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WITHIN-SESSION CHANGES IN RATS' FOOD-DEMAND ELASTICITY

CAMBIOS INTRA-SESIÓN EN LA ELASTICIDAD DE LA DEMANDA POR COMIDA EN RATAS

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Abstract

A common finding in behavioral economics is that demand assessed under an open economy is more elastic than that obtained under a closed economy. Although elasticity traditionally has been conceptualized in terms of price sensitivity, a potential confounding variable is session duration because open economies typically arrange markedly briefer sessions than closed economies. To assess the role of session duration on demand elasticity, we arranged an open economy in which 6 male Long-Evans rats lever-pressed for food and water reinforcers in 1- and 6-hr sessions. The fixed ratio for food reinforcers increased across sessions. Both reinforcer magnitude (1 or 2 pellets) and session duration were manipulated across conditions. Cumulative hourly food consumption data were fit to both the linear and exponential demand

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models such that the elasticity parameters yielded could be compared. For all rats, as time within the session elapsed, cumulative exponential demand for food became progressively less elastic, as did initial linear demand elasticity; however cumulative linear demand for food remained relatively unchanged for 5 of 6 rats. These results suggest that session duration modulates only initial demand elasticity with small price increases, and that these changes do not reflect changes in price sensitivity. Thus, session duration does not appear to account for the differences in elasticity previously obtained under open and closed economies.

Keywords: behavioral economics, demand elasticity, open economy, closed economy, lever press, rats

Resumen

Un hallazgo común en la economía conductual es que la demanda que se observa bajo una economía abierta es más elástica que la demanda que se obtiene bajo una economía cerrada. Aunque la elasticidad tradicionalmente se ha conceptualizado en términos de la sensibilidad al precio, una potencial variable de confusión es la duración de la sesión, ya que las economías abiertas típicamente resultan en sesiones marcadamente más cortas que las economías cerradas. Con el propósito de determinar el papel de la duración de la sesión en la elasticidad de la demanda, se programó una economía abierta en la que seis ratas Long Evans presionaron una palanca para obtener comida y agua como reforzadores en sesiones de una hora y seis horas. El programa de razón fija conforme al cual se entregó comida como reforzador aumentó a través de las sesiones. Tanto la magnitud del reforzador (1 ó 2 pellets) como la duración de la sesión se manipularon a través de las condiciones. Los datos del consumo de comida acumulado por hora se ajustaron a modelos de demanda exponencial y lineal, de tal forma que fue posible comparar los parámetros de elasticidad obtenidos. Para todas las ratas, conforme transcurrió el tiempo de la sesión la demanda exponencial acumulada por comida se hizo progresivamente menos elástica, al igual que la elasticidad inicial de la demanda lineal; no obstante la demanda lineal acumulada por comida permaneció relativamente estable para cinco de las seis ratas. Estos resultados sugieren que la duración de la sesión únicamente modula la elasticidad inicial de la demanda con pequeños aumentos del precio y que estos cambios no reflejan los cambios en la sensibilidad al precio. Por lo tanto, la duración de la sesión no parece explicar las diferencias en la elasticidad que se obtuvieron previamente bajo economías abiertas y cerradas.

Palabras clave: economía conductual, elasticidad de la demanda, economía abierta, economía cerrada, presiones a la palanca, ratas

In behavioral economics, the demand curve expresses the consumption of a commodity as a function of its price (Hursh, 1980) and serves as a primary analytic tool.

In operant assays using nonhuman subjects and food reinforcers, price has been manipulated by increasing the fixed-ratio (FR) response requirement. Economic demand for food can be quantified by plotting reinforcers earned as a function of the FR value (price). As that value increases, consumption tends to decrease; on a double logarithmic scale, the relative rate of decrease in consumption with relative increases in price is termed demand elasticity.

Demand elasticity reflects behavioral sensitivity to price manipulations and can be used as a quantitative index of reinforcer effectiveness in the face of increasing prices, with less-elastic commodities considered having higher *essential value* than more elastic commodities (Hursh & Silberberg, 2008). Using animal models, demand curves have been used to index the relative abuse liability of self-administered drugs (e.g., Hursh & Winger, 1995) and to assess how demand for a food or a drug reinforcer changes with continued access to the commodity (Christensen, Silberberg, Hursh, Huntsberry, & Riley, 2008; Galuska, Banna, Willse, Yahyavi-Firouz-Abadi, & See, 2011; Wade-Galuska, Galuska, & Winger, 2011).

Caution must be exercised in making elasticity comparisons, however, because the procedure used to generate a demand curve may affect its elasticity. Hursh (1980), for example, proposed that elasticity of demand depends on the type of economy arranged by the experimenter. Hursh defined a closed economy as one under which a commodity is available only within an experimental session, whereas under an open economy, the commodity also is available extra-experimentally. Responding for commodities under open economies generally yields greater elasticity of demand relative to that obtained under closed economies (Bauman, 1991; Foster, Blackman, & Temple, 1997; Hursh, 1978; Hursh, 1980; Hursh, Raslear, Shurtleff, Bauman, & Simmons, 1988; Ito, Kobayashi, & Saeki, 2001; Ladewig, Sorensen, Nielsen, & Matthews, 2002; Lucas, 1981; Timberlake & Peden, 1987). Traditionally, the differentially greater elasticity observed under open economies is thought to reflect greater price sensitivity due to the availability of a functionally equivalent commodity at no cost outside of the experimental arrangement (Collier & Johnson, 2000; Foster et al., 1997; Green & Freed, 1993; Hursh, 1984, 1991; Ladewig et al., 2002).

Another possible explanation for the more elastic demand curves obtained under open economies is that sessions often are substantially shorter than those arranged under closed economies. Typically, sessions under open-economy arrangements last approximately 30 to 60 min, whereas under closed-economy arrangements, sessions often last 12 to 24 hr. To assess the role of session duration on demand elasticity, Foster, Kinloch, and Poling (2011) studied demand for grain in hens during sessions ranging from 10 to 120 min by manipulating the FR requirement across sessions and the session duration across conditions. They then fitted consumption data to the linear demand equation proposed by Hursh et al. (1988) to describe demand curves:

$$\ln Q = \ln L + b(\ln P) - a \qquad \text{(Equation 1)}$$

The Q and P parameters refer to consumption (i.e., reinforcers earned) and price (i.e., FR requirement), respectively. The L parameter is a free parameter and estimates initial level of consumption at a minimally low price. Both of the free parameters, b and a, characterize elasticity of demand. The b parameter is the initial downward slope in consumption with minimal price increases, and the a parameter is the acceleration of the slope of the curve at subsequent price increases. In most cases, b parameters are negative and close to zero, reflective of the fact that the initial slope of the decrease in consumption with minimal price increases is small. When the a parameter equals zero, then the demand curve plots as a straight line (i.e., has no slope and represents inelasticity). As that value increases, however, demand becomes more elastic.

Foster et al. (2011) found that as session duration increased, changes in hens' initial demand for food at low price increases became less elastic. That is, b tended to increase (i.e., approach zero) across session durations and within sessions. Subsequent elasticity (i.e., a) did not decrease systematically. Furthermore, demand for food during the first 10, 40, and 60 min of 2-hr sessions were comparable to the demand for food in a single session of the same duration. Thus, the opportunity to earn and consume additional food later in the 2-hr session did not appear to affect current demand. Overall, these findings suggest that session duration —not solely the economy type— plays a role in modulating demand elasticity. However, an interpretation of these findings is complicated by the fact that only reliable changes in b but not a were obtained. Under most circumstances, differences in demand elasticity usually are manifested by changes in a (e.g., Hursh et al., 1988). Therefore, these results invite replication and should also be extended to a larger range of session durations and other species.

Although Foster et al. (2011) analyzed their data set using the linear demand equation (Hursh et al., 1988), Hursh and Silberberg (2008) proposed an exponential demand equation with only one parameter indexing elasticity to quantify the relation between consumption and price:

$$\log Q = \log (Q_0) + k\,(e^{-\alpha P}-1) \qquad \text{(Equation 2)}$$

where Q represents total reinforcer consumption at each price (P), Q_0 provides an index of the initial level of demand or consumption when price is set infinitely low, k is a scaling parameter that specifies the range of log Q, and α represents the relative rate of exponential decrease in consumption with relative increases in price across the entire curve. Large α values reflect greater elasticity, and small α values reflect less elasticity. The α also can be interpreted as the essential value of a commodity. Commodities that differ in terms of their elasticity of demand serve as more or less effective reinforcers: commodities that yield less elastic demand curves (and lower α values) are considered to have greater essential value than those that yield more elastic demand curves. Hursh and Silberberg argued that the exponential demand equation should be considered advantageous to the linear demand equation because it includes just one parameter as an index of elasticity (i.e., more parsimonious) while the variance in that data accounted for does not differ significantly from the fits yielded by the linear demand equation.

The purpose of the present experiment was to assess the effects of session duration on elasticity of food demand by systematically replicating findings reported by Foster et al. (2011). Using both the exponential and linear demand models, we compared price sensitivity at different session durations (1 and 6 hr) and also monitored hourly changes in price sensitivity during 6-hr sessions. We extended the results of Foster et al. in four ways. First, a different species (*rattus*) was used. Second, we investigated a broader range of session durations. Third, whereas Foster et al. did not manipulate reinforcer magnitude, we obtained demand curves for both 1- and 2-pellet reinforcers. Doing so allowed us to determine whether the level of food consumption was governed by its unit price (FR / reinforcer magnitude), a finding common in the closed-economy literature (e.g., Bickel, DeGrandpre, Higgins, & Hughes, 1990; Hursh, 1980; Hursh, 1984; Hursh et al., 1988; Lemaire & Meish, 1985). Finally, investigators studying food demand obtained under closed economies of long duration usually provide within-session access to a water source. Because food and water are known economic complements (e.g., Bolles, 1961), the availability of water might enhance the reinforcing effectiveness of food under these arrangements. Water typically has not been provided when obtaining demand curves under relatively brief sessions. Here, we controlled for this variable by providing access to water under a continuous reinforcement schedule.

Method

Subjects

Six adult male Long-Evans rats with a prior history of lever pressing for consumable reinforcers under FR schedules served as the subjects. Rats were housed singly in standard plastic cages in a temperature-controlled colony under a 12-hr reversed light-dark cycle. Sessions were conducted during the dark period on weekdays. Rats were maintained at approximately 85% (range: 84 – 88%) of their previously established free-feeding body weights via as-needed post-session feedings (8604 Teklad Rodent Diet, Harlan Laboratories, Indianapolis, IN) that occurred within 30 min of session termination. Supplemental feedings did not occur if rats earned a sufficient amount of food within the session — typically 18 g — to maintain their body weights within this range. When pre-session body weights exceeded the range above, sessions were not conducted and rats were fed approximately 10 g daily until body weights decreased to within range. This often occurred after sessions with the lowest response requirement. When pre-session body weights fell below the target range, sessions were not conducted and the supplemental food ration was increased. This rarely occurred.

Apparatus

Three commercial operant chambers (30 cm X 24 cm X 20c m; ENV-008; Med-Associates, St. Albans, VT) each were enclosed in sound-attenuating cubicles (ENV-022V) equipped with ventilation fans. Two retractable levers (ENV-112CM) were mounted on the front wall, 1.5 cm in from each side and 7 cm above the grid floor. A food-pellet dispenser (ENV-203M-45) delivered 45-mg dustless precision pellets (F0021; Bio-Serv, Frenchtown, NJ) to a receptacle centered beneath the two levers. A liquid dispenser was stationed to the right of the pellet dispenser, and a dipper could deliver 1-mL water reinforcers to the same receptacle. A houselight, centered on the back wall 2 cm from the ceiling, provided general illumination. An IBM PC running Med-Associates software (St. Albans, VT) controlled experimental events and recorded data.

Procedure

Preliminary training. Prior to the start of the present experiment, the rats served as subjects in an undergraduate laboratory course. During that time, lever presses were shaped and subsequently maintained by sweetened condensed milk on various FR schedules ranging from 1 to 30. Upon completion of this course project, the rats began participation in the current study. At this point, the laboratory, operant chamber, and reinforcer changed. The illumination of the houselight and the insertion of the left lever signaled session onset. Left lever presses produced 1 food pellet according to an FR schedule that increased across sessions by steps of 5 or 10 until a terminal value of 100 was reached. Water was not available during these sessions. Sessions lasted for 1 hr. The extinguishing of the houselight and retraction of the left lever signaled session termination.

General procedure. The illumination of the houselight and insertion of the two levers indicated session onset. Food-pellet reinforcers were presented after completion of the prevailing FR requirement on the left lever. The FR requirement for food increased across daily sessions in ascending order according to the following series: 1, 15, 45, 90, 180, and 360. Right-lever presses resulted in an 8-s dipper presentation, providing access to 1 mL of water, according to an FR 1 schedule. Left-lever presses were recorded and food pellets could be delivered while the dipper was raised (i.e., water delivery did not suspend the food schedule). A 0.2-s tone accompanied all reinforcer deliveries. The extinguishing of the houselight and retraction of both levers signaled session offset.

Initially, sessions lasted 1 hr for Rats M13, M15, and DC15 and 6 hr for Rats M10, M12, and M14. Each FR in the series was assessed three times with a 1-pellet reinforcer, and then was assessed three more times using a 2-pellet reinforcer. Next, the three rats that initially were assigned to 1-hr sessions received 6-hr sessions and the three rats that initially were assigned to 6-hr sessions received 1-hr sessions. Again, each FR in the series was assessed three times. The order in which the FRs and the reinforcer magnitudes were presented remained constant.

Data analysis. Visual and statistical analyses were conducted using Prism (GraphPad Software, Inc., San Diego, CA). Equation 2 was fit to the mean number (based on the determinations at each FR) of pellets earned at each unit price (FR / pellets per reinforcer) for both the 1-hr and 6-hr sessions.

The parameters of interest were α, which provided an index of elasticity, and Q_0, which estimated consumption when the price of food was infinitely low (i.e., the y-intercept). The scaling parameter k represented the range of the dependent variable in logarithmic units. It was set constant at 3 for all analyses because it was the smallest whole number whose antilog (1000) produced a range (1-1000) that accommodated the data set.

Data from the 6-hr sessions then were reanalyzed in terms of cumulative consumption in 60-min increments, providing an hour-by-hour index of elasticity. Foster et al. (2011) found that consumption and response rates during the first 10-, 40-, and 60-min periods of a 2-hr session were comparable to consumption and response rates in 10-, 40-, and 60-min sessions, which allowed us to operate under the assumption that any responding occurring *x* hours into a 6-hr session would resemble responding in an *x*-hr session. For all analyses, α and Q_0 values were obtained for each subject as well as for pooled group data, as was goodness of fit (r^2) values. Additionally, data from the 6-hr sessions were fit to Equation 1 such that we obtained values for the elasticity parameters *b* and *a* at cumulative 60-min increments with which we could compare to the elasticity results reported by Foster et al.

Results

Figures 1 and 2 show total pellets earned as a function of unit price (FR / pellets per reinforcer) for 1-hr and 6-hr sessions, respectively. A single curve was fit to the 1-pellet (filled squares) and 2-pellet (open squares) data. The r^2 values on each panel indicate the goodness of fit of the exponential demand equation. For all rats, consumption was well regulated by unit price at both session durations. Table 1 shows the α and Q_0 values for these demand curves. For all rats, demand curves obtained under 6-hr sessions had higher Q_0 values and were less elastic (lower *a* values) than demand curves obtained under 1-hr sessions.

Figure 3 shows cumulative pellets earned as a function of unit price in hourly increments within 6-hr sessions (shown across panels). The exponential demand equation was fit to each cumulative hourly data set (solid curve). Table 2 shows the obtained α, Q_0, and r^2 values for these group data. From a visual examination of Figure 3 and Table 2, at the level of the group, cumulative demand for food became more inelastic at each hour increment in the 6-hr session.

The horizontal line shown in the bottom right panel of Figure 3 (6 hr) shows the consumption level corresponding to 18 g of food. Rats did not receive supplemental feeding if this amount of food (or more) was earned. Thus, the 6-hr session resulted in within-session consumption that functionally resembled a closed economy at lower response requirements. At higher FR values, supplemental feeding was provided.

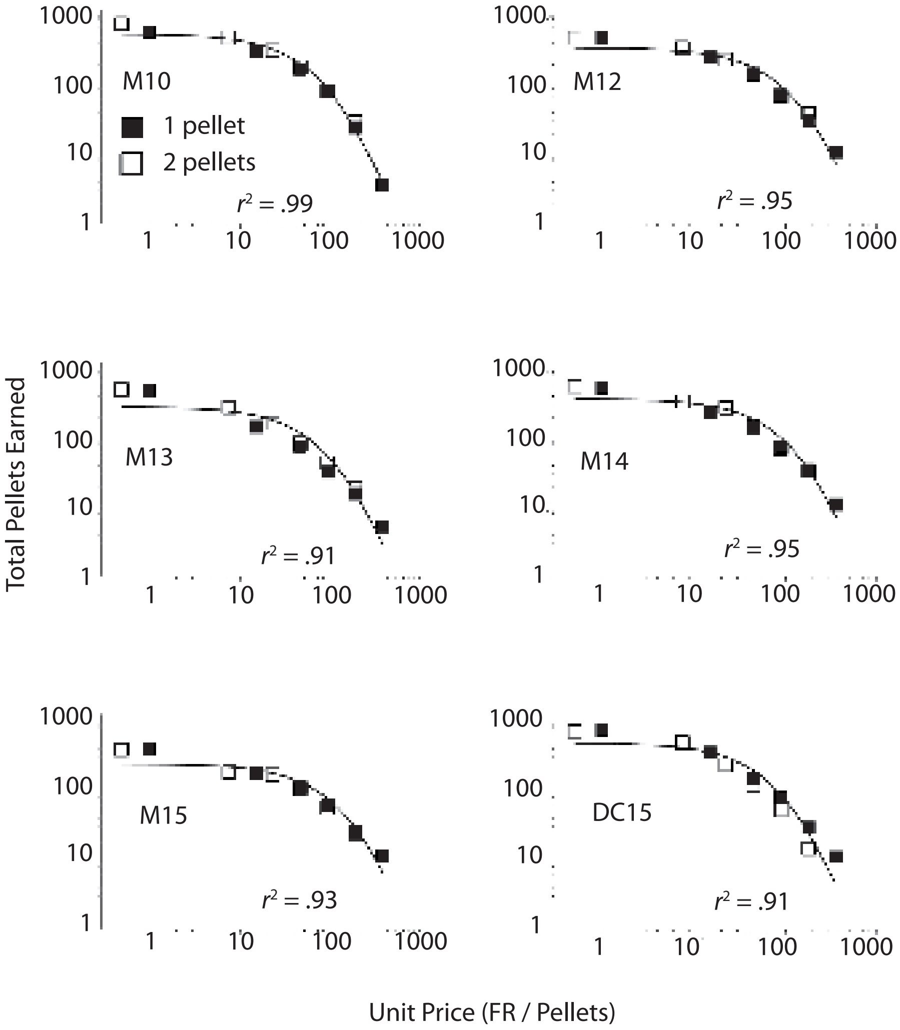

Figure 1. Total pellets earned as a function of unit price (FR / pellets per reinforcer) for 1-hr sessions. The filled squares represent a 1-pellet reinforcer and the open squares represent a 2-pellet reinforcer. r^2 values indicate the goodness of fit of the exponential demand equation.

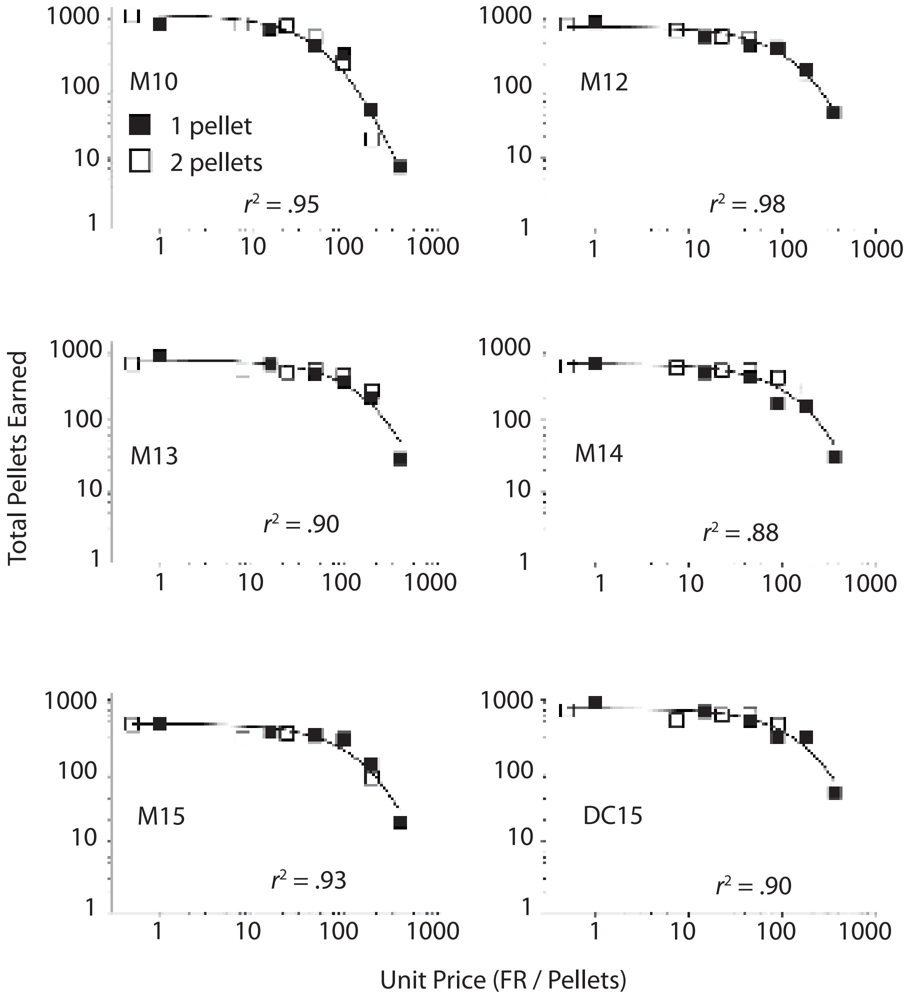

Figure 2. Total pellets earned as a function of unit price (FR / pellets per reinforcer) for 6-hr sessions. Additional details are the same as those in Fig 1.

Table 1

Best-fit parameters from the exponential demand equation for the demand curves obtained in individual rats shown in Figures 1 (1 hr) and 2 (6 hr)

	1 hr		6 hr	
Rat	α	Q_0	α	Q_0
M10	6.2E-6	554.0	3.4E-6	1027.0
M12	6.5E-6	350.1	2.0E-6	692.8
M13	10.6E-6	282.9	1.9E-6	711.7
M14	6.3E-6	368.3	2.1E-6	623.2
M15	8.4E-6	246.0	3.2E-6	462.3
DC15	6.5E-6	490.1	1.5E-6	755.8

Table 2

Best-fit parameters and goodness of fit from the exponential demand equation for the group demand curves shown in Figure 3

Cum hr	α	Q_0	r^2
1	7.3E-6	319.8	.95
2	4.5E-6	443.6	.98
3	3.4E-6	524.7	.98
4	2.8E-6	594.6	.98
5	2.5E-6	646.1	.98
6	2.1E-6	687.7	.97
24	2.3E-6	616.8	1.0

Except at the highest FR value, the majority of food consumed was earned during the session, as rats usually received a total (in-session plus post-session) of approximately 18 g of food to maintain their target body weights.

The left panels of Figure 4 represent the exponential demand analysis and show cumulative hourly essential value ($1/\alpha$) and estimates of initial consumption (Q_0) for individual rats within the 6-hr sessions. The essential value for each rat increased linearly as the 6-hr session elapsed. Data from DC15 showed this effect most dramatically. For M15 and M10, demand was not only more elastic than the other 4 rats

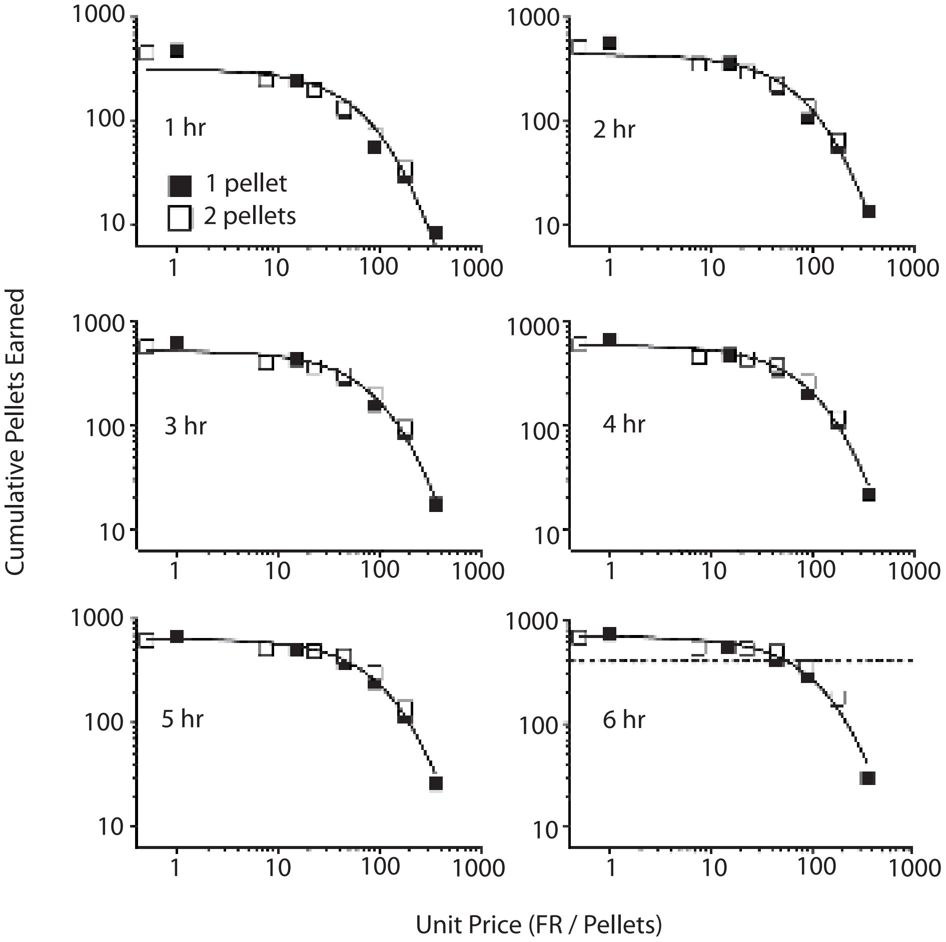

Figure 3. Group demand curves at hourly increments in 6-hr sessions. Each data point represents the mean of 6 rats. A single curve represents the fit of the exponential demand function to the cumulative food consumption data for both 1-pellet (filled squares) and 2-pellet (open squares) conditions. Hr refers to time elapsed since onset of the session.

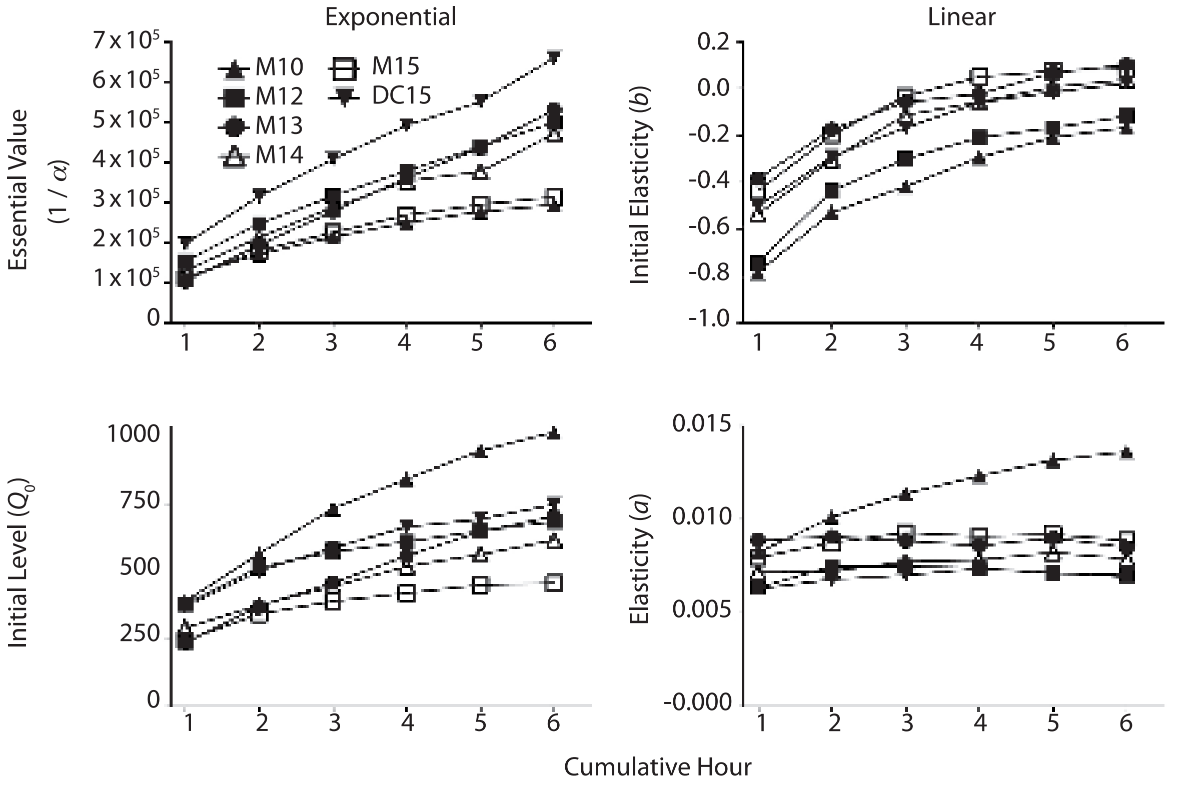

Figure 4. The left panels are individual essential values (1 / α) and estimates of initial consumption (Q_0) with hourly increments in session duration. Obtained parameters are based on fits of the exponential demand equation to cumulative food intake at hourly increments. The right panels are individual initial elasticity (*b*) and elasticity (*a*). Obtained parameters are based on fits of the linear demand equation to cumulative food intake at hourly increments.

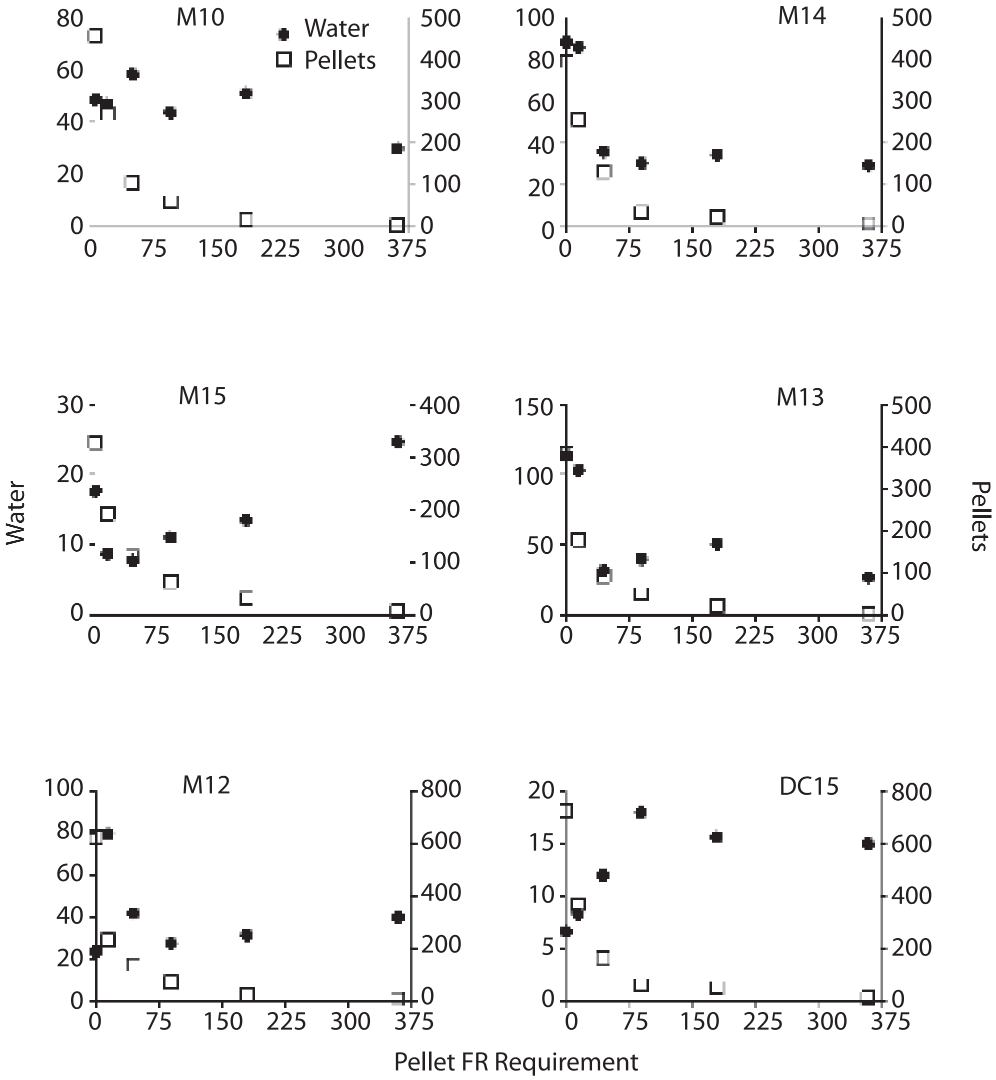

Figure 5. Individual rats' water (closed circles; left y-axis) and pellet (open squares; right y-axis) deliveries earned as a function of the FR requirement for food during the 1-pellet reinforcer condition for the first hour of 6-hr sessions. Each data point represents the mean of 3 determinations for the given FR requirement.

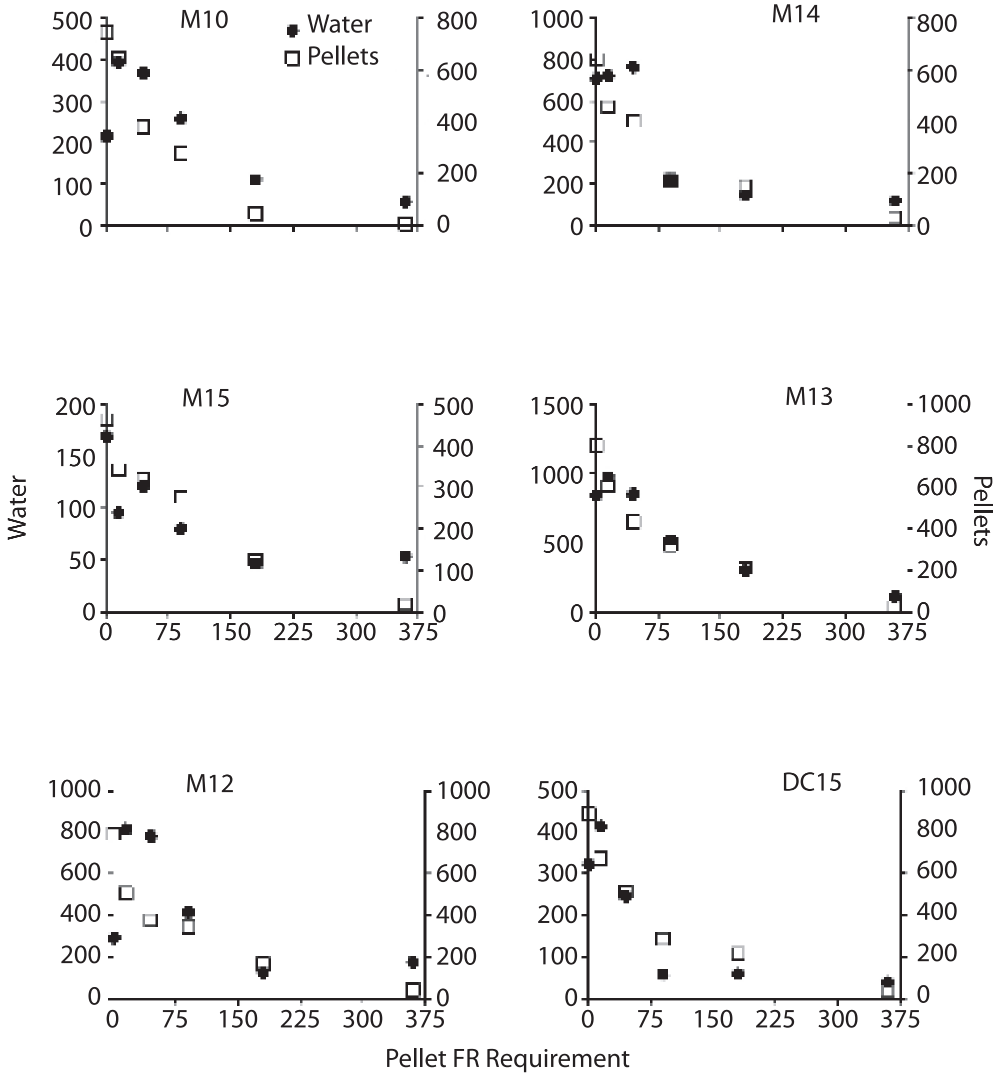

Figure 6. Individual rats' water (closed circles; left y-axis) and pellet (open squares; right y-axis) deliveries earned as a function of the FR requirement for food during the 1-pellet reinforcer condition for 6-hr sessions. Each data point represents the mean of 3 determinations for the given FR requirement.

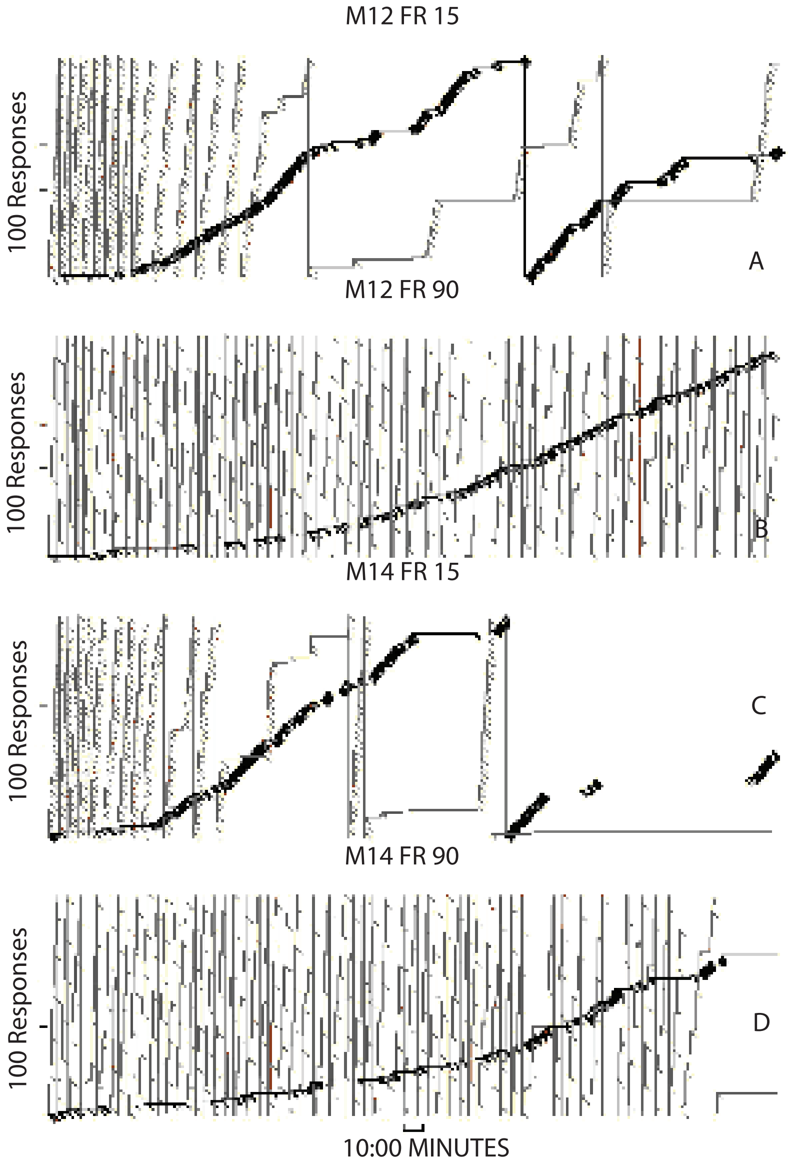

Figure 7. Sample cumulative responses in a 6-hr session for a 1-pellet food reinforcer (grey fine line with response pen deflections more dispersed) and a 1-ml water reinforcer (black bold line with response pen deflections closer together) for M12 at FR 15 (Panel A) and FR 90 (Panel B), as well as M14 at FR 15 (Panel C) and FR 90 (Panel D).

but also essential value increased to a lesser extent with each hour in the 6-hr session. The Q_0 and L (not shown) values for each rat also increased with each hour in the 6-hr session. These findings were expected because consumption measures were cumulative. Interestingly, the Q_0 increases within the first half of the session appeared to be slightly greater than changes that occurred towards the end of the session (i.e., from 5 hr to 6 hr).

The right panels of Figure 4 represent the linear demand analysis and show initial elasticity (*b*) and changes in elasticity across price increases (*a*) for individual rats within the 6-hr sessions. For all rats, initial elasticity approached zero (i.e., demand for food became more inelastic) as more of the session was included in the analysis. Initial demand elasticity continued to decrease even toward the end of the session for some rats (e.g., M10 and M12), whereas it seemed to reach an asymptote for other rats (e.g., M14 and M15). For all rats except M10, elasticity indicated by the *a* parameter changed minutely and unsystematically across cumulative hours. For M10, according to the *a* parameter, demand for food across price increases became increasingly elastic during the 6-hr session.

Figures 5 and 6 show the number water dipper presentations and food pellets earned — on the left and right y-axes, respectively — as a function of the FR requirement for pellets during the first hour (Figure 5) and for the entire 6-hr session for 1-pellet reinforcers (Figure 6). In the first hour of 6-hr sessions, consumption of water decreased with initial food price increases for all rats except DC15. At subsequent price increases that led to substantial decreases in earned pellets, however, water consumption either remained stable (Rats M10, M12, M13, and M14) or increased (Rats DC15 and M15). This relation usually was observed only during the first few hours of the session. Figure 6 shows that, by the end of 6-hr sessions, all rats earned fewer water dipper presentations as the price of food increased. Data from the 1-hr sessions, the 2-pellet condition, and hour-by-hour water consumption are not shown because the general pattern of results was comparable to that shown in Figures 5 and 6. These data can be found in Appendices A, B, and C.

Figure 7 shows representative cumulative records from 6-hr sessions in the 1-pellet condition for two rats (M12 and M14) at two FR values. When the FR was relatively low, the rats responded at high rates for food and made few water responses towards the beginning of the sessions. Responding for both food and water in the middle and last third of the sessions occurred in bursts followed by longer periods of pausing. When the FR for food was relatively high, the rats responded fairly consistently for food throughout the session but responded for water at lower rates near the start of the session followed by increased water intake later in the session.

Discussion

One purpose of the experiment was to compare demand for food at two session durations and two different reinforcer magnitudes. In both the 1-hr and 6-hr condition, overall food consumption was governed by unit price (FR / pellets per reinforcer), consistent with findings obtained under closed economies (e.g., Collier et al., 1992, Hursh et al. 1988). A second purpose was to compare the economic relation between food and water at two session durations. In the 6-hr sessions, water consumption decreased with increases in the price of food and decreases in food consumption. This suggests a complementary relation between food and water and is consistent with long-standing findings (e.g., Bolles, 1961). In the 1-hr sessions and at the beginning of the 6-hr sessions, however, food and water consumption either did not covary or were inversely related. The latter observation suggested that food and water may have been functioning as economic substitutes under these conditions. These results could be explained by a change in deprivation predicted by the minimum-needs hypothesis (Shurtleff, Warren-Boulton, & Silberberg, 1987). The food-deprived rats had free access to water in their home cages immediately prior to session commencement; therefore, the allocation of initial responses to food rather than water allowed them to meet minimum physiological needs. As the 6-hr session progressed, but never in the 1-hr session, a complementary relation appeared to emerge.

The primary purpose of the experiment was to compare food-demand elasticity with changes in session duration. Using the linear demand model, Foster et al. (2011) reported that initial demand (*b*) became less elastic with increases in session duration but subsequent elasticity (*a*) with further price increases was not systematically related to session duration. Our results from cumulative hourly increments of 6-hr sessions were consistent with those reported by Foster et al. When the data were fit to the exponential demand equation, which provides only one index of elasticity (α), demand for food became less elastic within the 6-hr session as more of the session was included in the analysis.

The orderly changes in *b* (and α), yet not *a*, as session duration increases beg for an explanation. Hursh et al. (1988) noted that *b* usually is negative and close to zero because consumption decreases minimally at the lowest price increases. Behavior appears to be rather insensitive to these small price increases. Arguably, manipulations resulting in systematic changes in *b* values, such as the present results as well as those reported by Foster et al. (2011), do *not* reflect changes in price sensitivity. Rather, other variables, such as session duration, affect *b* independently of price sensitivity. For example, in our study, when the session duration was short, consumption likely decreased at minimal price increases more so relative to longer session durations because time placed a constraint on maximal consumption. At low response requirements, the rats responded consistently during the first portion of a long session but not during the entire session. Cumulative records indicated that as the session progressed, responding tended to occur in bursts punctuated by periods of nonresponding. At minimal prices, the current degree of satiation and habituation to the reinforcer regulate consumption (Killeen, 1995; McSweeney, Hinson, & Cannon, 1996; McSweeney & Swindell, 1999; McSweeney, & Weatherly, 1998; Posadas-Sanches & Killeen 2005) unless session duration constrains it.

We suggest that decreases in consumption with further price increases (i.e., the *a* parameter of the linear demand model) do, in fact, reflect price sensitivity. With increases in price, response output first increases to defend consumption and then decreases on the elastic portion of the demand curve (e.g., Hursh et al., 1988). This general pattern occurred even during 1-hr sessions. That the *a* parameter did not systematically change with session duration indicates that session duration functioned as less of a constraint on responding at higher prices. For example, at the extreme, response output is relatively low at an FR 1000 regardless of the duration of the session. Thus, session duration appears to affect consumption less as the price of the commodity increases. Together with the results of Foster et al. (2011), our results suggest that changes in elasticity with session duration are the result of session duration constraining consumption at small response requirements; we suggest that session duration does not meaningfully alter price sensitivity.

Hursh (1978; 1980; 1984; 1991) and others (e.g., Collier & Johnson, 1997; Hall & Lattal, 1990; Zeiler, 1991; 1999) have argued that behavior is regulated in fundamentally different ways depending on the prevailing economy type. Specifically, previous research directly comparing demand curves obtained under open and closed economies has demonstrated that demand for commodities is more elastic under an open economy than a closed economy (Bauman, Raslear, Hursh, Shurtleff, & Simmons, 1996; Ito et al., 2001; Ladewig et al., 2002). Comparing and interpreting elasticity differences under open and closed economies can be challenging because open economies approximate closed economies when subjects earn most of their daily food allotment during the session. Our 6-hr sessions likely approximated a closed economy arrangement more so than an open economy because post-session food was provided only when the FR was relatively high. The 1-hr sessions, and even the first hour of 6-hr sessions, more resembled an open economy. The purpose of the experiment, however, was to evaluate session duration as a possible confound underlying previously reported elasticity differences. To this end, it appeared that price sensitivity (i.e., the *a* parameter of the linear demand model) was not affected by session duration: Elasticity for 1-hr sessions, as well as in the first hour of 6-hr sessions, was comparable to elasticity for 6-hr sessions. Therefore, the obtained differences in the *a* parameter as a function of economy type obtained reliably in previous studies likely cannot be attributed solely to differences in session duration.

To conclude, measures of demand elasticity are commonly conceptualized as indexing price sensitivity, but not all changes in these measures reflect price sensitivity changes. In addition to shedding light on elasticity differences between open and closed economies, recognizing that changes in the α parameter of the exponential demand model (Hursh & Silberberg, 2008) may not always reflect changes in price sensitivity suggests caution in conceptualizing the α parameter as a measure of the essential value under relatively brief session durations. Our results suggest that the two-parameter linear demand model might be superior to the exponential demand equation in yielding an elasticity measure (*a*) that is a purer measure of price sensitivity relative to α.

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Appendix A

Individual rats' pellet and water consumption for 1-hr sessions for 1- and 2-pellet reinforcers at each FR. P and W denote pellets and water reinforcers earned.

		1 pellet		2 pellets				1 pellet		2 pellets	
Rat	FR	P	W	P	W	Rat	FR	P	W	P	W
M10	1	589	54	771	35	M14	1	531	80	561	67
	15	304	89	483	55		15	235	142	335	126
	45	172	23	317	22		45	145	65	271	65
	90	82	34	183	27		90	75	31	145	34
	180	25	49	81	23		180	35	25	71	24
	360	4	41	30	33		360	11	30	34	28
M12	1	486	3	481	29	M15	1	394	7	388	55
	15	253	22	347	31		15	181	5	186	38
	45	143	19	235	20		45	114	4	169	26
	90	72	19	150	14		90	62	6	110	11
	180	31	32	71	23		180	25	6	56	17
	360	11	34	39	24		360	11	12	25	12
M13	1	488	23	502	41	DC15	1	749	3	718	4
	15	145	45	275	78		15	354	7	496	2
	45	74	18	163	34		45	149	13	237	4
	90	32	24	84	18		90	79	10	118	6
	180	16	46	44	33		180	29	23	52	10
	360	5	35	19	37		360	11	12	15	12

Appendix B

Individual rats' pellet and water consumption for 6-hr sessions for 1- and 2-pellet reinforcers at each FR. P and W denote pellets and water reinforcers earned.

		1 pellet		2 pellets				1 pellet		2 pellets	
Rat	FR	P	W	P	W	Rat	FR	P	W	P	W
M10	1	745	215	977	491	M14	1	639	707	575	710
	15	644	393	753	661		15	464	745	545	865
	45	378	367	709	815		45	397	738	497	787
	90	279	257	493	663		90	175	224	516	887
	180	47	111	213	189		180	156	166	400	599
	360	7	58	18	142		360	31	120	263	261
M12	1	793	291	741	603	M15	1	461	169	450	174
	15	506	814	621	475		15	342	96	293	58
	45	378	781	509	970		45	320	121	339	306
	90	341	466	479	834		90	276	80	317	60
	180	170	168	348	401		180	125	47	278	20
	360	42	175	145	390		360	19	54	79	38
M13	1	801	846	624	994	DC15	1	888	322	708	586
	15	608	977	491	926		15	675	414	511	648
	45	434	850	475	770		45	512	246	605	558
	90	352	564	519	975		90	291	102	607	449
	180	209	291	426	606		180	290	104	449	397
	360	29	115	257	544		360	50	43	297	264

Appendix C

Individual rats' cumulative pellet and water consumption within 6-hr sessions for both 1- and 2-pellet reinforcers at each FR. P and W denote pellets and water reinforcers earned.

			1 pellet		2 pellets					1 pellet		2 pellets	
Rat	Hr	FR	P	W	P	W	Rat	Hr	FR	P	W	P	W
M10	1	1	456	49	617	49	M12	1	1	625	24	615	47
		15	271	47	334	95			15	235	80	382	52
		45	106	58	207	107			45	140	42	230	44
		90	60	44	123	74			90	75	28	125	68
		180	19	51	41	39			180	29	32	69	42
		360	6	30	12	44			360	11	40	35	53
	2	1	557	118	715	193		2	1	684	72	667	119
		15	413	150	448	280			15	358	239	509	183
		45	187	134	349	281			45	232	153	349	196
		90	110	91	205	203			90	149	49	233	145
		180	30	76	79	77			180	54	64	134	79
		360	7	45	15	81			360	17	81	61	129
	3	1	676	163	832	274		3	1	711	114	689	179
		15	530	236	557	445			15	403	371	547	277
		45	254	225	453	472			45	289	322	402	445
		90	152	143	275	318			90	209	115	309	289
		180	39	94	112	112			180	78	87	194	145
		360	7	51	16	99			360	23	108	85	217
	4	1	733	193	862	335		4	1	732	173	697	305
		15	613	339	612	552			15	421	507	573	353
		45	321	299	539	620			45	327	511	445	619
		90	202	184	347	434			90	260	204	375	473

Appendix C (continued)

Individual rats' cumulative pellet and water consumption within 6-hr sessions for both 1- and 2-pellet reinforcers at each FR. P and W denote pellets and water reinforcers earned.

			1 pellet		2 pellets					1 pellet		2 pellets	
Rat	Hr	FR	P	W	P	W	Rat	Hr	FR	P	W	P	W
		180	44	104	149	128			180	106	111	249	224
		360	7	54	18	109			360	29	131	109	290
	5	1	744	209	893	444		5	1	764	236	708	447
		15	622	374	753	634			15	486	679	615	423
		45	360	351	640	748			45	364	690	476	814
		90	253	229	418	552			90	302	317	426	686
		180	47	109	178	164			180	136	116	303	307
		360	7	55	18	135			360	37	147	127	348
	6	1	745	215	977	491		6	1	793	291	741	603
		15	644	393	753	661			15	506	814	621	475
		45	378	367	709	815			45	378	781	509	970
		90	279	257	493	663			90	343	417	479	834
		180	47	111	213	189			180	167	126	348	401
		360	7	58	18	142			360	42	175	145	390
M13	1	1	385	114	297	151	M14	1	1	396	88	391	130
		15	178	103	153	194			15	256	86	233	153
		45	91	31	165	110			45	133	36	225	92
		90	49	40	101	57			90	35	31	142	69
		180	21	51	75	56			180	26	35	77	26
		360	4	27	43	41			360	9	30	35	24
	2	1	563	287	379	385		2	1	463	343	423	338
		15	272	294	255	409			15	323	324	339	409
		45	171	148	267	269			45	210	187	302	327

Appendix C (continued)

Individual rats' cumulative pellet and water consumption within 6-hr sessions for both 1- and 2-pellet reinforcers at each FR. P and W denote pellets and water reinforcers earned.

			1 pellet		2 pellets					1 pellet		2 pellets	
Rat	Hr	FR	P	W	P	W	Rat	Hr	FR	P	W	P	W
		90	105	106	195	208			90	68	52	232	242
		180	55	81	157	143			180	49	72	139	85
		360	8	52	85	95			360	17	55	79	58
	3	1	636	479	439	585		3	1	491	496	425	451
		15	366	486	305	611			15	408	484	374	576
		45	238	300	315	437			45	264	320	424	489
		90	164	193	289	387			90	95	81	306	440
		180	90	133	235	267			180	74	93	213	164
		360	13	70	127	197			360	22	80	130	90
	4	1	744	673	514	767		4	1	542	607	491	554
		15	463	683	393	742			15	422	585	477	742
		45	303	474	374	574			45	329	472	461	685
		90	228	293	366	592			90	125	121	392	622
		180	123	173	285	395			180	100	113	282	284
		360	19	88	167	301			360	26	96	152	218
	5	1	775	758	578	895		5	1	545	658	491	622
		15	547	853	445	828			15	437	678	528	825
		45	368	662	442	707			45	377	644	497	748
		90	290	399	444	802			90	145	194	494	773
		180	167	218	359	504			180	125	144	310	412
		360	21	99	212	414			360	29	110		
	6	1	801	846	624	994		6	1	639	707	575	710
		15	608	977	491	926			15	456	720	545	865

Appendix C (continued)

Individual rats' cumulative pellet and water consumption within 6-hr sessions for both 1- and 2-pellet reinforcers at each FR. P and W denote pellets and water reinforcers earned.

			1 pellet		2 pellets					1 pellet		2 pellets	
Rat	Hr	FR	P	W	P	W	Rat	Hr	FR	P	W	P	W
		45	434	850	475	770			45	404	763	497	787
		90	325	521	519	975			90	175	224	516	887
		180	213	299	426	606			180	153	146	400	599
		360	29	115	257	544			360	31	120	263	261
M15	1	1	328	18	373	16	DC15	1	1	725	7	444	73
		15	192	9	155	21			15	368	8	255	100
		45	110	8	169	21			45	168	12	215	73
		90	63	11	106	5			90	63	18	220	22
		180	30	14	69	4			180	52	16	121	40
		360	6	25	26	13			360	15	15	61	37
	2	1	411	50	419	71		2	1	805	21	531	195
		15	286	39	211	40			15	535	46	380	232
		45	202	23	222	55			45	274	37	302	217
		90	125	22	190	21			90	113	30	329	134
		180	52	27	127	9			180	102	35	203	126
		360	10	38	45	22			360	24	22	115	99
	3	1	422	100	420	135		3	1	810	57	632	295
		15	326	84	239	73			15	562	97	403	351
		45	271	80	236	142			45	361	67	389	306
		90	180	43	243	46			90	155	43	439	234
		180	77	33	183	14			180	151	49	284	199
		360	12	43	55	29			360	29	29	163	149

Appendix C (continued)

Individual rats' cumulative pellet and water consumption within 6-hr sessions for both 1- and 2-pellet reinforcers at each FR. P and W denote pellets and water reinforcers earned.

			1 pellet		2 pellets					1 pellet		2 pellets	
Rat	Hr	FR	P	W	P	W	Rat	Hr	FR	P	W	P	W
	4	1	445	140	420	141		4	1	838	106	643	402
		15	326	85	239	77			15	646	174	447	438
		45	305	120	325	215			45	463	84	486	422
		90	234	53	267	54			90	194	53	505	321
		180	101	40	234	16			180	214	59	367	300
		360	16	48	65	33			360	36	32	211	190
	5	1	458	149	447	169		5	1	839	209	647	462
		15	337	86	283	80			15	646	272	473	559
		45	305	120	325	295			45	508	175	545	499
		90	264	69	305	57			90	250	54	562	381
		180	114	45	263	19			180	214	59	404	350
		360	16	51	75	37			360	44	38	263	230
	6	1	461	169	450	174		6	1	888	322	708	586
		15	342	96	293	92			15	675	414	511	648
		45	320	121	339	306			45	512	246	605	558
		90	276	80	317	60			90	287	58	607	449
		180	125	47	278	20			180	214	59	449	397
		360	19	54	79	38			360	44	40	297	264