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Demand for sucrose in the genetically obese Zucker (*fa*/*fa*) rat

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ABSTRACT

Obese Zucker rats (*fa*/*fa*) eat more food than lean controls in free-feeding conditions, which strongly influences their phenotypic expression. Few studies, however, characterize their food consumption in environments that are more representative of foraging conditions, e.g., how effort plays a role in food procurement. This study examined the reinforcing efficacy of sucrose in obese Zucker rats by varying the responses required to obtain single sucrose pellets. Male Zucker rats (15 lean, 14 obese) lever-pressed under eight fixed ratio (FR) schedules of sucrose reinforcement, in which the number of lever-presses required to gain access to a single sucrose pellet varied from 1 to 300. Linear and exponential demand equations, which characterize the value of a reinforcer by its sensitivity to price (FR), were fit to the number of food reinforcers and responses made. Free food consumption was also examined. Obese Zuckers, compared to leans, consumed more food under free-feeding conditions. Moreover, they had higher levels of consumption and response output, but only at low FR values. Both groups were equally sensitive to price increases at higher FR values. This suggests that environmental conditions may interact with genes in the expression of food reinforcer efficacy.

1. Introduction

1.1. Obese Zucker rats

The obese Zucker rat (*fa*/*fa*) is a well-established model of obesity and has been used for over 50 years to model health-related aspects of obesity, such as hypertension (Kurtz et al., 1989; Siddiqui et al., 2009) and diabetes (e.g., Inokuchi, 2006), as well as behavioral ones, such as hyperphagia (Beck, 2000). The obese Zucker rat has two homozygous *fa* "fatty" alleles, which is associated with the inhibition of the expression of the leptin receptor. Leptin is a hormone released by adipose tissue, which is responsible for controlling levels of adipose through fat metabolism and the inhibition of appetite-stimulating signals, such as neuropeptide Y (e.g., Beck, 2000; Sahu, 2004) and endocannabinoid neurotransmitters, such as anandamide (DiMarzo et al., 2001). Without the expression of functional leptin receptors, the regulation of satiety is impaired.

Obesity-related behavioral data on obese Zuckers are based mostly on free food intake studies (e.g., Drewnowski and Grinker, 1978; Vickers et al., 2003; Yoshimatsu et al., 1993). Here, a rat is placed in a home cage in which a plentiful amount of food is readily available. The effort or cost required to obtain food is minimal, in that the rat simply moves a few inches at most toward the food receptacle and eats freely. The amount of food eaten in this context is compared between obese and lean rats, and obese rats consistently eat more food than lean rats (e.g., Bjenning and Rimvall, 2000; Lutz, 2006; Thanos et al., 2008; Zucker and Zucker, 1962). From these types of studies, it is concluded that higher food intake supports that food is more rewarding, i.e., has more hedonic value, for obese Zuckers compared to leans.

Consumption of freely available food may be a useful measure of the hedonic value of food, but it has limitations. One, the value of food, i.e., the reinforcing efficacy of food (see Bickel et al., 2000) is not constant; indeed, it depends on a variety of contexts. Some examples include the delay to the food (Odum et al., 2006; Rasmussen et al., 2010), and level of deprivation and food palatability (e.g., Barbano and Cador, 2005; Barbano et al., 2009). Free food intake, then, only measures food value in a situation in which large amounts of food are highly available, easily accessible, immediate, and there are no other food-related or non-food-related outcomes. In the natural environment, this situation is a rarity; foraging for food, in which food patch size, availability, probability, and immediacy varies, is conversely related to conditions in free-feed studies in the laboratory. Moreover, for generalization to humans, a more complex environment for which these types of variables are accounted is necessary to understand the conditions under which overeating (and therefore obesity) occurs.

A recent study compared the reinforcing value of sucrose between lean and obese rats in conditions that required effort. Rasmussen and Huskinson (2008) compared the behavior of obese and lean Zucker rats using progressive ratio schedules of reinforcement, a well-established procedure for determining the value

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of a reinforcer. Here, a 45 mg sucrose pellet was programmed for delivery after a small response requirement (e.g., one lever press). The response requirement for each subsequent sucrose pellet increased systematically within session until ratio strain occurred. The baseline data from this study suggested that breakpoints (the response requirement at which ratio strain occurs) for sucrose ranged between 30 and 55 responses for lean and obese rats, and that obese rats had slightly, though not significantly, higher breakpoints than lean rats. These data may suggest that when effort to obtain food is higher than free-feeding conditions, differences between lean and obese rats' consumption may become smaller.

1.2. Behavioral economics

Another way to understand food consumption in the context of effort may be through consumer demand theory, an area of behavioral economics in which the value of food (and other reinforcers, such as drugs of abuse) is determined by the effort required to obtain it (see Hursh, 1980, 1984, 2000; Hursh and Silberberg, 2008). The more a reinforcer costs in terms of response requirement, the less likely an organism will exert effort toward earning that reinforcer. Indeed, when the number of reinforcers is plotted against effort (or price), e.g., the number of lever-presses needed to produce a food pellet, the pattern is predictable: the slopes, in general, positively accelerate in a decreasing fashion as a function of price. Their shapes depend on the value of the commodity—a relation called the *elasticity of demand*. At lower price values, demand is *inelastic*, or insensitive to price increases. When the number of reinforcers earned decreases sharply (e.g., at high price values), this is termed *elastic* demand (Hursh, 2000). Steeper slopes of the curve indicate a more rapid decline in reinforcers earned, and therefore, more elastic demand. The price at which the slope of the demand curve is equal to −1 is an objective indicator of the point of elasticity, or the price at which behavior becomes especially sensitive to price (called p_{max}). The p_{max} value is used as a referent for the value of the reinforcer. The advantage of the demand curve is that it allows for a fuller characterization of the value of the reinforcer to be determined. If one considers how many reinforcers are consumed at low prices *only* (such as that with free food intake), a mischaracterization of the value of the reinforcer is likely.

While the application of behavioral economic theory has been successfully applied to drug abuse (i.e., the drugs as reinforcers model—see Bickel and Vuchinich, 2000; Strang and McWhirter, 2004 for reviews), its application to the study of obesity has been underutilized. Nonetheless, the behavioral economic framework has potential for application to obesity and has been reported. Among obese humans, food has been shown to be an effective reinforcer, and obese individuals will tolerate higher response requirements for access to food (Epstein and Saelens, 2000; Saelens and Epstein, 1996). Moreover, Epstein et al. (2007a,b) showed that some obese individuals possess a genotype that is associated with alterations that affect dopamine (D2) receptor expression. These individuals exhibited heightened sensitivity to food reinforcement compared to others without the genotype. These studies suggest that food reinforcement is a result of the environmental arrangement of food, genetics, and a combination of these factors. Animal models, such as the genetically obese Zucker rat (*fa*/*fa*; Zucker and Zucker, 1962) can assist in determining which variables influence sensitivity to food reinforcement most heavily.

1.3. Purpose of the present study

The present study was conducted to determine whether the consumption of sucrose with lean and obese Zucker rats differs at prices that vary from low to high. In addition, we used behavioral economic analyses to examine whether animals that have a rigid phenotypic expression, in terms of hyperphagic behavior, have heightened sensitivity to food reinforcement, which may be indicated by values related to elasticity of demand (e.g., higher p_{max} values). While most studies on obesity and food procurement have relied on free-access food intake to answer this question, the current study questions whether the high amounts of food intake are based on an artifact of the free-feeding environment, in which the response cost for food is low.

2. Materials and methods

2.1. Subjects

Twenty-nine male Zucker rats ($n = 15$ control, *Fa*/*fa* or *Fa*/*Fa*; $n = 14$ obese, *fa*/*fa*) were purchased from Harlen (Livermore, CA, USA) at 3 weeks of age and served as subjects. They were housed individually in clear, plexiglass home cages and maintained on a 12 h light:dark cycle (lights on at 7 am). They were given *ad libitum* access to food and water, and free food intake (g consumed) was monitored daily for 8 weeks (before experimental sessions began). Daily food intake was measured at the same time every day (±15 min) by providing 40 g of Purina® grain-based food per day in a wire aperture on top of each rat's home cage. Twenty-hours later, the amount of food (in g) left was subtracted from 40 g, and this was recorded as the rat's daily intake.

After 8 weeks of free-feeding, rats were allowed to free-feed for two hours 21 h prior to each experimental session to establish food as a reinforcer. This method resulted in lean and obese Zucker rats eating about 10.48 g (SD = 0.4) and 11.48 g (SD = 0.32), respectively, or 2.6% of their body weights during the free-feed sessions. In addition, this free-feed period prevents rapid excessive weight gain in the Zucker rat, which can lead to health problems. At the time of operant testing, lean rats ranged in weight from 238 to 310 g and obese rats ranged from 395 to 486 g.

2.2. Apparatus

Seven Coulbourn® Habitest (Coulbourn Instruments, Whitehall, PA, USA) standard rat experimental chambers were used for data collection. Each chamber was equipped with two levers on the right side wall panel. The levers were situated 5 cm from the bottom of a grid floor. Under certain conditions, 45-mg 95% sucrose pellets (TestDiet®, Richmond, IN, USA) were delivered to a collection area above the floor that was centered between the two levers. A 28-V houselight was situated 13 cm above the food dispenser. A speaker placed in the upper left corner of the left side wall panel of the chamber generated white noise. A 2 in. × 2 in. fan was situated in the upper right corner of the left wall. A sound-attenuating cubicle surrounded each chamber. Graphic State® software (Coulbourn Instruments, Whitehall, PA, USA) on a Windows-based computer controlled all reinforcement contingencies and data collection with 0.01-s resolution. Computers and software were stationed in a room separate from the chambers. Sessions were conducted in the mornings and afternoons at the same time (±15 min) from Monday to Friday.

2.3. Procedure

When rats reached three mos of age, lever-pressing on the right lever was trained by individually placing rats in experimental chambers. A fixed ratio 1 (FR1) schedule of reinforcement was implemented, such that each right lever press produced a sucrose pellet. There were no programmed consequences for left lever-presses. Sessions lasted 3 h, and rats were considered lever-press trained if at least 70 responses on the right lever were emitted

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by the end of the session. If fewer than 70 responses occurred, then a second, or possibly third, session of FR 1 was repeated on subsequent days. Most rats acquired the lever-press within three sessions; rats that did not meet this criterion were hand-shaped to lever press using successive approximations. There were no group differences in the number of sessions required for acquisition of the lever-press.

Lever-pressing was then placed under eight fixed ratio (FR) schedules of reinforcement, in which a fixed number of lever-presses resulted in the delivery of a sucrose pellet. Sixty-minute sessions were conducted beginning with FR 1, in which a single lever-press produced a food pellet. After stability under the schedule ensued (defined as three consecutive sessions in which the number of reinforcers did not differ by more than 10% of the mean of those sessions and no trends were apparent), the next schedule, FR 5, was placed in effect until stability ensued. Subsequent schedules included FR 15, FR 30, FR 50, FR 90, FR 150, and FR 300. FR schedules were presented in increasing order to ensure that changes from one FR to the next were constant across rats; in this manner, it was similar to a progressive ratio schedule of reinforcement (see Hodos, 1961; Stafford et al., 1998), except response requirement changes took place between sessions, rather than within sessions. All rats received each FR schedule, even in situations in which they earned no reinforcers with a previous FR. All procedures were approved by the Idaho State University's Institutional Animal Care and Use Committee.

3. Analysis

The number of reinforcers and responses each rat earned under the last three stable sessions of each FR schedule were averaged into one datum for each rat. Means for these values were then determined across group and FR, and were compared using a two-way ANOVA with repeated measures (group as between-subjects variable and FR as within-subjects variable). All 29 rats' data were used for these analyses.

As a secondary analysis, the linear-elasticity demand equation (e.g., Hursh et al., 1988; Raslear et al., 1988) was fit to the reinforcer data using non-linear regression:

$$\ln Q = \ln L + b \ln P - aP \quad (1)$$

where Q is the quantity of reinforcers consumed, and price (P) is the FR schedule. The free parameters L, b and a were dependent variables of interest. L (or the y-intercept of the curve) refers to the projected level of consumption at a very low price. The parameter, b, is the projected slope of the demand curve when there is a small increase from a low price. Usually, this slope is very small, since little change occurs at this point in the curve. The parameter, a, represents the slope of the demand curve when prices are high enough to affect consumption. In situations in which 0 reinforcers were earned in a session, 0.1 was substituted, such that log transformation of the data was possible. Two rats' data from the lean group were excluded from this analysis due to poor fit (r^2 values <0.6), so a total of 27 rats (13 control, 14 obese) were used for demand analyses.

From the values of b and a, the point of unit elasticity (p_{max}) was determined for each rat. p_{max} value refers to the price at which the slope of the demand curve is −1, or a 1% increase in price leads to a 1% decrease in consumption. Values for p_{max} are determined for each animal by Eq. (2):

$$p_{max} = \frac{b+1}{a} \quad (2)$$

The p_{max} values were then compared across group (lean vs. obese) using independent samples t-tests. Each rat's o_{max} (the maximal response output) value was determined by finding the solution for Eq. (3) at each rat's p_{max} value (or P):

$$\ln(O) = \ln(L) + (b+1)(\ln P) - a(P) \quad (3)$$

The mean values of all free parameters were compared between groups using independent samples t-tests.

Data were also analyzed using Hursh and Silberberg's (2008) essential value analysis, which characterizes demand as a single parameter, the exponential decay of the reinforcer as a function of unit price:

$$\log Q = \log Q_0 + k(e^{-\alpha QP} - 1) \quad (4)$$

Here Q_0 refers to consumption at the lowest price (y-intercept). The free parameter α refers to the exponential decay of the reinforcer that describes sensitivity to price increases (i.e., the essential value). The parameter k refers to the range in the values in log units.

Free food intake (g per day) was also compared in lean and obese rats using data from the last 2 weeks of their 8-week free-feeding session. All 29 rats were used in this analysis. These data were compared using a two-way ANOVA with repeated measures in which day was used as a within-subjects variable and group was used as a between-subjects variable. Curves were fit to these data using linear regression.

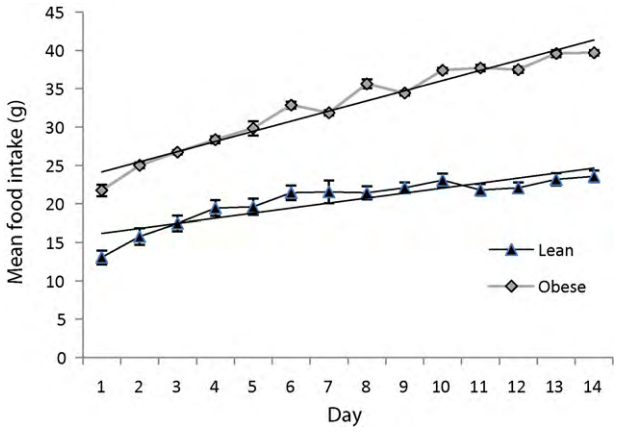

Fig. 1. Free food intake in grams for lean (black triangle) and obese (grey diamonds) Zucker rats across a 14-day period. Linear fit lines describe the data.

4. Results

4.1. Free food intake

Fig. 1 shows mean daily free food intake in grams before rats were food deprived. Across the last 14 days of free-feeding, the number of grams consumed increased significantly for both groups, $F(14, 392) = 108.31$, $p < 0.01$, $\eta^2 = 0.80$. Obese rats ate about twice as much as leans across the 14-day interval, $F(1, 28) = 337.95$, $p < 0.01$, $\eta^2 = 0.92$. There was also a day × group interaction, $F(14, 392) = 12.59$, $p < 0.01$, $\eta^2 = 0.31$. Linear fits to the functions (lean $r^2 = 0.78$; obese $r^2 = 0.95$) suggest that lean rats increased their food intake by 0.65 g/day, and obese increased their intake by 1.32 g/day during this time period.

4.2. Reinforcers

The top panel of Fig. 2 shows mean number of reinforcers (log scale) earned as a function of price (fixed ratio, log scale) for lean (black triangles) and obese (grey diamonds) rats. As price increased, the number of reinforcers decreased in an accelerating fashion. A two-way repeated measures ANOVA confirmed a FR-related significant decrease, $F(7,189) = 154.07$, $p < 0.01$, $\eta^2 = 0.85$. There was

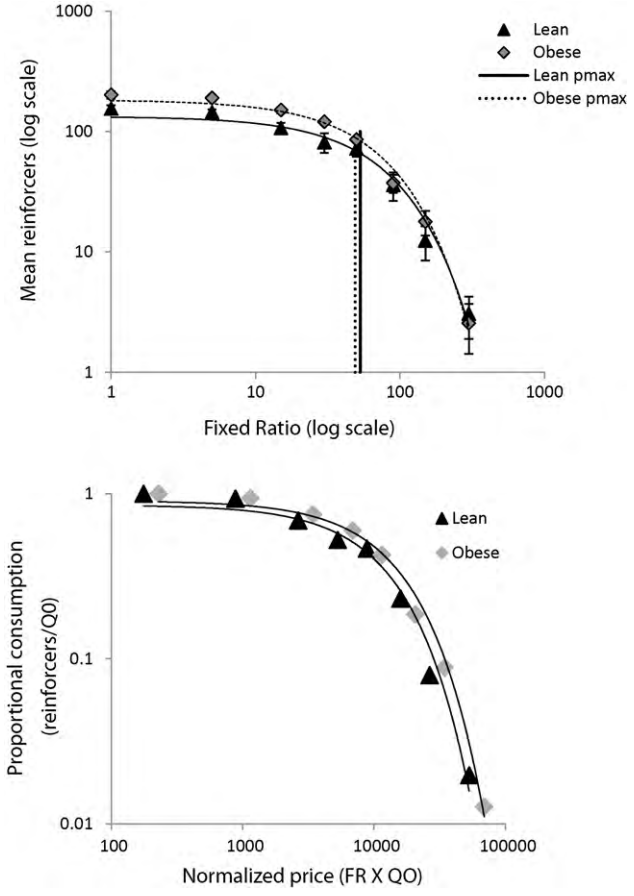

Fig. 2. Top panel shows mean number of reinforcers earned under each FR schedule for lean (black triangles) and obese (grey diamonds) rats. Error bars = 1 SEM. p_{max} values for obese (dotted) and lean (bold) rats are represented by vertical lines. Note that in some instances the error bars are smaller than the data markers. The bottom panel shows the same data as normalized demand curves.

a marginal difference between lean and obese rats overall, $F(1, 27) = 3.39$, $p = 0.07$, $\eta^2 = 0.14$, and a marginal group × price interaction, $F(7, 189) = 1.86$, $p = 0.08$, $\eta^2 = 0.10$. However, when lower fixed ratios (1–50) were examined only, obese rats earned significantly more sucrose reinforcers at the lower fixed ratios (1–50) than leans, $F(1, 27) = 4.28$, $p = 0.045$, $\eta^2 = 0.14$. There were no significant differences at the higher ratios (90–300), $p = 0.81$.

Table 1 shows free parameter values of the linear-elasticity demand analysis (top) and the exponential essential value analysis (bottom). The linear-elasticity demand model was a good fit for both lean and obese rats, as an average of 93% of the data was accounted for. Obese rats, however, demonstrated a significantly better fit than leans. Obese rats had significantly higher levels of

Table 1
Mean (SEM) free parameters of the demand equations fit to data on reinforcers.

	Lean	Obese	*t* (df)	*p*-value
Linear-elasticity model				
L	157.71 (8.86)	199.01 (12.54)	−1.92 (25)	0.03
a	−0.0089 (0.35)	0.0265 (0.007)	−0.98 (25)	Ns
b	−0.0493 (0.099)	0.101 (0.008)	−0.98 (25)	Ns
r^2	0.89 (0.02)	0.96 (0.01)	−3.29 (25)	<0.01
p_{max}	49.03 (10.84)	53.02 (6.76)	−0.317 (25)	Ns
Exponential model				
Q_0	176.15 (17.95)	228.64 (17.53)	−2.09 (25)	0.05
α	1.87×10^{-5}	7.81×10^{-6}	1.75	Ns
k	2.42	2.42		
r^2	0.85 (0.04)	0.93 (0.02)	−2.00	0.06

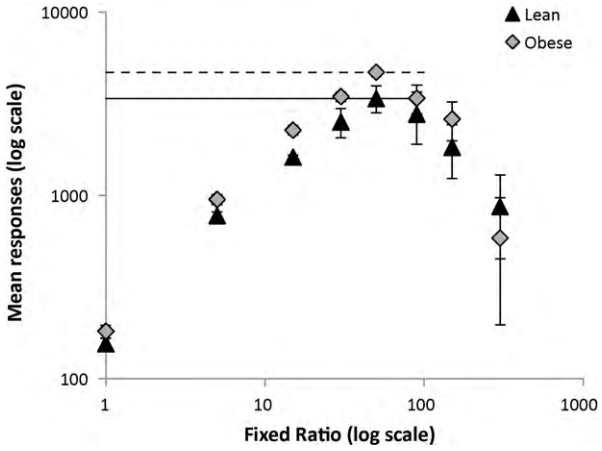

Fig. 3. Mean responses earned under each FR schedule for lean (black triangles) and obese (grey diamonds) rats. Error bars = 1 SEM. o_{max} values are represented by horizontal lines for obese (dotted) and lean (bold) rats. Note that in some instances the error bars are smaller than the data markers.

consumption (*L*) than lean rats, but there were no significant group differences in rates of decay of the demand curves (*a* and *b*), nor in p_{max} values (show as vertical lines on Fig. 2). For the exponential demand analysis (essential value), obese rats had significantly higher Q_0 values compared to lean rats, but the α values were not significantly different. The obese rats also demonstrated higher r^2 values than the lean rats with this equation, though this difference did not reach the traditional significance criterion.

Because obese rats had higher *L* and Q_0 parameters than leans in the linear and exponential analyses, respectively, we normalized each group's demand curves (see Hursh and Winger, 1995). This was done by dividing each rat's reinforcer value at each FR by its highest consumption value at FR 1 (i.e., its Q_0). Also, price was standardized by multiplying the FR value by Q_0 (Hursh and Silberberg, 2008). Normalized demand curves are shown in the lower panel of Fig. 2. The normalized exponential value analysis did not result in any group differences, however.

4.3. Responses

Fig. 3 shows mean responses as a function of price (fixed ratio). Responses increased with price, then decreased at the maximal response output (o_{max}) for both groups, $F(7,182) = 31.46$, $p < 0.01$, $\eta^2 = 0.55$. Obese rats exhibited more responses than lean rats in the ascending half of the curve (prices 1–50), $F(1,26) = 3.84$, $p = 0.05$, $\eta^2 = 0.14$, but not in the descending half of the curve (prices 90–300; $p = 0.45$). There were no significant group × price interactions in the ascending or descending halves of the curve (*p*'s < 0.50).

Table 2 displays the free parameters for the linear-elasticity demand equation for responses. Again, the demand equation fit the data well for both groups, but fit significantly better for the obese rats. o_{max} values were significantly higher for the obese rats compared to the lean rats, suggesting their maximal output for sucrose was greater than lean rats.

Table 2
Free parameters values for linear-elasticity demand equation for responses.

	Lean	Obese	*t* (df)	*p*-Value
L	147.65 (8.68)	170.05(15.98)	−1.2 (25)	Ns
a	0.039 (0.008)	0.035 (0.007)	−0.39 (25)	Ns
b	0.17 (0.09)	0.244 (0.09)	−0.58 (25)	Ns
r^2	0.87 (0.02)	0.94 (0.02)	−3.06 (25)	0.01
o_{max}	3379 (454.36)	4684.62 (371.76)	−2.22 (25)	<0.05

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5. Discussion

5.1. Free food intake

Before conducting operant sessions on food consumption under different FRs, all rats were allowed *ad libitum* access to rat chow 24 h a day for 8 weeks. During the last 14 days of this free-feeding episode, obese rats ate, on average, about twice the amount of food per day than lean rats. Moreover, obese rats increased their daily intake by more than twice as much as the leans rats (cf. slopes 0.65 vs. 1.32). This hyperphagic pattern replicates other studies comparing lean vs. obese Zucker free food intake (e.g., Beck, 2000; Bjenning and Rimvall, 2000; Lutz, 2006; Thanos et al., 2008; Zucker and Zucker, 1962).

5.2. Effort and consumption in lean vs. obese Zuckers

Consumption of sucrose pellets was examined across a range of efforts that varied between 1 and 300 lever-presses. As the fixed ratio increased, the number of sucrose reinforcers decreased for both groups, and this pattern replicates other studies conducted with food reinforcers with rats (e.g., Hursh, 1980; Hursh et al., 1988; Raslear et al., 1988; Freed and Green, 1998; Morato et al., 1994), mice (Chaney and Rowland, 2008), and baboons (Foltin and Fischman, 1988). Moreover, the linear-elasticity and exponential demand equations, which characterize this pattern as a positively accelerating decreasing function, described the data nicely for both groups, though significantly better for the obese group. Hence, our data replicate other behavioral economic studies on food-based reinforcement (e.g., Duran and McSweeney, 1987; Madden and Hartman, 2006). This study, to our knowledge, is the first to characterize demand curves for sucrose in the Zucker rat strain.

Differences in the lean and obese groups, however, were apparent. At the lower end of the demand curve there were main effects of group (genotype) on FRs 1–50, with obese rats earning more reinforcers than lean rats. These differences likely manifested in values for level of consumption (L) from the demand analysis that were also significantly different. In contrast, the number of reinforcers earned at higher prices did not result in significant group differences. Moreover, there were no differences in a or in p_{max} values, which are measures of elasticity that involve the higher FRs especially. A similar pattern appeared for the essential value analysis—obese rats had significantly higher Q_0 values compared to leans, but α values were no different. When the data were normalized, there were no differences in the α parameter values. With regard to reinforcers, then, obese rats' behavior appeared equally sensitive to higher prices, compared to lean rats. The differences in consumption, then, appear to be a function of the effort required to obtain the reinforcer with low effort conditions leading to higher consumption in the obese rat.

5.3. Effort and response output in lean vs. obese Zuckers

Responses increased with price for both groups, and then decreased once a maximal value (o_{max}) was obtained, suggesting that behavior was sensitive to price increases for both groups. For the lean rats, response output peaked at ~3400 responses (o_{max}) at FR 50 and dropped by about 75% to a mean of 869 responses at FR 300. The obese rats demonstrated a mean o_{max} value of approximately 4700 responses at FR 50; the responses then decreased by 87% to 583 responses under FR 300. The observation that responses decreased for both groups at the higher FR values suggests that the 1-h session, though short in duration, was able to create a large enough window in response output to capture changes in elasticity for both groups.

Obese rats had higher responses overall compared to lean rats, and this was especially visible on the ascending part of the curve of Fig. 3. Moreover, obese rats had significantly higher o_{max} values than lean rats, suggesting their maximal response output was greater than leans. Studies with obese humans (Epstein et al., 2007a,b; Saelens and Epstein, 1996) show a similar pattern—that obese individuals emit more responses for food than non-obese individuals, though in these studies, the differences were apparent on the descending limb of the curve, and no differences were observed in the ascending limb.

5.4. Effect sizes for genotype

The data from this study suggest that the obese phenotype observed with Zuckers may have genetic and environmental factors, but environment may play a large role in the expression of food reinforcer efficacy. Partial eta-squared (η^2), a measure of effect size for repeated measures ANOVAs, refers to the percent of variability accounted for by an independent variable (similar to r^2 values in regression analyses). In the demand analysis, partial eta-squared values for FR, an environmental contributor to sucrose pellet consumption, varied between 55 and 85%. Partial eta values for group, which describe genetic variation, accounted for no more than 14% of the variability. Moreover, when considering how much genetic variability contributed to all measures in this study, 92% of the variability in the free-feeding data came from genotype, 14% came from the small FR values (1–50), and 2% came from large FR values (90–300). These differences in effect size may suggest that the more challenging (i.e., the more effortful) it was to obtain sucrose, the less variability was contributed by genotype. This is interesting, given that the obese Zucker rat is one of a few strains of animals in which the obese phenotype appears invariant and rigid, and its expression is directly linked to a recessive allele. It also seems promising to humans, as genetic contributions to obesity, such as those that affect dopamine-2 (DRD2) receptor densities (Epstein et al., 2007a,b) which appear to be involved with food reward, are more complex than single trait genes; therefore, they are even less likely to contribute much variability to food reinforcer efficacy.

5.5. Limitations

There are some limitations to this study. Because we wanted to ensure that the differences in ratio steps were consistent across animals, we presented the FR schedules in increasing order, similar to a progressive ratio schedule of reinforcement (e.g., Hodos, 1961), which increases the response requirement for a reinforcer within session until behavior ceases (i.e., a breakpoint is reached). It is possible that age-related factors could have interacted with genotype when data from the higher FRs were collected and this could have lead to a lack of difference with those data. We find this to be unlikely, however. Some studies have compared p_{max} values of different reinforcers in behavioral economic studies with breakpoints under progressive ratios (PRs) schedules and have found positive correlations between p_{max} values and breakpoints under PR schedules (Madden et al., 2007; Rodefer and Carroll, 1997). As mentioned previously, Rasmussen and Huskinson (2008) examined the reinforcing value of sucrose in obese and lean Zucker rats using progressive ratio schedules, in which deprivation levels were similar to the ones used in the present study. Moreover, they used rats that were within the same age range as the ones in the present study. Recall that breakpoints for sucrose ranged between 30 and 55 responses for lean and obese rats, and that obese rats had slightly, though not significantly, higher breakpoints than lean rats. p_{max} values in the present study were right around

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50 responses for both groups, and therefore converge nicely with the range of the values presented in Rasmussen and Huskinson (2008). Moreover, because breakpoint values in that study were not significantly different between lean and obese rats, the lack of difference in the p_{max} and α values in the present study supports that obese rats may exhibit similar reinforcer efficacy for sucrose to lean rats. Future studies, however, may consider examining age-related effects on food-related reinforcer efficacy by using age as a manipulation.

The assertion that obese rats may have similar food reinforcer efficacy to lean rats still may be limited due to methodological issues. First, though sucrose was available only during the experimental session, it was not under a true closed economy because nutritive food was available outside the experimental session. Nutritive food was offered outside the experiment, so that an all-sucrose diet would not compromise the health of the subjects. Research using true closed economies shows that demand for a commodity is more inelastic than commodities under open economies (e.g., Collier et al., 1992; Houston and McNamara, 1989; Hursh, 1984). Therefore, we would hypothesize that with a true closed economy, sucrose may be less elastic in both groups, and perhaps stronger differences between groups may be revealed in that context.

Second, in this study, 1-h sessions were used. Session durations in behavior economic studies can vary from shorter session duration, e.g., 3 h for drug reinforcers (e.g., Carroll et al., 1991) to longer duration sessions, such as 11–12 h for nutritive food reinforcers (e.g., Madden et al., 2007). We used shorter durations in this study for two reasons: (1) we conceptualized sucrose as a non-nutritive reinforcer (e.g., likened to dessert, candy or drug) as opposed to a reinforcer that is essential for viability (such as nutritive food). As such, a shorter-duration session would be reasonable, given that an all-sucrose diet in a long-session closed economy could compromise the health of the rat. (2) Longevity of the Zucker rat had to also be considered. Obese Zucker rats have shorter life expectancies than lean Zuckers and standard rat strains (e.g., Azain et al., 2006)—on average just over a year. In this experiment, there was a higher number of subjects used (due to the assumptions of a design using between-subjects factors) than typical behavioral economic studies, which generally employ within-subjects designs with four to six subjects (e.g., Carroll et al., 1991; Madden et al., 2007). In these experiments, all subjects can be run concurrently for a long period of time. In our experiment, data for all subjects needed to be collected daily to ensure the rats were exposed to all eight schedules in a timely fashion, and all 29 subjects' sessions could not be conducted concurrently. Shorter sessions allowed for daily data collection with all rats. Though the session durations were shorter in this study, they nonetheless allowed for between-group differences to be revealed at the low FRs. Longer durations, however, may allow for larger between-group differences to become visible, especially at the higher fixed ratios. Therefore, we cannot state unequivocally that sucrose reinforcer efficacy does not differ between the two groups.

The data from this study suggest that hyperphagia associated with obese Zuckers may be an artifact of the free-feeding environment in which they often reside and that the expression of a genotype for food consumption may depend highly on environmental conditions that favor ready access to food. It would be interesting to conduct a study on lean and obese Zucker rats in which they acquire all of their nutritive and non-nutritive (sucrose) food pellets in long-duration experimental sessions (i.e., provide a true closed economy for both types of food pellets), and examine the degree to which effort plays a role in the development of obesity, i.e., in the expression of the obese genotype. It may be the case that effort-related food acquisition may suppress the expression of the obese phenotype.

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