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Affective and cognitive mechanisms of risky decision making

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ABSTRACT

The ability to make advantageous decisions under circumstances in which there is a risk of adverse consequences is an important component of adaptive behavior; however, extremes in risk taking (either high or low) can be maladaptive and are characteristic of a number of neuropsychiatric disorders. To better understand the contributions of various affective and cognitive factors to risky decision making, cohorts of male Long-Evans rats were trained in a "Risky Decision making Task" (RDT), in which they made discrete trial choices between a small, "safe" food reward and a large, "risky" food reward accompanied by varying probabilities of footshock. Experiment 1 evaluated the relative contributions of the affective stimuli (i.e., punishment vs. reward) to RDT performance by parametrically varying the magnitudes of the footshock and large reward. Varying the shock magnitude had a significant impact on choice of the large, "risky" reward, such that greater magnitudes were associated with reduced choice of the large reward. In contrast, varying the large, "risky" reward magnitude had minimal influence on reward choice. Experiment 2 compared individual variability in RDT performance with performance in an attentional set shifting task (assessing cognitive flexibility), a delayed response task (assessing working memory), and a delay discounting task (assessing impulsive choice). Rats characterized as risk averse in the RDT made more perseverative errors on the set shifting task than did their risk taking counterparts, whereas RDT performance was not related to working memory abilities or impulsive choice. In addition, rats that showed greater delay discounting (greater impulsive choice) showed corresponding poorer performance in the working memory task. Together, these results suggest that reward-related decision making under risk of punishment is more strongly influenced by the punishment than by the reward, and that risky and impulsive decision making are associated with distinct components of executive function.

1. Introduction

Decisions among options that vary in both their payoffs and their potential for adverse consequences are a consistent feature of everyday life. When faced with such choices, most individuals can weigh the relative risks and rewards associated with the competing options and decide adaptively; however, such choice behavior (henceforth referred to as "risky decision making") may be altered in several neuropsychiatric conditions, such that choices are strongly biased toward or away from "risky" options. For example, high levels of risk taking are present in ADHD and addiction, where they may contribute to some of the adverse outcomes associated with these conditions (Bechara et al., 2001; Drechsler, Rizzo, & Steinhausen, 2008; Ernst et al., 2003; Kagan, 1987). In contrast, abnormally low levels of risk taking (risk aversion) are found in anorexia nervosa and social anxiety ((Butler & Mathews, 1987; Kaye, Wierenga, Bailer, Simmons, & Bischoff-Grethe, 2013; Stanley, 2002) although see (Reynolds et al., 2013)). Hence, a better understanding of the neurobehavioral mechanisms underlying risky decision making may yield benefits across the clinical spectrum.

The current study employed a rat model of risky decision making in which rats make discrete trial choices between a small, "safe" food reward and a large "risky" food reward accompanied by varying probabilities of mild footshock (the "Risky Decision making Task", or RDT). Previous work has shown that male Long-Evans rats display marked individual variability in their preference for the large, risky reward in this task. Some rats show a strong preference for the large reward even with a high probability of shock (i.e., "risk takers"), whereas other rats show a strong

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preference for the small reward even when there is a low probability of shock (i.e., "risk averse") (Simon et al., 2011). These differences in performance are not associated with variability in reward motivation, anxiety, or shock reactivity (Simon, Gilbert, Mayse, Bizon, & Setlow, 2009; Simon et al., 2011). However, rats with a high preference for risk taking acquire cocaine self-administration more rapidly and have lower striatal dopamine D2 receptor mRNA expression than rats with a low preference for risk taking (Mitchell et al., 2014); Simon et al., 2011). Notably, elevated risk taking in humans is associated with both addiction and reduced striatal D2 receptor availability (Bechara et al., 2001; Goldstein et al., 2009; Rogers et al., 1999; Volkow, Fowler, Wang, & Swanson, 2004), supporting the validity of the RDT as a model of human risk taking behavior. The aim of the current study was to assess affective and cognitive mechanisms that may mediate RDT performance, by manipulating the affective value of the RDT task parameters, and by determining associations between risk taking and several measures of executive function. A first cohort of rats was exposed to varying magnitudes of footshock to determine the effects of punishment magnitude on RDT performance. A second cohort was presented with variable numbers of food pellets upon choice of the "risky" option, to determine the effects of reward magnitude on RDT performance. Finally, a third cohort of rats was trained on a set shifting task, a working memory task, the RDT, and a delay discounting task to determine relationships among these different aspects of cognition and decision making.

2. Materials and methods

2.1. Experiment 1: Effects of varying shock or reward magnitude on risky decision making task performance

2.1.1. Subjects

Two cohorts of male Long-Evans rats ($n = 16$ for Experiment 1A, and $n = 8$ for Experiment 1B, 275–300 g on arrival, Charles River Laboratories, Raleigh, NC) were individually housed and kept on a 12 h light/dark cycle (lights on at 0800 h) with free access to food and water except as noted. Prior to the start of behavioral testing, rats were reduced to 85% of their free feeding weights over the course of five days, and maintained at this weight for the duration of the experiment, with allowances for growth. Animal procedures were conducted from 0800 to 1700, and were approved by the University of Florida Institutional Animal Care and Use Committee and followed NIH guidelines.

2.1.2. Apparatus

Testing was conducted in standard behavioral test chambers (Coulbourn Instruments, Whitehall, PA) housed within sound-attenuating isolation cubicles. Each chamber was equipped with a recessed food pellet delivery trough fitted with a photobeam to detect head entries and a 1.12 W lamp to illuminate the food trough, which was located 2 cm above the floor in the center of the front wall. Forty-five mg grain-based food pellets (PJAI, Test Diet, Richmond, IN) could be delivered into the food trough. Two retractable levers were located to the left and right of the food trough, 11 cm above the floor. A 1.12 W house light was mounted on the rear wall of the isolation cubicle. The floor of the test chamber was composed of steel rods connected to a shock generator that delivered scrambled footshocks. Locomotor activity could be assessed throughout each session with an infrared activity monitor mounted on the ceiling of the test chamber. This monitor consisted of an array of infrared detectors focused over the entire test chamber. Movement in the test chamber (in x, y, or z planes) was defined as a relative change in the infrared energy falling on the different detectors in the array. Test chambers were interfaced with a computer running Graphic State 3 software (Coulbourn Instruments), which controlled task event delivery and data collection.

2.1.3. Behavioral procedures

2.1.3.1. Shaping. On the day prior to shaping, each rat was given five 45 mg food pellets in its home cage to reduce neophobia to the food reward used in the task. Shaping procedures followed those used previously (Cardinal, Robbins, & Everitt, 2000; Simon, Mendez, & Setlow, 2007; Simon et al., 2009). Following magazine training, rats were trained to press a single lever (either the left or the right, balanced across rats; the other lever was retracted during this phase of training) to receive a single food pellet. After reaching a criterion of 50 lever presses in 30 min, rats were then trained on the opposite lever under the same criterion. This was followed by further shaping sessions in which both levers were retracted and rats were shaped to nose poke into the food trough during simultaneous illumination of the trough and house lights. When a nose poke occurred, a single lever was extended (left or right), and a lever press resulted in immediate delivery of a single food pellet. Immediately following the lever press, the trough light was extinguished and the lever was retracted. Rats were trained to a criterion of 30 presses on each lever within 60 min.

2.1.3.2. Risky decision making task. In the RDT, rats made discrete trial choices between two response levers, one which delivered a small reward, and the other which delivered a large reward accompanied by varying risks of footshock. Testing procedures were identical to Simon et al. (2009) and Mitchell, Vokes, Blankenship, Simon, and Setlow (2011). In brief, sessions were 60 min in duration and consisted of 5 blocks of trials. Each 40 s trial began with a 10 s illumination of the food trough and house lights. A nose poke into the food trough extinguished the trough light and triggered extension of either a single lever (forced choice trials) or both levers simultaneously (free choice trials). If rats failed to nose poke within the 10 s time window, the lights were extinguished and the trial was scored as an omission. A press on one of the levers (either left or right, balanced across rats) resulted in one food pellet (the small safe reward) delivered immediately following the lever press. A press on the other lever resulted in immediate delivery of 3 food pellets (the large reward). Selection of this lever was also accompanied by a possible 1 s footshock (0.30 mA).

Risk of footshock was contingent on a preset probability specific to each trial block. The "risky" reward was delivered following every choice of this reward lever, regardless of whether or not the footshock occurred. The probability of footshock accompanying the large reward was set at 0% during the first block of trials. In subsequent blocks of trials, the probability of footshock increased to 25%, 50%, 75%, and 100%. Each trial block began with 8 forced choice trials (4 for each lever, used to establish the punishment contingencies in effect for that block) followed by 10 free choice trials. Once either lever was pressed, both levers were immediately retracted. Food delivery was accompanied by re-illumination of both the food trough and house lights, which were extinguished upon entry to the food trough to collect the food or after 10 s, whichever occurred sooner. On the forced choice trials (in which only one lever was present) the probability of shock following a press on the large reward lever was dependent across the four trials in each block. For example, in the 25% risk block, one and only one of the four large reward forced choice trials (randomly selected) always resulted in shock, and in the 75% risk block, three and only three of the four large reward forced choice trials always resulted in shock. In contrast, the probability of shock on the free choice trials (in which both levers were present) was independent, such that the probability of shock on each trial was the same, irrespective of shock delivery on previous trials in that block.

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