing ERPs. Decision-making literature reveals that the neural circuitry of decision-making involves areas associated with reward processing (Ernst et al., 2002). ERP components of reward processing include the P2a, which responds differentially to reward prediction among high and low impulsive individuals (Martin & Potts, submitted) and has an estimated neural source in the OFC (Martin & Potts, submitted; Potts et al., 2004), the P300, which responds differentially to large versus small rewards (Begleiter et al., 1983), and the MFN, which responds differentially to errors resulting in loss (Gehring & Willoughby, 2002).

Overall, the current studies indicated that the P2a, P300, and MFN respond differentially to signals of reward among high and low impulsive participants performing a decision-making task, however, the single-presentation and dual-presentation versions of the Iowa Gambling Task used in the current studies did not elicit the same ERP responses. For instance, the single-presentation version resulted in a left-lateralized differentiation of the P2a in
which high impulsive participants showed larger P2a amplitudes to the presentation of high-risk decks where as low impulsive participants showed larger P2a amplitudes to presentation of the low-risk decks. On the other hand, the dual-presentation version, which did not show a P2a differentiation between impulsivity groups, yielded a larger MFN amplitude when choices were made from the high-risk deck for low impulsive but not high impulsive participants. Differences in the cognitive demands of each task may be responsible for these results.

The single-presentation task required participants to simply accept or decline the presented card, whereas the dual-presentation task required participants to choose one deck over the other. Decisions to accept or decline in Experiment 2 resulted in more decisions to accept than decline indicating that accepting the card was perhaps an automatic decision and did not behaviorally differ as a function of impulsivity. Thus ERP results during the single-presentation task dealt primarily with the motivational aspects of card presentation rather than the decision-making processes of what cards to choose since stimulus-locked ERP components, P2a and P300, but not response-locked ERP components, MFN, showed significant differences between low and high impulsive participants. On the other hand, the decisions to choose one card over the other in the dual-presentation task required a decision be made based on the characteristics of each deck and allowed for examination of the response-locked ERP component, the MFN. The ERP results to the dual-presentation were
perhaps more indicative of decision-making strategies, as indexed by the MFN, than motivational characteristics associated with the card decks, as indexed by the P300 and P2a to card and feedback presentations due to forced choice decision made in the dual-presentation task.

ERP Indices of Motivation

The current results support findings that the P2a indexes task-relevant and motivational aspects of stimuli (Martin & Potts, submitted; Potts et al., 1996; Potts et al., 2004; Potts & Tucker, 2001). A left-lateralized P2a pattern found to card presentation in the single-presentation task indicated that high impulsive individuals place greater relevance on the high reward values associated with the high-risk deck whereas low impulsive individuals place greater relevance on the overall net-gain associated with the low-risk deck. This result showed a differentiation between deck types as the participant made a decision to accept or decline the presented card. However, variability in participant choice made comparisons of learning patterns among high and low impulsive participants difficult due to a behavioral strategy used by low impulsive participants who chose fewer cards on late trials to avoid punishment.

The dual-presentation task did not show P2a differentiation between high and low impulsive participants due to inherent differences in the type of decision that had to be made in Experiment 3. However, the dual-presentation task allowed for the comparison of early versus late trials and revealed larger P2a amplitudes to card presentations that led to choices from the high-risk deck on
early trials. Interestingly, this result demonstrated that the motivational properties of a stimulus change over time. Specifically, the P2a differentiated between decks on early trials most likely due to the high-reward values associated with the high-risk deck, however, after receiving high punishments from this deck the P2a amplitude no longer differentiated between decks.

Although Experiment 3 did not demonstrate impulsivity differences in responsiveness of the P2a to motivational aspects of card presentation, differences in P2a responsiveness did vary as a function of feedback. For instance, the dual-presentation task, elicited P2a responses to feedback in which rewarding feedback resulted in larger amplitudes than punishing feedback and feedback from the high-risk deck resulted in larger amplitudes than feedback from the low-risk deck. These results support a task-relevance function of the P2a by demonstrating differentiation between rewarding and punishing feedback as well as differentiation between feedback to high-risk and low-risk choices.

The P300 also indexed motivational aspects of stimuli as found in previous studies (Begleiter et al., 1983; Ramsey & Finn, 1997), however, motivational differences were found to feedback rather than card presentation. These results showed a trend during the single-presentation task in which amplitudes were larger to rewarding feedback compared to punishing feedback for high impulsive participants indicating enhanced sensitivity to reward and reduced sensitivity to punishment among high impulsive participants. Moreover, the dual-presentation task elicited larger P300 amplitudes to rewarding than
punishing feedback. These results are consistent with previous findings that the P300 produces larger amplitudes to positive compared to negative feedback (Johnson & Donchin, 1985).

**ERP Indices of Decision-making**

Experiment 2 did not show differences in ERPs directly related to decision-making due to the accept/decline decisions that were inherent in the task, and ERP comparisons of accept versus decline decisions could not be investigated due to relatively few trials during which participants declined cards. However, Experiment 3 was able to investigate ERPs related to decision-making. Specifically the MFN and P300 demonstrated differential response patterns among impulsivity groups. Low impulsive participants, but not high impulsive participants, showed enhanced responsiveness of the MFN when cards were chosen from the high-risk deck which was demonstrated by larger amplitudes to high-risk decisions.

In addition the P300 demonstrated differential responsiveness to deck type among both low and high impulsive groups supporting Donchin’s theory of context updating (Donchin & Coles, 1988). In particular, the P300 indicated that high-impulsive individuals made larger adjustments in the their decision-making model following choices from the low-risk deck, whereas low impulsive individuals made larger adjustments to their decision-making model following choices from the high-risk deck. Adjustments to decision-making models in Experiment 3 reflected decisions made that could potentially challenge the
participants' views of what card selections would be most advantageous to their goals. Previous research supports these findings in that goals for high impulsive individuals are related to immediate reward values (Moeller et al., 2001) whereas goals for low impulsive individuals are related to net gains.

Limitations

Despite promising differences in ERP indices of motivation and decision-making, behavioral differences in card selection were not apparent as a function of impulsivity with the exception of a learning strategy in which low impulsive individuals accepted less cards on late compared to early trials in Experiment 2. Group similarity may be responsible for the lack of behavioral results. By using a median split on an unscreened sample of normal college undergraduates to group low impulsive individuals and high impulsive individuals, some participants in the low impulsive group differed from some individuals in the high impulsive group by only a few points on their BIS-11 scores. ERP indices therefore appear to be a more sensitive measure than behavioral indices of decision-making when comparing individual differences between similar groups of individuals drawn from a normal population.

Conclusions

Taken together, results of the single- and dual-presentation tasks add to decision-making literature by indicating that individual differences among college students influence reward-based decision-making at an electrophysiological level. In the absence of significant behavioral differences between choice
patterns of high and low impulsive participants, the P2a, MFN, and P300 revealed potential differences in reward processing and decision-making circuitry. The P2a to card presentation in Experiment 2 and feedback presentation in Experiment 3 indexed motivational properties of stimuli thus tapping the reward expectation stage of decision-making. Experiment 3 revealed that the MFN more directly indexed decision-making and was enhanced only for the low impulsive group thus tapping the evaluation stage of decision-making. The P300 on the other hand indexed both motivational properties and decision-making processes in that the P300 responded to motivational aspects related to feedback presentation and responded to decision-making properties related to card presentation in Experiment 3. Further studies should attempt to untangle the influences of individual differences on decision-making by developing a task that can elicit both the P2a and MFN responses in decision-making.
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Appendix A

Stimuli for Experiment 1
Appendix B

Stimuli for Experiments 2 and 3
Appendix C

ROIs for Experiment 2

- ● Inferior Frontal ROI
- ○ Medial Frontal ROI
- ■ Central Parietal ROI
Appendix D

ROIs for Experiment 3

- Inferior Frontal ROI
- Medial Frontal ROI
- Central Parietal ROI