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# Impulsivity in decision-making: An event-related potential investigation

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ABSTRACT

Impulsive individuals make risky choices, motivated more by immediate reward than potential long-term negative consequences. We used event-related potentials (ERPs) to study the impact of reward and punishment sensitivity in impulsivity on risky decision-making in a two-card choice task in groups of 14 high and 14 low impulsive undergraduates formed by a median split on the Barratt Impulsiveness Scale score. The high impulsives had a larger P3 and the low impulsives a smaller P3 to the cards when making a low-risk choice suggesting that the high-risk option was the default choice of the high impulsives and the low-risk choice the default for the low impulsives. The low, but not the high impulsives had a larger error-related negativity (ERN) following high-risk choice indicating that the low impulsives evaluated the risky choice as a poor decision. The results indicate that high impulsive individuals are biased towards immediate reward during option evaluation but are less sensitive to the negative consequences of their choices.



## 1. Introduction

Impulsive individuals make risky decisions, choosing immediate rewards despite potential long-term negative consequences (Moeller, Barratt, Dougherty, Schmitz, & Swann, 2001). Decision-making consists of multiple operations including option evaluation and actions and outcome monitoring. The current study used event-related potentials (ERPs) in a two-card forced choice task between high- and low-risk/reward options in participants separated into high and low impulsive groups based on a median split on Barratt Impulsiveness Scale score (BIS-11; Patton, Stanford, & Barratt, 1995) to examine impulsivity related differences during the option evaluation and action and outcome monitoring stages of decision-making.

### 1.1. Impulsivity

Impulsivity is a personality dimension described as "acting without thinking" and is associated with several psychiatric and personality disorders including mania, substance abuse, and antisocial personality disorder (Moeller et al., 2001). Impulsive individuals make risky decisions, motivated more by immediate reward rather than by the potential long-term negative consequences of their choices, suggesting heightened sensitivity to reward and/or reduced sensitivity to negative outcomes (Ainslie, 1975). Impulsivity may be a multidimensional construct, including a lack of behavioral inhibition and selection of immediate rewards. One two-factor impulsivity model identified a reward-related approach factor and a disinhibition related rash impulsivity factor (Dawe, Gullo, & Loxton, 2004) while a three-factor model identified disinhibition, reward delay discounting, and a cognitive dimension as factors (Dom, De Wildea, Hulstijnb, & Sabbeb, 2007). Gray's biologically based personality model has two similar factors: a behavioral inhibition system (BIS) that organizes behavior in response to aversive events and reward based behavioral activation system (BAS) (Gray, 1982). Gray (1987) linked impulsivity to an over-reactive BAS resulting in increased reward sensitivity, and later work linked impulsivity to both a hyperreactive BAS and hyporeactive BIS (Corr, 2002).

### 1.2. Studying risky choice experimentally

In the Iowa Gambling Task (IGT; Bechara, Damasio, Damasio, & Anderson, 1994), participants choose a card from one of four decks, two high-risk/reward and two low-risk/reward. Choosing primarily from the high-risk decks results in occasional large wins but a net loss while the low-risk choice results in net gain. Frontal lesion patients, substance abusers, and self-described risk-takers choose impulsively on the IGT, selecting more from the high-risk decks, presumably lured by the high-win cards, whereas control participants learn to choose primarily from the low-risk decks (Bechara, Dolan, & Hindes, 2002; Bechara et al., 1994). ERP decision designs often employ fewer options, usually two or three (e.g. Gehring & Willoughby, 2002; Holroyd, Larsen, & Cohen, 2004).

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### 1.3. ERP indices of decision-making

ERP decision- related components include the P3 and the error-related negativity (ERN). The P3 is a centroparietal positivity approximately 300–400 ms post-stimulus most commonly associated with expectation violation (e.g. Courchesne, Hillyard, & Galambos, 1975; Donchin & Coles, 1988) and is also larger to motivationally salient and rewarding outcomes (Begleiter, Porjesz, Chou, & Aunon, 1983; Martin & Potts, 2004; Yeung & Sanfey, 2004).

The ERN is a frontocentral negativity occurring about 100 ms after an incorrect response (Gehring, Goss, Coles, Meyer, & Donchin, 1993) thought to index either error detection (Scheffers, Coles, Bernstein, Gehring, & Donchin, 1996) or response conflict (Gehring & Fencsik, 2001). Holroyd and Coles (2002) proposed that the ERN reflects reward system activity comparing expected reward from an action with the reward actually received to optimize the motivation value of behavior.

If the participant does not know the correct response there is no ERN at motor execution, rather the ERN is elicited to feedback signaling the error. As the individual learns the task the ERN shifts from the feedback to the action (Nieuwenhuis, Yeung, Holroyd, Schurger, & Cohen, 2004). An ERN can also occur in the absence of an error when a choice yields a reward that is less than the best available outcome (Gehring & Willoughby, 2002).

### 1.4. ERPs and impulsivity

Impulsive individuals have smaller and slower P3s compared to control subjects (Harmon-Jones, Barratt, & Wigg, 1997; Moeller et al., 2001), effects often seen in mental and neurological disorders (Polich & Herbst, 2000), sometimes interpreted as indexing general cognitive impairment. P3 amplitude is negatively correlated with BIS-11 score in cocaine dependent participants (Moeller et al., 2004) and impulsive aggressive prison inmates and college students (Barratt, Stanford, Kent, & Alan, 1997; Gerstle, Mathias, & Stanford, 1998). Impulsive individuals also differ on early sensory and attention-related components, having smaller P1s and larger N1s indicating reduced gating and enhanced orienting (Houston & Stanford, 2001).

ERN findings in impulsivity indicate impaired behavior monitoring and reward bias. Participants who respond impulsively (faster with more errors) have smaller ERNs (Pailing, Segalowitz, Dywan, & Davies, 2002) as do individuals with borderline personality disorder and those who score high on externalizing personality (de Bruijn et al., 2005; Hall, Bernat, & Patrick, 2007), interpreted as reflecting reduced behavior monitoring efficiency and cognitive control. Impulsive individuals have larger ERNs when a reward violates their expectation, suggesting greater reward sensitivity (Martin & Potts, 2004). Impulsive individuals and low socialized individuals, individuals more likely to be impulsive, have smaller ERNs on punishment compared to reward motivated trials, suggesting reduced punishment sensitivity (Dikman & Allen, 2000; Potts, George, Martin, & Barratt, 2006).

Prior studies used simple attention or choice reaction time designs to elicit differential ERP responses in impulsivity. While these ERP responses index cognitive operations involved in decision-making, to our knowledge there have been no studies that examine the impact of impulsivity on these ERP components in the context of risky choice.

### 1.5. The current study

The current study used ERPs to investigate the impact of impulsivity on option evaluation and action and outcome monitoring during risky decision-making. Participants chose cards from one of two decks where one deck contained occasional large wins but consistently choosing from that deck would result in overall loss while the other deck contained smaller individual win values but would result in overall gain. We predicted that high impulsives would be more neurally sensitive to reward during evaluation of the choice options, indexed by the card-related P3, and less sensitive to risky choice during action monitoring, indexed by the ERN. Visual inspection of the waveforms also revealed apparent differences in the attention-related N1 to both the card and feedback so those were also analyzed.

## 2. Methods

### 2.1. Participants

Rice University's Institutional Review Board approved the procedures and participants provided informed consent. Twenty-eight Rice University students were divided into high and low impulsive groups by median split of BIS-11 score (median BIS = 59.5; high group: $n = 14$, female = 8, mean age = 19.1, SD = 1.2, mean BIS = 70.8, SD = 7.5; low group: $n = 14$, female = 3, mean age = 19.2, SD = 1.0, mean BIS = 55.1, SD = 2.2) (note that there was an unequal distribution of subject sex between groups but there were no significant differences for sex on any measures). Six low impulsive and three high impulsive participants were excluded from the feedback-locked analysis due to artifact.

### 2.2. Task and stimuli

Stimuli were presented and behavioral responses collected using E-Prime (PST, Inc., Pittsburgh, PA). Each trial began with 1000 ms of fixation followed by simultaneous presentation to the right and left of a high- and a low-risk card differentiated by back design and color. The location of the high- and low-risk cards and the payoff amount were randomized across trials. Participants chose a card by pressing a left or right key after which feedback appeared reporting the trial outcome and the running total for the block (the feedback followed the response by 25–40 ms, the 15 ms variation due to when in the monitor refresh cycle the response occurred). The feedback screen stayed on until the participant initiated the next trial. The low-risk deck contained a relatively low reward value ($0.75) and low to moderate loss values (−$0.05, −$0.25, −$0.75, −$1.00, and −$1.25), and the high-risk deck contained a higher reward value ($1.25) and moderate to high loss values (−$0.75, −$1.25, −$1.75, −$2.25, −$2.75). Each deck also contained neutral cards yielding neither win nor loss. There were six blocks of 100 trials each. Participants were instructed to maximize their winnings but were not informed about the nature of the decks. The card backs changed each block so participants had to relearn which deck was high- and low-risk. Participants began with $5 and their total was reset to $5 at the beginning of each block. Participants were paid the highest amount won on any block or $5, whichever was greater.

### 2.3. Behavioral analysis

Reaction time was analyzed by repeated-measures ANOVA with Choice (high-risk, low-risk) as the within factor and Group (high impulsive, low impulsive) as the between factor. Choice pattern was also analyzed with Net Choice (number of low-risk selections minus number of high-risk selections) and Group as factors. We also included trial within block, divided into five bins with Time (T1 = trials 1–20, T2 = trials 21–40, etc.), and Block (blocks 1–6) to examine learning rates.