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Delay discounting predicts binge-eating in Wistar rats☆

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ABSTRACT

Multiple measures of impulsivity predict both obesity and binge-eating disorder; however, those who binge-eat represent a behaviorally distinct subset of all overweight individuals. In the current experiment, 10 male Wistar rats completed three conditions in counterbalanced order: (a) impulsivity assessed with a delay discounting task; (b) binge-eating measured by consumption of intermittently available Oreo cookies; and (c) diet-induced obesity proneness measured by weight gain when provided with a sweet high-fat diet *ad libitum* for 2 consecutive weeks. Impulsivity predicted binge-eating but not diet-induced obesity, and binge-eating and proneness to diet-induced obesity were unrelated to each other. The current data represent the first time binge-eating behavior has been associated with impulsivity in rats and suggest that recent interventions which increase subjects' tendencies to choose larger-later rewards in discounting tasks should be tested for their effects on binge-eating behavior.

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1. Introduction

Impulsivity is a multifaceted trait that can include both positive and negative characteristics. Impulsive individuals have frequently been described as impatient, inattentive, and likely to speak or act without forethought. However, they may also be good at taking advantage of sudden opportunities (Evenden, 1999). Impulsivity can be measured by self-report questionnaires or by behavioral tasks such as delay discounting. Discounting tasks quantify the extent to which small, immediate reinforcers are valued over larger, delayed ones and are useful with both human and non-human subjects (Evenden, 1999; Green et al., 2014).

Both self-reported impulsivity and delay discounting scores have repeatedly been associated with a myriad of undesirable outcomes. For example, the extent to which pathological gamblers discounted hypothetical monetary rewards was related to gambling severity as well as to scores on impulsivity questionnaires (Alessi and Petry, 2003). Eysenck Impulsivity Scale scores were related to gambling onset in low socioeconomic participants (Auger et al., 2010) and to risky sexual behaviors in young women (Kahn et al., 2002).

Considerable research links impulsivity to substance abuse. For example, the Attention and Non-planning subscales of the Barratt Impulsiveness Scale predicted nicotine dependence (Ryan et al., 2013), and total Barratt Impulsiveness scores predicted cocaine and amphetamine cravings (Tziortzis et al., 2011). In a study conducted with cocaine-dependent participants, steeper discounting of hypothetical monetary rewards predicted reduced abstinence from cocaine after treatment (Washio et al., 2011).

Impulsive individuals may not only be more likely to struggle with drug addiction but also with addiction to food. For example, Davis et al. (2011) found that obese participants meeting criteria for food addiction according to the Yale Food Addiction Scale were more impulsive according to discounting and Barratt Impulsivity Scale scores, as well as to performance on a delay of gratification task, when compared to obese controls who did not meet criteria for food addiction. Other research has demonstrated that obese individuals discounted delayed hypothetical monetary rewards more than non-obese individuals (Lawyer et al., 2015), and overweight women who discounted hypothetical monetary rewards most steeply were also most likely to order high-calorie meals from restaurants (Appelhans et al., 2012). In another study, participants' percentages of body fat (but not BMIs) predicted impulsive choices for hypothetical food rewards (Rasmussen et al., 2010). Additionally, a meta-analysis of research on pediatric obesity reported that overweight children were more impulsive (as measured by a combination of behavioral and questionnaire methods) than children who were not overweight (Thamotharan et al., 2013).

Impulsivity has been consistently linked to the development and expression of binge-eating behavior. A recent longitudinal study

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of children demonstrated that impulsivity as measured by negative urgency (*i.e.*, the tendency to act rashly when distressed) combined with depression predicted binge-eating (Pearson et al., 2015). Galanti et al. (2007) found that impulsivity scores on Barratt Impulsiveness Scale predicted both binge-eating self-report scores and test meal intake in overweight adult participants. In a review of studies that examined impulsivity in women with eating disorders, Waxman (2009) found that while individuals who engaged in binge/purge behaviors were impulsive, those who restricted their food intake were not; she suggested that, "bingeing and restricting behaviours may be seen as lying on opposite ends of a spectrum of impulsive behaviours" (p. 416).

Findings from studies on impulsivity in rats resemble those obtained with human participants. For example, rats that discounted food reinforcers most steeply self-administered larger amounts of cocaine (Perry et al., 2005) and alcohol (Poulos et al., 1995) compared to less impulsive rats. Impulsive behavior has recently also been related to obesity in rats; obese Zucker rats selected more small, immediate food reinforcers than lean Zucker rats in a discounting task (Boomhower et al., 2013).

Binge-eating has been studied in laboratory rats (Boggiano et al., 2007) and mice (Czyzyk et al., 2010) by measuring subjects' consumption of intermittently available palatable food. As is the case in humans, binge-eating in rats can occur independently from susceptibility to diet-induced obesity (Boggiano et al., 2007). However, to our knowledge, binge-eating has not been investigated in combination with impulsive behavior in laboratory rodents. The objective of the current study was to examine impulsivity and its relationship to both binge-eating and proneness to diet-induced obesity. Using a sample of Wistar rats, we examined (a) impulsivity measured by performance on a delay discounting task, (b) binge-eating measured by the consumption of periodically available palatable food, and (c) proneness to diet-induced obesity measured by weight gain when fed a sweet, high fat diet *ad libitum*.

2. Methods

2.1. Subjects

Twelve 7-month old male Wistar rats obtained from Simonsen Laboratories (Gilroy, CA) were housed individually and maintained under a 12 h light/dark cycle. Subjects had previously been used in an undergraduate Learning laboratory course in which they were trained by students to lever-press for food reinforcers. All subjects had continuous *ad libitum* access to water; feeding regimens differed by condition and are described below. Experimental procedures were approved by the Institutional Animal Care and Use Committee (UAA IACUC Protocol# 767807).

2.2. Materials and procedure

Subjects completed the following three conditions in a counterbalanced order and were given 5–7 days of *ad libitum* access to Mazuri® Rodent Pellets (PMI Nutrition International, LLC, Brentwood, MO) between conditions.

2.2.1. Delay discounting condition

Two operant conditioning boxes (33 cm × 33 cm × 38 cm) containing two Med Associate (St. Albans, VT) retractable levers (ENV-112CM) each were housed in sound-attenuating chambers. Experimental events were presented and data were recorded by Med Associates software run by an IBM-compatible computer. Reinforcers consisted of 45 mg banana flavored sucrose pellets (Bio-Serv®, Frenchtown, NJ). Subjects were maintained at 85% of their *ad libitum* weights by post-session feedings of Mazuri® Rodent Pellets.

The delay discounting task was based on methods reported by Evenden and Ryan (1999). Subjects completed two phases of training before testing. First, subjects responded on a continuous reinforcement schedule, earning a single pellet reinforcer for each response. The right and left levers were active on alternating days, and subjects continued this training until they had emitted at least 100 responses on each lever in a 20-min session. In the second phase of training, both levers were active, with one lever generating 5 pellet reinforcers while the other produced a single pellet reinforcer. No delays to reinforcement were present during this phase of training, but the 5-pellet lever would become the larger, later lever during testing while the 1-pellet lever would be the smaller, sooner one. For half of the subjects, the larger, later lever was on the left during training and testing, while for the other half, the larger, later lever was on the right. Subjects completed 60 lever-presses per day for a total of 13 days during this phase of training. All 12 subjects rapidly displayed sensitivity to reinforcer magnitude, selecting the 5-pellet lever an average of 91.13% of the time on day 1 (*SEM* = 2.22) and 98.43% of the time on day 13 (*SEM* = 0.29).

During the experiment proper, subjects chose between a single sucrose pellet available immediately and five pellets available after a delay of 0, 10, 20, 40, or 60 s. Subjects were exposed to each delay for 12 consecutive trials per session. After each choice, the levers were retracted until the programmed delay had elapsed and the food pellets were delivered. Following a 20-s intertrial interval, the levers were reinserted for the next trial. Because Evenden and Ryan (1999) used only ascending order, we were concerned about potential carry-over effects from one delay to the next. Additionally, using the same order of delays could potentially confound the interpretation of results due to within-session changes in responding (*e.g.*, McSweeney and Murphy, 2014). Therefore, we counterbalanced the order of the delays for the 5-pellet reinforcers between subjects to be either ascending or descending within the session. Another departure from the Evenden and Ryan (1999) procedure was that we did not conduct challenge days with shorter delays to verify the subjects' sensitivity to changes in the delay of the larger, later reinforcer. The reasons for our departure is because Evenden and Ryan (1996) concluded that rats remain sensitive to changes in delay even after many months of training, suggesting that these challenge days were not needed for the brief discounting procedure used in the current study.

Two subjects (16.7% of the sample) were removed from the experiment due to failure to meet the criterion of choosing the larger later reward even when the delay was 0 s (despite selecting this lever 98.3% and 100% of time at the end of training). Evenden and Ryan (1996) reported 12.5% of their subjects failing to meet the same training criterion when using a similar within-session delay discounting procedure. For the remaining 10 subjects in our study, delay discounting continued until stability with the requirement that each subject completed a minimum of 15 sessions. Responding was considered stable when the choices during the last five sessions on the delayed or immediate lever did not exceed the highest number emitted for the entire condition. If this criterion was not met, more sessions were conducted until responding was deemed stable. All sessions were 90 min long and were conducted 5–6 days per week. The average of the last five sessions for each delay was used for data analyses.

2.2.2. Binge-eating condition

Binge-eating was measured using a method adapted from Boggiano et al. (2007). Subjects had *ad libitum* access to Mazuri Rodent Pellets throughout this condition. Additionally, Double Stuf Oreo cookies were provided every five days. Subjects had access to the cookies for 24 h; however, as Boggiano and colleagues found that differences between binge-eating prone and binge-eating resistant rats were greatest after 4 h, we measured subjects' cookie

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