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Research report

Individual differences in impulsive and risky choice: Effects of environmental rearing conditions

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HIGHLIGHTS

- Moderation of individual differences by early rearing environment was examined.
- There were substantial individual differences in all tasks.
- Individual differences were correlated across several tasks.
- Isolation rearing increased impulsive choice, locomotion, and PR break points.
- Monoamine concentrations were correlated with multiple behavioral indices.

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ABSTRACT

The present experiment investigated early-rearing environment modulation of individual differences in impulsive and risky choice. Rats were reared in an isolated condition (IC; $n = 12$), in which they lived alone without novel stimuli, or an enriched condition (EC; $n = 11$), in which they lived among conspecifics with novel stimuli. The impulsive choice task involved choices between smaller-sooner (SS) versus larger-later (LL) rewards. The risky choice task involved choices between certain-smaller (C-S) versus uncertain-larger (U-L) rewards. Following choice testing, incentive motivation to work for food was measured using a progressive ratio task and correlated with choice behavior. HPLC analyses were conducted to determine how monoamine concentrations within the prefrontal cortex (PFC) and nucleus accumbens (NAC) related to behavior in different tasks. IC rats were more impulsive than EC rats, but they did not differ in risky choice behavior. However, choice behavior across tasks was significantly correlated (i.e., the more impulsive rats were also riskier). There were no group differences in monoamine levels, but noradrenergic and serotonergic concentrations were significantly correlated with impulsive and risky choice. Furthermore, serotonin and norepinephrine concentrations in the NAC significantly correlated with incentive motivation and the timing of the reward delays within the choice tasks. These results suggest a role for domain general processes in impulsive and risky choice and indicate the importance of the NAC and/or PFC in timing, reward processing, and choice behavior.

1. Introduction

Individual differences in impulsive and risky behaviors have been identified as predictors of substance abuse and pathological gambling (e.g., [7,14,18,58]). Impulsive and risky choice have also been identified as potential trait variables, showing test-rest reliability statistics in the range of other personality variables in human participants [36,38,46,52–55,60]. In addition, stable individual differences in impulsive choice have been reported in rats across different choice parameters, suggesting that impulsive choice may also serve as a trait variable in rats [25,28,73].

Impulsive choice is often defined as the choice for smaller-sooner (SS) over larger-later (LL) rewards (e.g., [1]), while risky choice is often defined as the choice for uncertain-larger (U-L) over certain-smaller (C-S; e.g., [37]) rewards. The fact that both impulsive and risky choice behaviors are risk factors in similar problem

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behaviors suggests the possibility of shared underlying processes. In addition, both impulsive and risky choice can be accounted for by the hyperbolic discounting equation, $V = A/(1 + kX)$, where V is the subjective value of reward and A is the amount of reward [47,48,65]. In impulsive choice, X is the delay to reward, which decreases the value of a reward as delay increases, thus leading to the discounting of reward value with delay. In risky choice, X is the odds against receiving the larger risky reward, which leads to the discounting of probabilistic rewards. In both cases, k is the discounting rate which determines the effect of delay or probability on subjective value and serves as an individual difference parameter.

Despite the similar patterns of impulsive and risky choice, and their shared correlation with other behaviors, there is surprisingly little research examining their interrelationship. The few examinations that have been undertaken have revealed inconsistent results, with weak to moderate correlation patterns in individual differences in impulsive and risky choice behavior in humans [5,51,60,69], and moderately strong correlations in pigeons [41].

Neurobiological studies have indicated partial overlap in the substrates involved in impulsive and risky choice and their component processes of delay, probability, and reward processing (see [20,61,63]). The nucleus accumbens (NAC) and prefrontal cortex (PFC) are involved in both impulsive and risky choice [3,13,20,27,50,61,63,75], as are dopamine (DA) and serotonin (5-HT) levels [10,12,16,22,81,86]. Therefore, given the shared neural mechanisms of impulsive and risky choice, one would expect to observe behavioral correlations as well.

Peters and Büchel [60] proposed that domain general and specific processes contribute to impulsive and risky choice. Domain-general reward processes emerge from the NAC and PFC, and involve shared processes related to the overall valuation and incentive salience of rewards. Domain-general processes should result in comorbidities of impulsive and risky choice. On the other hand, domain-specific processes are involved in the determination of task-specific information. In impulsive choice, delay is a task-specific factor, whereas probability is specific to risky choice. Magnitude is involved in both of these tasks and would produce some shared task variance (although magnitude would still be considered domain specific as it would not contribute to other choice tasks such as effort discounting or social discounting). Given that domain-general processes participate in both tasks, coupled with the involvement of reward magnitude processing in both impulsive and risky choice, one would expect to observe robust correlations in individual differences in impulsive and risky choice. Accordingly, the present study sought to further assess the presence of these correlations in individual rats.

One variable that has been shown to participate in impulsive and risky choice, dopaminergic and serotonergic function, and neural functioning within the NAC and PFC is the post-weaning rearing environment [9,34,39,59,66,82–84,87]. The differential rearing paradigm has typically compared rats raised in an isolated condition (IC) and an enriched condition (EC; [67,72]). EC rats are housed with other rats and novel objects, whereas IC rats are housed individually without novel objects. The present study sought to determine whether these extreme rearing conditions would interact with individual differences in impulsive and risky choice. If rearing conditions moderate individual differences, then this could provide a potential route for the development of future interventions to decrease impulsive and risky choice behaviors, as well as providing some further understanding of mechanisms of impulsive and risky choice.

Accordingly, the goal of the present report was to investigate the moderation of individual differences in impulsive and risky choice by differential rearing, examining both the relevant behavioral and neurobiological processes. Despite the effects of differential rearing on brain and behavioral functioning, there has not been, to our knowledge, a comprehensive analysis of an interaction of rearing environment with individual differences. In addition, relatively little is known about the effects of rearing environment on comorbidities of impulsive and risky choice. Therefore, the present study sought to yield further understanding of these processes. We also included measures of timing and reward processing as potential indices of domain-specific processes, and their possible modulation by environmental rearing, relationship with impulsive and risky choice, and correlations with monoamine concentrations.

2. Materials and methods

2.1. Animals

Twenty-four experimentally naïve male Sprague–Dawley rats arrived to the colony at Kansas State University (Manhattan, KS) at 21 days of age (Charles River, Portage, MI). Their housing conditions varied according to their group assignment (see Section 2.3.1). Following rearing, and prior to the onset of behavioral testing, the rats were placed on a restricted diet to achieve 85% of their target weights determined by growth charts obtained from the supplier. During behavioral testing, the rats received part of their daily ration in the form of 45-mg pellets (BioServ, Frenchtown, NJ) that were delivered in the experimental chambers. The rats had free access to water at all times. The colony room was maintained on a 12:12 h reversed light:dark cycle with the lights off at 8 a.m. Several red lamps illuminated the room during the dark cycle.

2.2. Apparatus

2.2.1. Locomotor testing

Environmental rearing is known to produce robust and long-lasting effects on locomotor behavior (e.g., [72]), so this assay assessed the effectiveness of the rearing conditions. Locomotor testing was conducted in an enclosed, novel environment measuring 40.6 cm × 40.6 cm × 40.6 cm. The chamber consisted of Plexiglas walls and plastic flooring that was covered with bedding. The chamber also had a photo beam sensor ring that consisted of a 16 × 16 (x-axis) photocell array that created a detection grid with individual beams spaced 2.5 cm apart (TruScan 2.01, Coulbourn Instruments, Whitehall, PA) and was linked to a personal computer. Photobeam interruptions were recorded every 50 ms. A white-noise generator (~70 dB) was used to mask extraneous sounds.

2.2.2. Operant behavioral testing

The choice and progressive ratio procedures were conducted in 24 identical operant chambers (Med Associates, St. Albans, VT). Each chamber measured 25 cm × 30 cm × 30 cm and was housed inside a ventilated, noise attenuating box measuring 74 cm × 38 cm × 60 cm. The chambers were located in two separate rooms, with 12 chambers in each room. Two levers (ENV-122CM) were situated on either side of the food cup and presses were recorded by a micro-switch. Nose poke keys with cue lights (ENV-119M-1) were located directly above each lever. A magazine pellet dispenser (ENV-203) delivered 45-mg food pellets into the food cup. Water was available through a metal tube located on the lower-center of the back wall, directly opposite the food cup. MED-PC IV controlled the experiment and recorded the time of events with a 2-ms resolution [76].

2.3. Procedure

2.3.1. Environmental rearing

Upon arrival, the rats were pair-housed in standard shoebox cages for two days prior to the initial activity test. They were then randomly assigned to initial groups and their activity levels