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3 The Effects of Price Changes on Alcohol Consumption in Alcohol-Experienced Rats

Jeffrey K. Sarbaum, Solomon W. Polachek, and Norman E. Spear

3.1 Introduction

This paper reports the results of an experiment designed to study ethanol (ETOH) consumption. The innovation is that we analyze the behavior of ethanol-experienced rats as opposed to humans, the usual subjects in current economics-based studies. The reason for using animal subjects is interesting, but first we give some background.

Current economic studies view alcohol as an addictive commodity. Addictive commodities are ones that have repercussions on future consumption. As such, consuming this type of commodity affects one's benefit from consuming this commodity at some time in the future. Addiction thus implies a time complementarity that enables economists to derive predictable theorems regarding intertemporal consumption patterns. For example, under plausible assumptions, two theorems emerge: First, long-run responses to a price change are relatively larger than short-run responses for addictive compared to nonaddictive commodities (Becker, Grossman, and Murphy 1991). And second, past as well as future prices affect consumption behavior, rather than simply current prices as is typical for nonaddictive commodities (Becker and Murphy 1988).

Empirical studies validate these theorems essentially by regressing current consumption on past, present, and future prices. Current studies (Chaloupka 1991; Becker, Grossman, and Murphy 1994; Grossman, Chaloupka, and Sirtalan 1995; Grossman, Chaloupka, and Brown 1996) analyze the demand for cigarettes, alcohol, and cocaine. Aggregate data analysis examines cross-sectional

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state data by making use of interstate variations in prices. Studies (Grossman, Chaloupka, and Sirtalan 1995; Grossman, Chaloupka, and Brown 1996) utilizing panel data (e.g., the University of Michigan's Institute for Social Research's Monitoring the Future panels) analyze cross-sectional as well as time-series price changes. Both types of studies find responses to price changes to be greater in the long run, implying larger long-run elasticities. However, a deficiency with these studies is that there are numerous other explanations why long-run elasticities are larger than short-run elasticities. As such, long-run elasticities exceed short-run elasticities for many commodities, not just addictive ones. Past studies lack the data on other commodity purchases to compare differences in long-run and short-run elasticities between addictive and nonaddictive commodities. As such one does not know whether alcohol, cigarettes, and drugs have long-run elasticities that exceed short-run elasticities because common economic theory dictates this or because these commodities exhibit the time-complementarities inherent in addictive consumption. Thus, a controlled experiment is needed to calibrate response differences between addictive and nonaddictive commodities.

The use of animal subjects in place of human subjects is desirable in this study for several reasons. Logistical considerations surrounding the construction of a multiple commodity comparison is much simpler with rats; it is easier to control the environment, there is increased homogeneity within the multiple subjects, and costs are significantly reduced. It is not unreasonable to use rats when the ultimate goal is to understand human behavior. There are numerous examples of the value of this approach. Scientific disciplines have long realized the commonalities between humans and other species and have successfully utilized these in advancing their research. There is no reason to believe that such commonalities stop short of issues relevant to economic study.

While we discuss long-run versus short-run elasticities, our primary purpose is to perform controlled experiments to compare behavior and demand elasticities between addictive and nonaddictive commodities. Only by first determining such elasticities can one begin to study relative long-run and short-run differences. In the experiment, ethanol-experienced rats facing a fixed budget (limited number of reinforcements) choose between two alternative nonethanol commodities in a morning control session and between an ethanol and a nonethanol commodity in an afternoon session. Their response to an increase in the price of the ethanol commodity in this circumstance is compared against their response to an increase in the price of a nonethanol commodity derived from a series of controls. The design enables direct comparisons to be made between the demand elasticities for the ethanol and nonethanol commodities.

In carrying out these experiments, we first confirm Samson's (1986) finding that rats can be induced to consume ethanol, and will do so even when faced with nonethanol alternatives. This outcome implies that current ethanol consumption depends on past ethanol use, a test of the habit-formation or addiction framework. Second, we find unambiguously that price changes affect behavior. This is true for nonethanol as well as ethanol commodities, though the magnitudes differ for each. Third, we find that, in general, ethanol-experienced rats respond less to ethanol price changes than to otherwise identical nonethanol price changes. Although tentative, these results confirm that the price structure can be used to affect behavior, even for addictive commodities.

3.1.1 An Experimental Model of Consumer Choice Using Laboratory Animals

Models of consumer choice study how consumers respond to changes in the relative price of commodities when facing a budget or income constraint. Downward-sloping demand curves imply that, other things being equal, the quantity demanded of a commodity will fall as the relative price of that commodity increases. The downward-sloping demand curves are based on the assumption that consumers maximize satisfaction, a function of the commodities they consume, subject to a budget constraint. The budget constraint in a two-commodity world is represented by

$$Q_X * P_X + Q_Y * P_Y = M, \tag{1}$$

where P_X and P_Y are the prices of the two commodities, Q_X and Q_Y are the quantities consumed of each of the two commodities, and M is the consumer's budget or income.

To model these circumstances, rats in an experimental testing chamber were given a budget to allocate between two alternative commodities, X and Y. The operant chamber was equipped with two levers, each of which delivered a reinforcing liquid commodity when pressed. The budget was set by limiting the number of lever presses available to the subject in a given test session. The price of each commodity was determined by the number of lever presses required to obtain 0.1 ml of liquid commodity from the associated dispenser. Relative prices were determined by the price ratio (P_X/P_Y) of the two alternative commodities. Income was determined by a fixed number of available lever presses. Responsiveness to a change in price was measured by the price elasticity of demand. Price elasticity of demand is measured by fitting a log-log function to the price-consumption data recorded during the experiments:

$$\log Q_X = \log \alpha_0 + \alpha_1 \log(P_X/P_Y), \tag{2}$$

where α_1 measures the price elasticity of demand. In the context of these experiments, the price elasticity of demand can be viewed as a measure of the degree to which a subject is willing to substitute one commodity for the other when the price, measured in terms of the forgone opportunity to consume the alternative commodity, changes.

3.1.2 Experimental Testing Apparatus

Subjects were tested in a custom operant chamber measuring 30 cm long, 35 cm wide, and 28 cm high (San Diego Instruments). Two metal levers projected into one wall of the chamber. Flavored sucrose and sucrose-ethanol solutions were delivered from two separate liquid dripper mechanisms located to the side of each lever. Depression of a lever resulted in a calibrated drop of the solution from the dripper onto a drinking tray recessed in a hole on the panel next to each lever. Drop sizes were adjustable, ranging in size from 0.025 ml to 0.2 ml. Computer-based programming equipment controlled the number of lever presses available for operating the dispensers during each session. Two white lights, one over each lever, were illuminated whenever liquid-dispensing lever presses were available. When a subject exhausted its budgeted lever presses, the white lever lights went off. A single 7.5 W green light and an 80 db Sonalert, located between the levers, were activated for signaling purposes during the second experiment. The entire operant chamber was housed in a soundproof chamber equipped with an exhaust fan. A single 7.5 W white house light, located on the roof of the soundproof box above the operant chamber, remained on throughout the session. The programming equipment automatically recorded the number of depressions made on each lever, the time into the session each lever press was made, and the time required to exhaust the budgeted number of lever presses.

3.2 Experiment A

3.2.1 Methods

Subjects

Six adult male, 60–80-day-old Sprague-Dawley rats from our laboratory's breeding facility (rats 1, 2, 3, C1, C2, and C3) were singly housed in standard hanging cages in a temperature- and light-controlled colony room. Subjects had ad-lib access to water and standard laboratory rat chow while in their home cages. Subjects 1, 2, 3, and C2 were exposed to a variant of the Samson sucrose-ethanol fading technique in their home cages prior to testing in an experimental chamber (Samson 1986), as detailed in the experimental design subsection. Subjects C1 and C3 were ethanol-naive rats and served as controls during the experimental testing.

Experimental Design

Table 3.1 shows the baseline and experimental parameters (solution flavors, budgets, and drop sizes per lever press) for each subject, as well as the mean lever presses, solution intake levels, intake standard deviations, and ethanol intake (g/kg) under each condition.

Modified Samson (1986) Ethanol-Sucrose Fade. On test days 1–34, subjects 1, 2, 3, and C2 were trained to drink ethanol-sucrose solutions in their home cages during daily 30-minute drinking sessions. On test days 35–49, subjects 1, 2, and 3 received concurrent 30-minute access to two alternatively flavored (0.2 g Kool-Aid) solutions in their home cages. Subjects 1 and 3 received a 10 percent sucrose/15 percent ETOH/strawberry solution versus a 10 percent sucrose/orange solution. Subject 2 received a 10 percent sucrose/15 percent ETOH/cherry solution versus a 10 percent sucrose/grape solution. On four of the concurrent home-cage exposure days (test days 40–43), subjects were exposed to 2 ml each of two different alternative flavor sucrose solutions two hours prior to the ethanol exposure. The purpose of this exposure was to determine whether access to 4 ml of 10 percent flavored sucrose earlier in the day affected total and relative intake of the solutions described above. Subject C2 served as a control and was maintained on the 5 percent sucrose/15 percent ETOH solution according to table 3.1 until test day 50.

Operant Shaping. On test days 50–52, subjects 1, 2, and 3 were deprived of water overnight and trained to lever press for water in the operant chamber using standard shaping procedures. Following each operant training session, subjects were returned to their home cage and given one-hour access to water followed by 30-minute access to their two respective flavored solutions. Beginning on day 53, subjects 1, 2, and 3 received two daily 30-minute operant sessions, an early session between 1 P.M. and 2 P.M. and a late session between 3 P.M. and 4 P.M. In the early session, one of two alternative 10 percent sucrose/Kool-Aid flavors was delivered, contingent upon a fixed-response schedule of one press on the respective lever (FR-1, 0.05 ml for both levers), and in the late session, a 10 percent sucrose/Kool-Aid flavor was associated with one lever and a 10 percent sucrose/15 percent ETOH/alternative Kool-Aid flavor was associated with the other (FR-1, 0.05 ml on both levers). Table 3.1 shows the specific flavors associated with each lever for each session and subject.

Baseline Parameters: Initiation of the Budget Constraint. Following the establishment of steady responding during the two daily 30-minute sessions (test day 54–56 depending on the subject), a budget of 80 lever presses per each daily session was initiated, allowing for a total intake of 4 ml each session. Each time a subject exhausted its 80 lever press budget, or failed to exhaust its budget within a 45-minute maximum session length, it was removed from the operant chamber and returned to its home cage. Under baseline conditions, subjects were run for approximately 30 days on the 80 press, FR-1, 0.05 ml/press/lever schedule. Table 3.1 shows the specific number of days each subject was tested under baseline.

Experimental Parameters: Initiation of a 100 Percent Price Change. Following the baseline period, the relative cost or price of the alternative solutions was

Table 3.1 Summary Data

	Subject 1				Subject C2			
	Early Experiment		Late Experiment		Early Experiment		Late Experiment	
	Lever 1	Lever 2	Lever 1	Lever 2	Lever 1	Lever 2	Lever 1	Lever 2
Liquid	Cherry	Grape	Strawberry ETOH	Orange	Strawberry	Orange	Strawberry ETOH	Orange
Baseline data								
Days of data	28		28		10		15	
Budget	80		80		40		40	
Drop size (ml)	0.05	0.05	0.05	0.05	0.10	0.10	0.10	0.10
Mean lever press	16.04	63.61	72.83	7.17	12.90	27.10	27.07	12.93
Mean quantity (ml)	0.80	3.18	3.64	0.36	1.29	2.71	2.71	1.29
Std. dev. (quantity)	0.31	0.33	0.29	0.29	0.34	0.34	0.36	0.36
Mean ETOH intake (g/kg)			0.91				0.66	
Experimental Data								
Days of data	13		29		10		15	
Budget	134		152		67		66	
Drop size (ml)	0.05	0.025	0.025	0.05	0.10	0.05	0.05	0.10
Mean lever press	61.92	68.62	71.62	28.97	38.90	28.10	43.93	22.07
Mean quantity (ml)	3.10	1.72	1.79	1.45	3.89	1.41	2.20	2.21
Std. dev. (quantity)	0.91	0.51	0.87	1.77	0.74	0.37	0.28	0.56
Mean ETOH intake (g/kg)			0.41				0.50	

	Subject 2				Subject C3			
	Early Experiment		Late Experiment		Early Experiment		Late Experiment	
	Lever 1	Lever 2	Lever 1	Lever 2	Lever 1	Lever 2	Lever 1	Lever 2
Liquid	Strawberry	Orange	Cherry ETOH	Grape	Strawberry	Orange	Cherry	Grape
Baseline Data								
Days of data	28		28		10		10	
Budget	80		80		80		80	
Drop size (ml)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Mean lever press	64.25	15.72	71.00	7.80	45.50	34.50	36.00	44.00
Mean quantity (ml)	3.21	0.79	3.55	0.39	2.27	1.73	1.80	2.20
Std. dev. (quantity)	0.41	0.41	0.34	0.34	0.43	0.43	0.48	0.48
Mean ETOH intake			0.77					
Experimental data								
Days of data	28		28		12		12	
Budget	73		76		63		58	
Drop size (ml)	0.05	0.1	0.05	0.1	0.05	0.10	0.05	0.10
Mean lever press	33.40	39.60	66.20	8.80	22.00	41.00	17.92	40.08
Mean quantity (ml)	1.67	3.96	3.31	0.88	1.10	4.10	0.90	4.01
Std. dev. (quantity)	0.33	0.66	0.35	0.59	0.23	0.47	0.27	0.53
Mean ETOH intake			0.65					

altered by changing the drop size per lever press. For subjects 2 and 3, the drop size per lever press on one of the two levers was increased to 0.1 ml during both daily sessions. This change doubled the relative cost of choosing the lever that provided a 0.05 ml drop of solution and halved the relative cost of choosing the lever that provided a 0.1 ml drop of solution. For subject 1, the drop size per lever press on one of the two levers was decreased to 0.025 ml during both daily sessions, causing a relative price change similar to subjects 2 and 3.

Table 3.1 (continued)

	Subject 3			
	Early Experiment		Late Experiment	
	Lever 1	Lever 2	Lever 1	Lever 2
Liquid	Cherry	Grape	Orange	Strawberry ETOH
Baseline data				
Days of data	32		32	
Budget	80		80	
Drop size (ml)	0.05	0.05	0.05	0.05
Mean lever press	9.60	70.40	10.40	69.60
Mean quantity (ml)	0.48	3.52	0.52	3.48
Std. dev. (quantity)	0.27	0.27	0.32	0.32
Mean ETOH intake (g/kg)				0.90
Experimental data				
Days of data	30		30	
Budget	76		76	
Drop size (ml)	0.1	0.05	0.1	0.05
Mean lever press	44.10	31.90	13.60	62.40
Mean quantity (ml)	4.41	1.59	1.36	3.12
Std. dev. (quantity)	0.13	0.67	1.11	0.56
Mean ETOH intake (g/kg)			0.75	

For all subjects, the relative price of ethanol (in the later session) was increased. The change in relative drop sizes was accompanied by a change in allotted budgets for each subject in order to hold baseline income constant. For subjects 2 and 3 (subject 1) the price change was accompanied by a decrease (increase) in the budget in order to compensate for the larger (smaller) drop size per lever press available under the experimental condition. The budget adjustments allowed each subject the opportunity to consume, on average, exactly what it consumed under the baseline condition for each daily session. In general, subjects were run for approximately 30 days under experimental conditions.

Control Conditions. To determine if prior ethanol exposure via the Samson fading technique was responsible for the ethanol consumption in the home-cage choice environment, subject C1, an ethanol-naive animal, was tested under similar conditions. Subject C1 was given daily concurrent 30-minute access to two alternative 10 percent sucrose/Kool-Aid flavors for five days and then given similar access to the same solutions, except that 15 percent ethanol was added into one of the two solutions for the following five days.

This study was designed so that for most purposes, each subject could serve as its own control. Under the design, the behavior resulting from an increase in the price of ethanol during the late session could be compared directly to the behavior resulting from an increase in the price of an otherwise similar nonethanol commodity during the early session. Two complications arose from this type of control. First, the effect of the earlier daily session could have influenced behavior during the late session—although this was not found to be the case in the context of the home-cage exposure. Second, the difference in the time of day between the two daily sessions could have differently influenced behavior during the sessions. Two control subjects, C2 and C3, were tested under different experimental parameters in order to ascertain whether the two complications had any confounding affects on the within-subjects comparison between the two daily sessions.

On test day 50, subject C2 received concurrent 30-minute access to a 10 percent sucrose/15 percent ETOH/strawberry solution and a 10 percent sucrose/orange solution in its home cage and was then tested similarly to subjects 1, 2, and 3 until the beginning of the baseline testing sessions. Under the baseline condition, subject C2 was tested only once daily for 15 sessions, choosing between a 10 percent sucrose/15 percent ETOH/strawberry flavor on one lever and an alternative 10 percent sucrose/orange flavor on the alternative lever (baseline: FR-1, 0.05 ml/press, both levers). Next, a price change was introduced similar to that for subjects 1, 2, and 3, and subject C2 was tested over 15 subsequent daily sessions (see table 3.1 for details). Under this design, subject C2 was not tested in a session prior to the ethanol session each day, eliminating any influence an earlier session might have had and providing an estimate of this influence on the behavior of the other subjects. Following this test, subject C2 was tested again, at the same time of day and only once per day, choosing between alternative 10 percent sucrose/strawberry and 10 percent sucrose/orange solutions and facing a similar experimental price change. The subject was run for 10 days baseline and 10 days experimental condition (see table 3.1 for details). Running the ethanol and nonethanol experiments back to back allowed a within-subject comparison to be made between the two experiments. Although subject C2's experimental design eliminated the concern over the effect of two daily sessions and differences in time of day, it created a slight difference in this subject's age for the second test.

Subject C3, an ethanol-naive animal, was tested similarly to subjects 1, 2, and 3 except that it chose between two nonethanol solutions in the late session. Subject C3 allowed a within-subject comparison to be made between the effects of a similar price change in early and late sessions, in the absence of ethanol. The only differences between the sessions was the time of day and specific Kool-Aid flavors being used. Subject C3 was tested for 10 days baseline and 12 days experimental condition.

3.2.2 Results

Home Cage Intake

Figure 3.1 compares relative mean intake in the home cage under ethanol and nonethanol conditions for control subject C1. Figures 3.2, 3.3, and 3.4 compare mean intake levels during the home-cage condition to intake during each of the operant conditions. Lines on each bar indicate standard deviation.

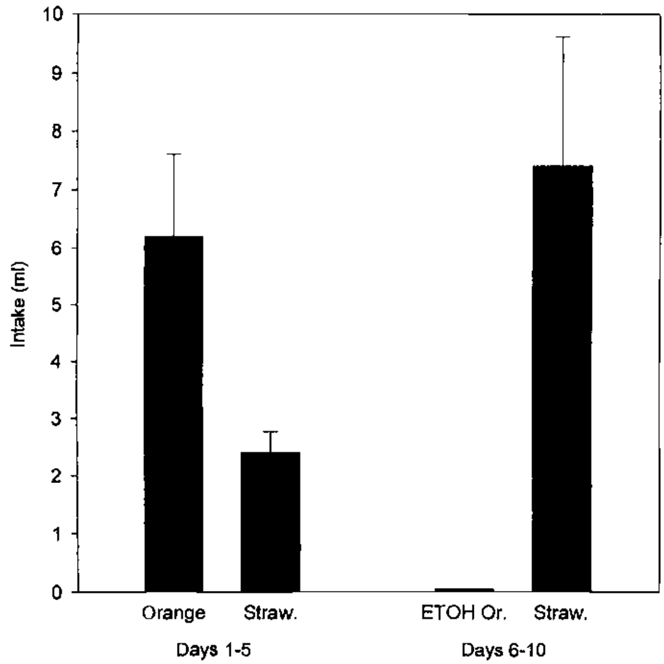

Fig. 3.1 Subject C1—concurrent home-cage intake before and after the introduction of ethanol to an ethanol naive rat

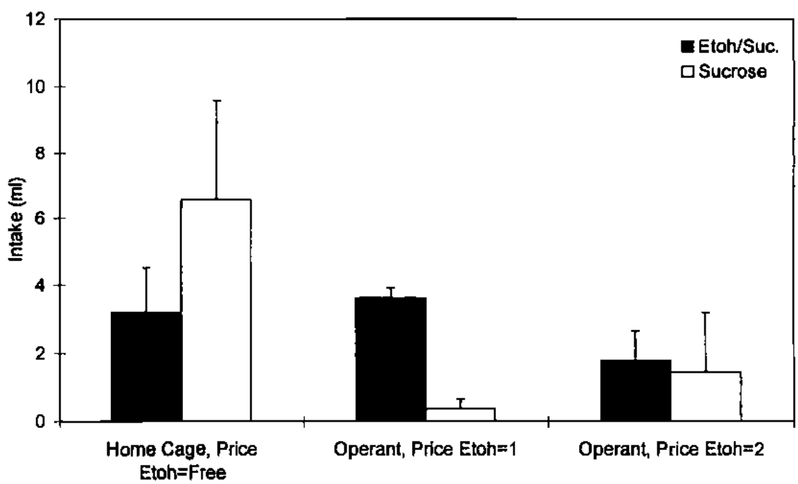

Fig. 3.2 Subject 1—average daily intake under alternative price conditions

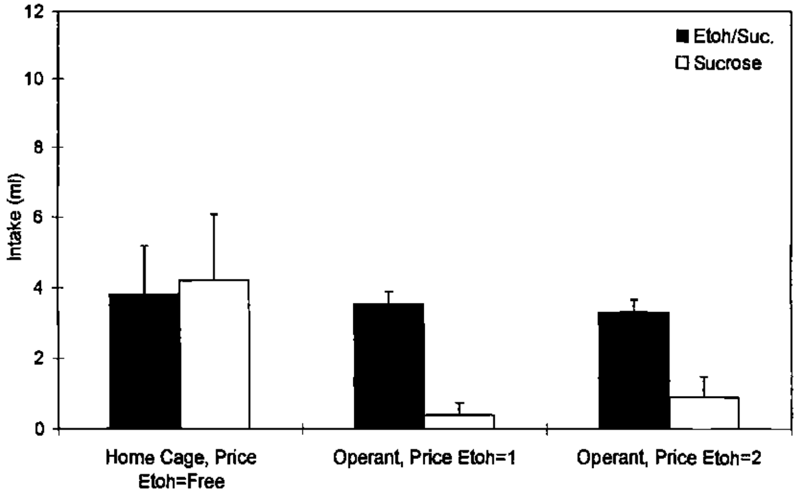

Fig. 3.3 Subject 2—average daily intake under alternative price conditions

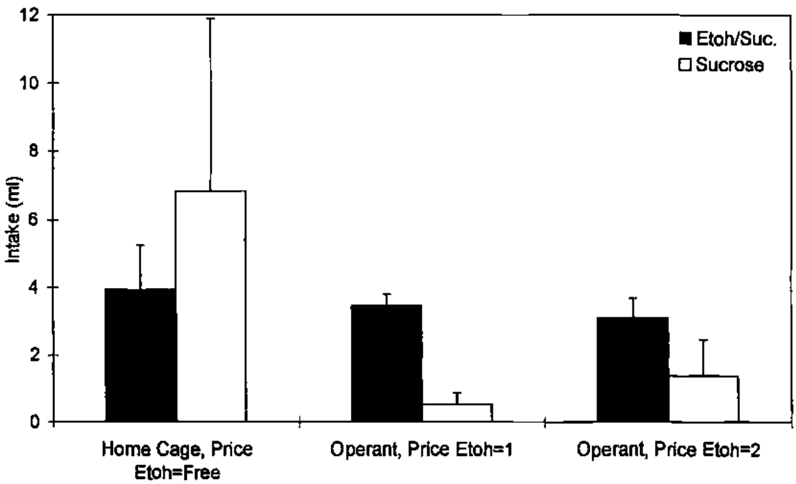

Fig. 3.4 Subject 3—average daily intake under alternative price conditions

Table 3.2 reports the price elasticity of demand estimated from equation (2) for each subject.

Control Subject C1. During the first 5 of the 10 days of daily concurrent 30-minute access to 10 percent sucrose/orange and 10 percent sucrose/strawberry in the home cage, subject C1 indicated a preference for the orange flavor. Average orange intake was 6.2 ml and average strawberry intake was 2.4 ml. During the second 5 days, 15 percent ethanol was added to the orange commodity.

Table 3.2 **Demand Elasticities**

Subject/Session	Commodity	Elasticity	*T* Statistic	R^2	*N*
1, early	Grape	−0.94	−10.18	0.73	41
1, late	ETOH Strawberry	−1.27	−6.99	0.46	59
2, early	Strawberry	−0.96	−14.21	0.78	56
2, late	ETOH Cherry	−0.10	−2.41	0.10	56
3, early	Grape	−1.38	−7.06	0.45	62
3, late	ETOH Strawberry	−0.18	−2.89	0.12	62
C2, early	Orange	−0.99	−6.53	0.70	20
C2, early	ETOH Strawberry	−0.30	−4.07	0.37	20
C3, early	Strawberry	−1.05	−7.20	0.72	22
C3, late	Cherry	−1.03	−5.38	0.59	22

During this period, average consumption of orange dropped to less than 0.1 ml and strawberry consumption rose to 7.4 ml. These results confirm, as expected, that a previously ethanol-naive subject will not consume an ethanol-sucrose commodity when an alternative nonethanol-sucrose commodity is concurrently available.

Subjects 1, 2, and 3. Subjects 1, 2, and 3 consumed both the ethanol- and nonethanol-sucrose commodities when they were concurrently available in the home cage. In light of the results from subject C1, these results suggest, also as expected, that prior ethanol exposure via the Samson fading technique is necessary to make subjects consume ethanol in the context of an otherwise similar nonethanol commodity. Average intake of each commodity was similar for all three subjects. Each drank more of the nonethanol-sucrose commodity than of the ethanol-sucrose commodity, indicating that there was no preference for the ethanol commodity when both were freely available. Average intake over the 14-day period can be seen in the "Home Cage" bars in figures 3.2, 3.3, and 3.4.

Home-Cage Intake versus Baseline Operant Intake

Unlike the home-cage environment in which subjects had unlimited access (for 30 minutes) to both commodities, in the operant chambers subjects faced a budget that limited their total intake. Under this paradigm, choosing to consume one commodity decreased the opportunity to consume the alternative commodity. The price of a commodity was determined by the exchange rate between the two commodities. During the baseline sessions, the cost of using a lever press to consume one commodity was giving up the opportunity to use the press to consume an equal amount of the alternative commodity, making the price of each commodity equal to one press. The total budget available to each subject was 4 ml of liquid. Intake of the solutions was confirmed by checking the drinking troughs for unconsumed solution following each session. For all of the subjects during all of the sessions, unconsumed solution was never observed, suggesting that subjects drank all of the solution obtained by lever pressing.

During the baseline operant period, subjects 1, 2, and 3 exhausted almost all of their budgeted 4 ml of liquid on the ethanol commodity. Average daily ethanol intake was very similar for the home-cage session and the baseline operant sessions, differing on average by less than 0.5 ml. On the other hand, consumption of the nonethanol commodity fell dramatically, as would be required to maintain ethanol consumption given the limited budget of the baseline operant sessions. Intake of the nonethanol commodity for subjects 1, 2, and 3 fell by 6.21 ml, 3.82 ml, and 6.34 ml respectively. The bar graphs labeled "Home Cage" and "Operant, Price Etoh = 1" in figures 3.2, 3.3, and 3.4 illustrate the magnitude of the changes in consumption between the two conditions.

Operant Intake: The Effect of a 100 Percent Price Increase on the Consumption of an Ethanol Commodity versus a Nonethanol Commodity

Relative price was changed between the operant baseline and experimental condition. In the earlier daily control session, the price of one of the two nonethanol commodities was doubled. In the later ethanol session, the price of ethanol was doubled. Figures 3.5–3.9 show three-day moving averages of the daily intake of each solution as well as total intake during the operant baseline and experimental condition. In figures 3.5–3.9, the effect of the price change on intake can be seen by looking at the relative change in consumption across conditions—the commodity indicated by the solid symbols doubled in price during the experimental condition and the commodity indicated by open symbols was halved in price.

Subjects 2 and 3. Subjects 2 and 3 both responded to the price change in the earlier, nonethanol control sessions by increasing consumption of the cheaper commodity and reducing consumption of the more expensive commodity. Subject 2's price elasticity of demand for strawberry when choosing between that and orange was -0.96 ($t = -14.21$), indicating that consumption of strawberry decreased by 0.96 percent for each 1.00 percent increase in its price. Subject 3's price elasticity of demand for grape when choosing between that and cherry was -1.38 ($t = -7.06$), indicating that consumption of grape decreased by 1.38 percent for each 1.00 percent increase in its price. These results are consistent with the economic law of demand, indicating that the history of ethanol exposure did not interfere with the ability of these rats to make choices accordingly. Figures 3.5 and 3.6 show average daily intakes (derived from a three-day moving average of the actual daily intake data) prior to and following the price change. These graphs illustrate the statistically significant change in intakes that resulted from the change in price. As the price of one commodity increased (*solid circles or squares*), both subjects substituted away from that commodity into the relatively cheaper commodity (*open circles or squares*), which resulted in an increased total intake for the session.

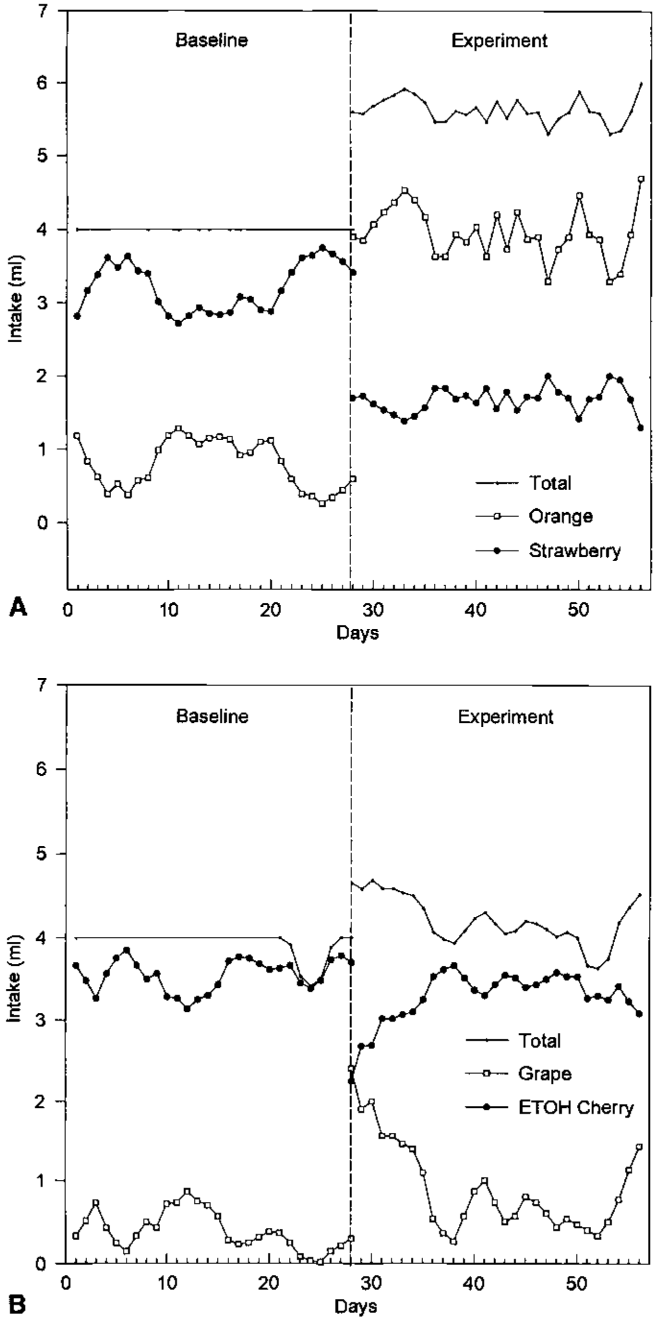

Fig. 3.5 Subject 2—response to a control commodity (strawberry) price increase (*A*) and to an ethanol commodity (ETOH/cherry) price increase (*B*) over days

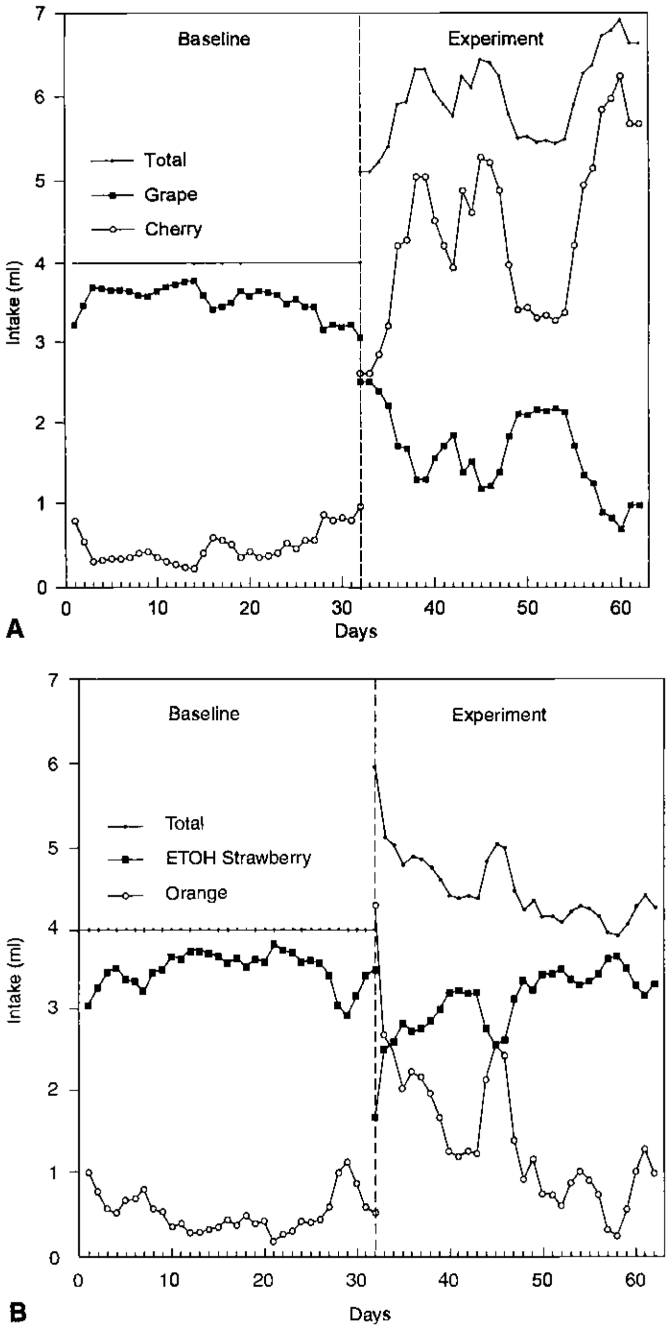

Fig. 3.6 Subject 3—response to a control commodity (grape) price increase (*A*) and to an ethanol commodity (ETOH/strawberry) price increase (*B*) over days

In the later ethanol sessions, subjects 2 and 3 both initially responded to the increase in the price of ethanol by reducing its consumption. Then, over subsequent testing days, ethanol consumption rose until it stabilized near the baseline level. Relative to the elasticity of demand for the nonethanol commodity during the control session, the elasticity of demand for the ethanol commodity was small for both subjects. Subject 2's price elasticity of demand for cherry with 15 percent ethanol when choosing between that and grape was -0.10 ($t = -2.41$), indicating that consumption of cherry with ethanol decreased by 0.10 percent for each 1.00 percent increase in its price. Subject 3's price elasticity of demand for strawberry with 15 percent ethanol when choosing between that and orange was -0.18 ($t = -2.89$), indicating that consumption of strawberry with ethanol decreased by 0.18 percent for each 1.00 percent increase in its price. Figures 3.5 and 3.6 show mean daily intake (derived from a three-day moving average of the actual daily intake) before and after the price change. Following the price change, the drop in consumption of ethanol indicates that the subjects reacted to the change in price initially but then increased consumption of ethanol, nearly back to the baseline level, over subsequent days. Figures 3.3 and 3.4 show bar graphs of the mean daily intake under each condition: home cage, operant with the price of ethanol equal to 1, and operant with the price of ethanol equal to 2.

When comparing the relative effect of the price change between the ethanol and nonethanol sessions, consistent differences exist. In the control session, both subjects switched consumption away from one sucrose-flavored commodity in exchange for an alternatively flavored sucrose commodity when the price of the former increased. In the ethanol session, the subjects did not, however, switch consumption away from the flavored ethanol-sucrose commodity in exchange for the alternatively flavored nonethanol-sucrose commodity when the price of the ethanol commodity increased. This suggests that ethanol is very reinforcing relative to the alternative reinforcer.

Previous studies of demand using an economic model of consumer choice in rats have employed the ABA design (baseline–experiment–baseline) used in the present study. All of these studies have shown that behavior similar to that of subjects 2 and 3 following the price change was a result of the price change and not random (Kagel et al. 1975; Kagel, Battalio, and Green 1995). In light of the results from these studies, and in consideration of the time and resources that would have been required to return the subjects to baseline, subjects 2 and 3 were not returned to baseline. It is reasonable to conclude that the present results are due to the difference in price between the baseline and experimental condition and are not random.

Subject 1. Subject 1's response to the price change in the early session of each day was similar to that of subjects 2 and 3. However, in the later (ethanol) session, the increase in the price of ethanol severely disrupted the subject's behavior, causing intermittently high and low levels of responding for ethanol as well as erratic responding for the alternative commodity. Following the price change, the subject often failed to exhaust its allotted budget within the 45-minute session time limit. In the nonethanol control session, subject 1's price elasticity of demand for grape when choosing between that and cherry was −0.94 ($t = -10.18$). In the ethanol session, the price elasticity of demand for strawberry with 15 percent ethanol when choosing between that and orange was −1.27 ($t = -6.99$).

Due to its erratic behavior during the experimental segment of the ethanol session, this subject was returned to baseline parameters consistent with the ABA design. In the early nonethanol control session, subject 1 returned to its original baseline behavior. However, in the ethanol session, consumption of ethanol increased but did not return to its original baseline level. Also, responding continued to be highly erratic. Figure 3.7 shows daily moving average intake levels for each session. Figure 3.2 shows average daily intake under each condition: home cage, operant with the price of ethanol equal to 1, and operant with the price of ethanol equal to 2.

Control Subjects C2 and C3. Subject C2's results were similar to those of subjects 2 and 3, helping to confirm that the difference in behavior between the ethanol and nonethanol sessions was caused by the presence of ethanol rather than the differing times of these sessions. Subject C2's price elasticity of demand for orange when choosing between that and strawberry was −0.99 ($t = -6.53$) and the price elasticity of demand for strawberry with 15 percent ethanol when choosing between that and orange was −0.30 ($t = -4.07$). Figure 3.8 shows the daily moving average intake levels for each session.

Subject C3's demand elasticities between two daily nonethanol sessions were virtually identical, further supporting the case for ethanol being the cause of the behavioral differences between sessions in subjects 1, 2, and 3. In the early session, subject C3's price elasticity of demand for strawberry when choosing between that and orange was −1.05 ($t = -7.20$), and in the late session, the price elasticity of demand for cherry when choosing between that and grape was −1.03 ($t = -5.38$). Figure 3.9 shows the daily moving average intake levels for each session.

3.2.3 Discussion

In a within-subjects design, rats were exposed to a variant of the Samson ethanol-fading technique and then tested in two similar daily operant sessions, which differed primarily by the presence of ethanol as an alternative reinforcer in one of the sessions. Using operant testing procedures based on an economic model of consumer choice, changes in ethanol consumption due to the imposition of a budget and changes in relative price were measured. Results from the experiment provide information on ethanol consumption and economic choice behavior toward ethanol in rats with a history of ethanol exposure.

Ethanol was used as a commodity because of its addictive properties. The

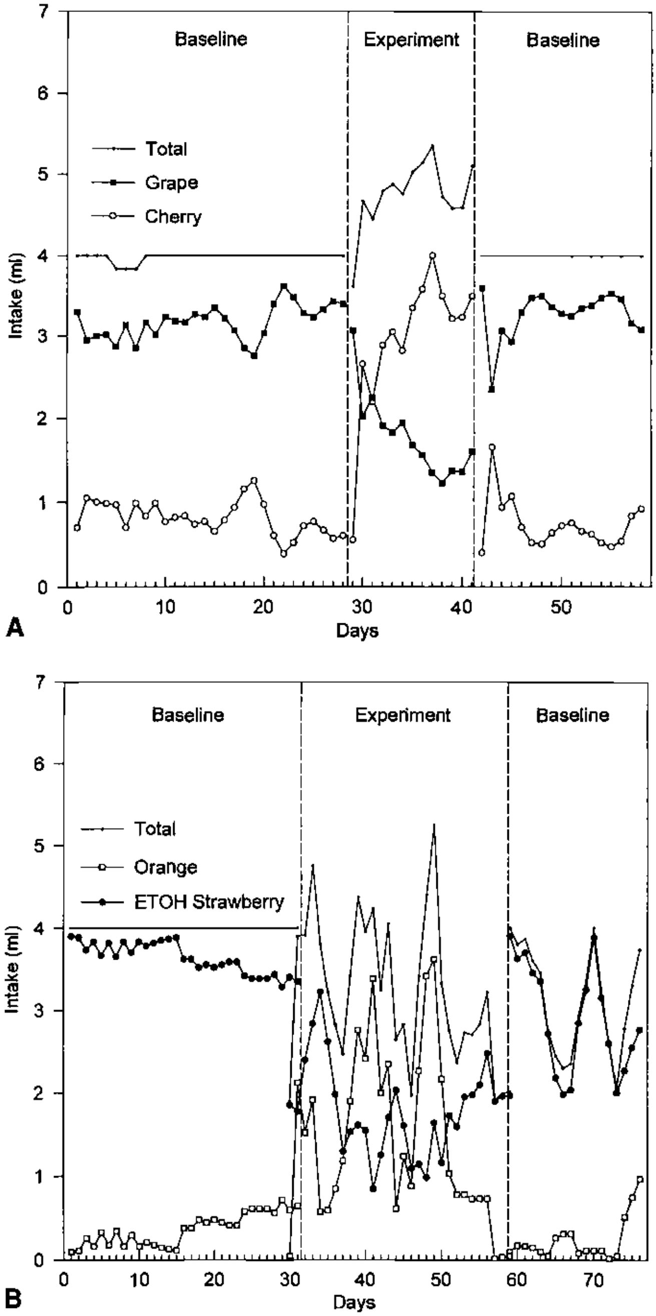

Fig. 3.7 **Subject 1—response to a control commodity (grape) price increase (*A*) and to an ethanol commodity (ETOH/strawberry) price increase (*B*) over days**

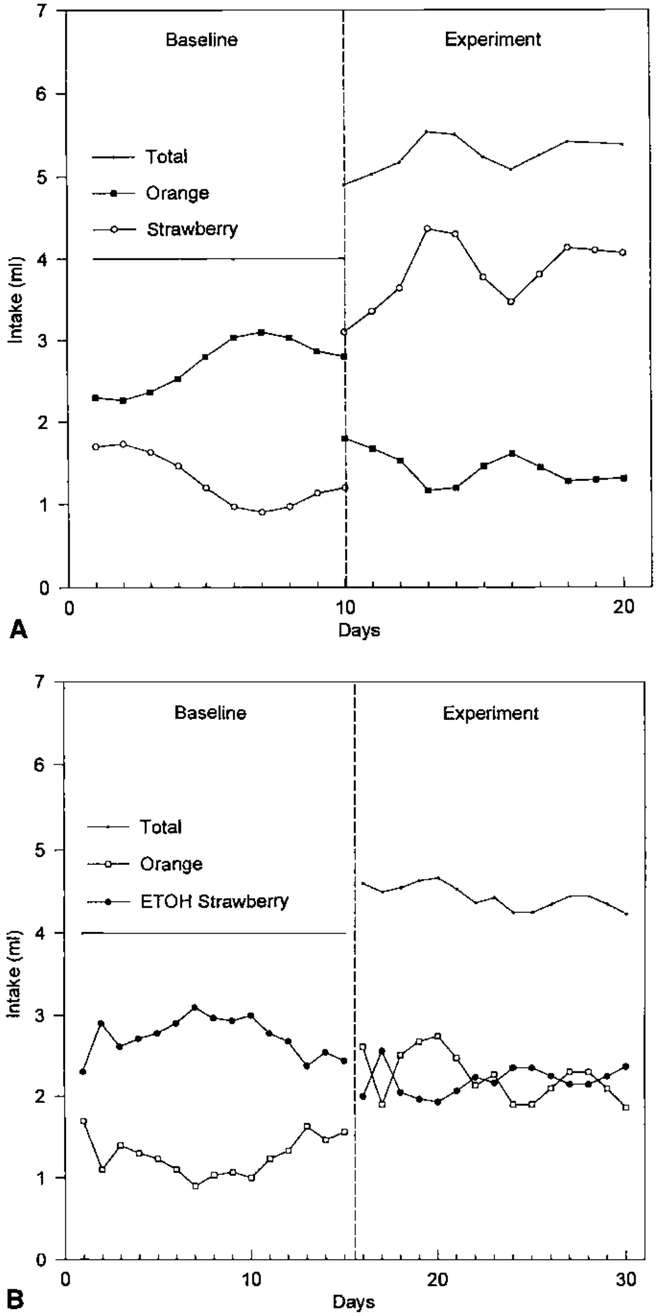

Fig. 3.8 Subject C2—response to a control commodity (orange) price increase (*A*) and to an ethanol commodity (ETOH/strawberry) price increase (*B*) over days

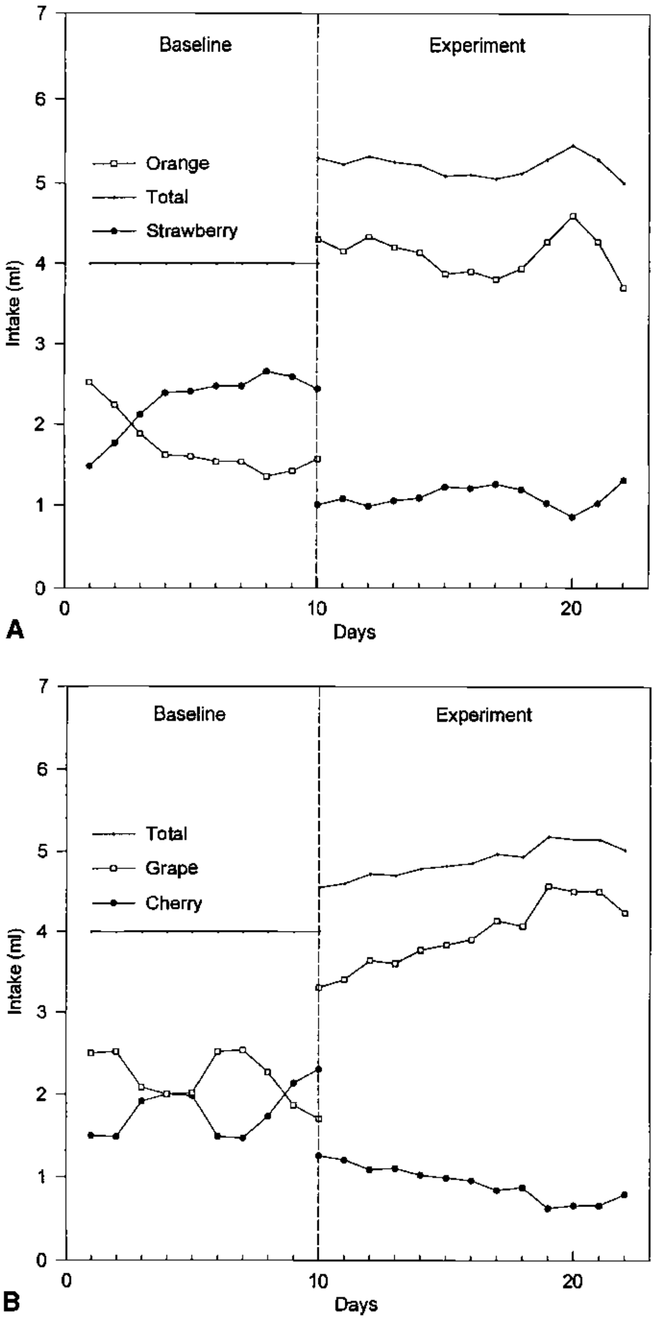

Fig. 3.9 Subject C3—response to a control commodity (strawberry) price increase (*A*) and to a control commodity (cherry) price increase (*B*) over days

focus of this experiment was consumer choice behavior when one commodity in the choice set was addictive. Addictive commodities such as ethanol can be viewed as commodities whose current consumption depends on previous exposure; in other words, a commodity that reinforces its own consumption over time is addictive (Becker and Murphy 1988). The use of the Samson fading procedure could be viewed as addicting rats to ethanol in that only through such past exposure were they willing to consume appreciable amounts of ethanol, although pharmacological addiction was not confirmed empirically in the present experiment.

Following exposure to ethanol via the Samson technique, subjects chose between concurrently available ethanol- and nonethanol-sucrose commodities. Under this design it was unclear that ethanol was driving the consumption of the ethanol-sucrose commodity, even though an alternative sucrose commodity was concurrently available. Subject C1, the ethanol-naive subject, confirmed that ethanol was driving the intake of the ethanol commodity; subject C1 did not drink the ethanol-sucrose commodity when an alternative nonethanol-sucrose commodity was concurrently available. This difference in behavior suggested that subjects that consumed ethanol were addicted in the sense that previous exposure, via the Samson sucrose-fading technique, was necessary for current intake.

Comparison between the home-cage, free-choice intake levels and intake during the baseline operant condition also supports the hypothesis that subjects were addicted to ethanol following the Samson procedure, again in terms of the definition of addiction applied in economic theory (Becker and Murphy 1988). In the home-cage environment, subjects 1, 2, and 3 consumed both the ethanol and nonethanol commodities, and somewhat more of the nonethanol commodity on average. When the total daily intake was limited by a 4 ml budget constraint per daily session and a response contingency, however, the subjects virtually gave up consumption of the nonethanol commodity but maintained ethanol consumption near the home-cage level. This suggests that the subjects were regulating ethanol intake in the home cage and that ethanol is highly reinforcing until some intake level, presumably near the home-cage, free-choice level, is met. This argument explains why the subjects gave up almost all of the nonethanol commodity when total intake was limited even though, in terms of total intake, they preferred the nonethanol commodity in the home cage.

The next segment of the experiment utilized an economic model of consumer choice to compare the effect of a relative price increase on ethanol consumption versus a similar nonethanol commodity. Comparison between the ethanol and nonethanol control sessions revealed the effects of ethanol on economic choice behavior within each subject. Demand elasticities were estimated for each session using ordinary least squares regression techniques on equation (1). Results showed significant price-change effects in each session and differences in the demand elasticities across sessions. Subjects 1, 2, and 3 all responded to the price change in the nonethanol session by switching consumption toward the cheaper commodity. The demand elasticities reported here are similar to results reported in previous studies of the consumer choice model in rats (Kagel, Battalio, and Green 1995) and indicate that prior ethanol exposure did not interfere with the subjects' ability to make decisions according to the maximizing principles of economic theory. Furthermore, when subject 1 was returned to baseline following the experimental condition, consumption returned to its original baseline levels. This suggests that the price change was responsible for all changes in behavior during the experimental condition and that the subject's preference structure was stable across conditions.

Subject 1, 2, and 3's responses to the price change during the ethanol session indicate that ethanol is highly reinforcing in rats that previously had consumed significant amounts of ethanol. When the cost of attaining ethanol doubled in terms of lost nonethanol-sucrose opportunity, subjects 2 and 3 both initially decreased ethanol consumption in exchange for a relatively larger amount of the nonethanol-sucrose commodity per lever press. However, over subsequent testing days this behavior reversed itself and the subjects returned to exhausting almost all of their budget on the ethanol commodity. As a result, the subjects continued to maintain a level of ethanol intake near that of their home-cage, free-choice level. These findings are not consistent with the rational addiction hypothesis (Becker, Grossman, and Murphy 1991) that long-run elasticities will be relatively larger than short-run elasticities for addictive versus nonaddictive commodities.

Subject 1's behavior following the price change in the ethanol session was very erratic compared to that of subjects 2 and 3. This might be attributed to how the price change was initiated between the subjects. For subjects 2 and 3 the price change was initiated by increasing the volume per lever press on the nonethanol solution and adjusting the budget downward, while for subject 1, the volume of ethanol per lever press was reduced and the budget was adjusted upward. Although the magnitude of the price change was the same for all subjects, this operational difference required subject 1 to press the lever twice as many times as subjects 2 and 3 in order to maintain baseline consumption levels. Regardless of this difference, subject 1's response to the price change during the nonethanol session was similar to that of subjects 2 and 3. This difference may have had an influence on behavior during the ethanol session, however. Gnawing at the ethanol drinking trough was observed in subject 1 during the sessions immediately following the decrease in ethanol volume per lever press, perhaps indicating emotional or adjunctive behavior. When the parameters were returned to baseline, subject 1's behavior remained erratic and did not return to original levels. Considering the erratic behavior and decrease in ethanol consumption during the experimental condition, the failure to return to baseline is consistent with the hypothesis that current ethanol consumption depends on prior intake levels. It also suggests that disruptions severe enough to decrease current intake also affect future intake.

The results from the operant control subjects helped confirm that ethanol was driving the behavioral differences between the ethanol and nonethanol sessions observed in the experimental subjects. Subject C1 was tested twice daily in two nonethanol sessions that differed by Kool-Aid flavor and time of day. Results between the two sessions were nearly identical. Subject C2 was tested holding the time of day and prior daily testing constant. Results showed this control subject to be much less responsive toward the increase in the price of ethanol than toward the increase in the price of the nonethanol commodity. These results provide suggestive but not conclusive evidence that the factors associated with time of day and of prior daily testing did not contaminate the effects of alcohol observed in the behavior of subjects 1, 2, and 3. The control results reported here are across subjects and should be interpreted accordingly. An alternative, within-subject, control procedure could have involved alternating the time the ethanol and nonethanol sessions were run across days or weeks. However, running the subjects in this way would have required changing the time of day within the ethanol and nonethanol sessions, introducing more severe control problems.

3.3 Experiment B

3.3.1 Overview

During experiment A, in general, the subjects' responses to the ethanol price increase were quite small. This result naturally raised the question of whether or not ethanol-experienced rats would respond more to a much larger price increase. To test this, when experiment A ended, subjects 1, 2, and 3 were returned to their home cages, where, over a number of days, they received daily 30-minute access to concurrently available plain sucrose and ethanol-sucrose solutions. The subjects were then tested for responses to a 400 percent increase in the price of ethanol using operant testing methods similar to those described in the 100 percent price change experiment. During 10 days of baseline operant testing, the total budget was set at 6 ml and the price ratio was set at one. Over the following 20 days, the subjects faced a 400 percent increase in the relative price of ethanol. The price was changed by halving the ethanol-sucrose solution dispensed per lever press to 0.025 ml and doubling the plain sucrose to 0.10 ml per press. The budget was adjusted to hold real income constant. During the final 10 days of operant testing, the price and budget were returned to baseline.

In addition to the larger price change, there were other differences in experiment B. The subjects were only tested once daily in the operant chamber, choosing between an ethanol-sucrose and a plain sucrose commodity. The baseline budget was larger at 6 ml compared to 4 ml. No control subjects were used, since no comparison between the effect of the 400 percent price increase on ethanol versus nonethanol consumption was made. Following the price change condition all of the subjects were returned to baseline. Finally, the subjects were tested over a shorter number of test days.

3.3.2 Results

In general, subject 1, 2, and 3's preferences for the plain sucrose and ethanol-sucrose commodities were similar to those exhibited during the 100 percent price change experiment. Responses to the 400 percent ethanol price increase were more pronounced, however.

Home-Cage Intake

Subjects 1, 2, and 3 consumed both ethanol and nonethanol sucrose commodities when they were concurrently available in the home cage. Average intake of each commodity was similar for all three subjects. Each drank more of the plain sucrose commodity than of the ethanol sucrose commodity, indicating that there was no preference for the ethanol sucrose commodity when both were freely available. Average intake over the 10-day period can be seen in the "Home Cage" bars in figures 3.10, 3.11, and 3.12.

Home-Cage Intake versus Baseline Operant Intake

During the baseline operant period, subjects 1, 2, and 3 exhausted most of their budgeted 6 ml of liquid on the ethanol commodity. Average daily ethanol intake was just over 4 ml for each subject during the baseline operant sessions, representing a small decline relative to home-cage intake. On the other hand, consumption of the nonethanol commodity fell dramatically, as would be required to maintain near home-cage ethanol levels given the limited budget of the baseline operant sessions. Intake of the nonethanol commodity for subjects

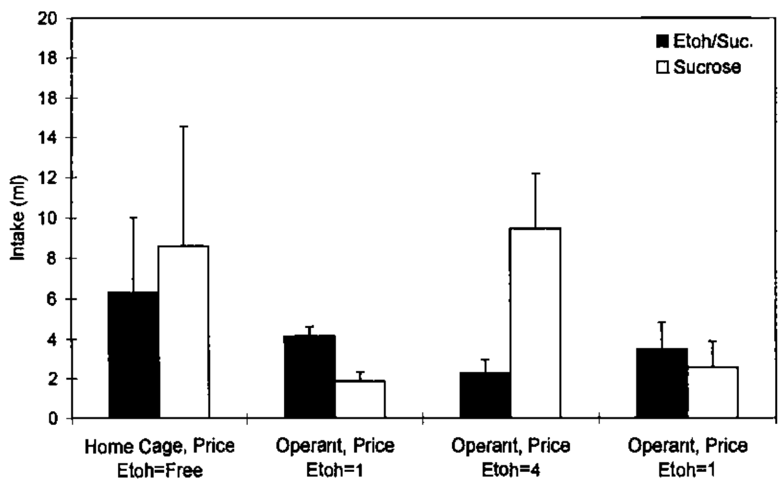

Fig. 3.10 Subject 1—average daily intake under alternative price conditions

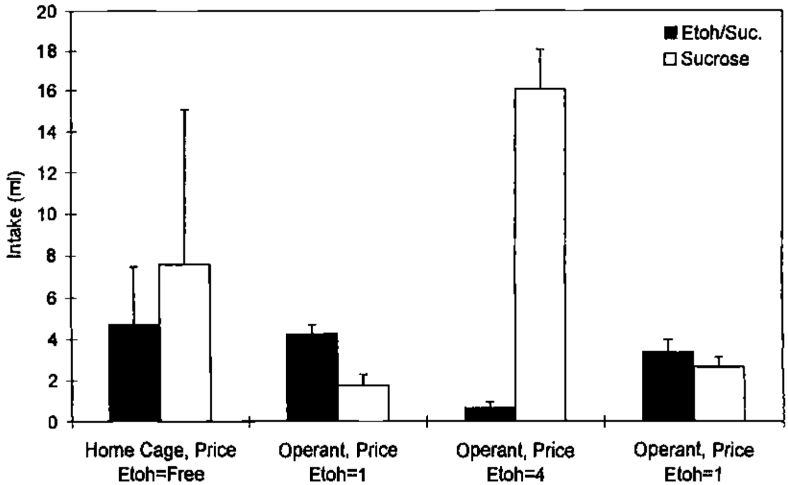

Fig. 3.11 Subject 2—average daily intake under alternative price conditions

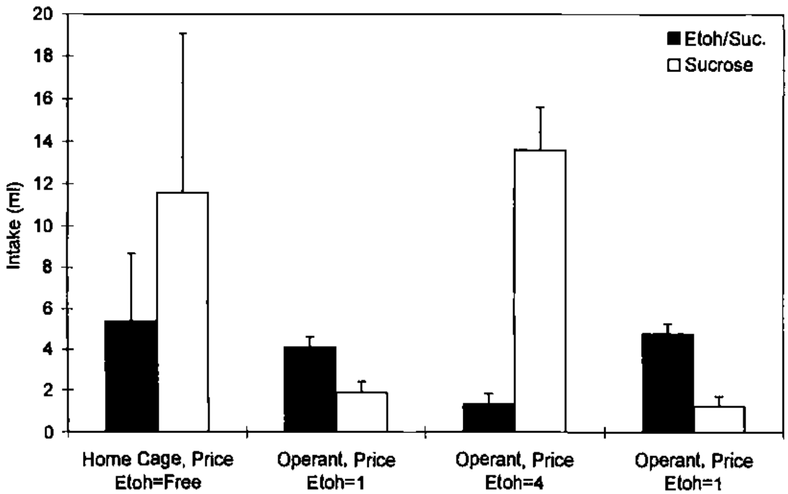

Fig. 3.12 Subject 3—average daily intake under alternative price conditions

1, 2, and 3 fell by 6.76 ml, 5.84 ml, and 9.71 ml, respectively. The bar graphs labeled "Home Cage" and "Operant, Price Etoh = 1" in figures 3.10–3.12 illustrate the magnitude of the changes in consumption between the two conditions.

Operant Intake: The Effect of a 400 Percent Price Increase on the Consumption of an Ethanol Commodity

Subjects 1, 2, and 3 all responded to the increase in the price of ethanol by reducing consumption of the ethanol commodity. Subject 1's price elasticity of demand for ethanol was −1.25 ($t = -6.26$). Subject 2's price elasticity of demand for ethanol was −0.59 ($t = -12.35$). Subject 3's price elasticity of demand for ethanol was −0.83 ($t = -6.26$). The bar graphs labeled "Operant, Price Etoh = 1" and "Operant, Price Etoh = 4" in figures 3.10–3.12 illustrate the magnitude of the changes in consumption in response to the price change.

Return to Operant Baseline

Subjects 1, 2, and 3 were returned to operant baseline following the 400 percent price change condition. Consumption behavior for each subject returned to near its original operant baseline level. The bar graphs labeled "Operant, Price Etoh = 1," "Operant, Price Etoh = 4," and "Operant, Price Etoh = 1" in figures 3.10–3.12 illustrate the return to baseline response.

3.3.3 Discussion

Experiment B represents an extension of experiment A. The decision to conduct the experiment was made following the observation of small consumption effects in response to a 100 percent increase in ethanol's price. The purpose of experiment B was to attempt to ascertain whether a larger increase in the price mechanism would result in a similar, small response. Experiment B was conducted using the same subjects and similar procedures as experiment A.

To begin experiment B, the subjects were returned to their home cages and given daily 30-minute access to concurrently available plain sucrose water and ethanol-sucrose water solutions. Doing this essentially replicated the initial home-cage condition of experiment A, with the exception that no Kool-Aid flavors were involved. Comparing the "Home Cage" bars in figures 3.2, 3.3, and 3.4 from experiment A to the "Home Cage" bars in figures 3.10, 3.11, and 3.12 from experiment B shows very similar relative intakes. Again, each subject drank more plain sucrose solution relative to ethanol solution, confirming that plain sucrose was preferred to an ethanol-sucrose solution when both were freely available.

The subjects were then tested in an operant chamber in a manner similar to that used in experiment A. A budget and equal prices were first imposed. Behavior was nearly identical to the similar circumstance in experiment A. In response to the limited income, all subjects dramatically reduced plain sucrose consumption and maintained near home-cage ethanol intake, again confirming the behavior in experiment A. This behavior suggests that the subjects seek to maintain some minimum ethanol intake level.

The subjects' behavior in response to a 400 percent increase in ethanol's price was significantly different from their responses to the 100 percent increase in experiment A. All of the subjects responded by dramatically reducing ethanol consumption. The result suggests that significant increases in ethanol's price, measured by the forgone opportunity to consume an alternative plain sucrose commodity, influences ethanol consumption. Also, for experiments A and B, the magnitude by which each subject responded to the change in price was of similar order—subject 2's elasticity was relatively smallest, subject 3's was second, and subject 1's was largest.

Caution must be taken, however, when making comparisons between experiment A and B. During experiment B there was no earlier nonethanol operant session, because of the concern that an earlier 400 percent price change session might cause satiation prior to the later ethanol session. As such, it is possible that ethanol's relative value differed between experiments A and B. However, relative ethanol consumption during the similar baseline conditions of experiments A and B was nearly identical, suggesting that the magnitude of the price change was primarily responsible for behavior differences.

Finally, experiment B returned the subjects to the baseline conditions. As can be seen in figures 3.10 and 3.11, subject 1 and 2's ethanol intake did not completely return to their higher baseline levels. Although clearly inconclusive, such behavior is consistent with the notion that an addictive commodity, such as ethanol, is a time complement. More important, the general return to baseline by each subject strongly suggests that the reduced ethanol intake during the experimental condition was a direct result of ethanol's increased price.

3.4 General Conclusions

This study utilized economic models of consumer choice to study the demand for an addictive commodity. Our approach differs dramatically from current economic studies of addictive consumption. By adopting the experimental psychologist's controlled experiment methodology we were able to compare the impact of a given price change on addictive and nonaddictive consumption. Because traditional economists do not use controlled experiments, this result has not before been attainable. Further, the results provide new information on the reinforcing effects of ethanol in rats.

The focus of this study was to compare demand elasticities between addictive and nonaddictive commodities as a means to begin looking at economic theorems of addictive behavior. We employed ethanol because it exhibits addictive properties. We employed rats because it allowed for necessary experimental controls that are unreasonable in human subjects.

We confirmed Samson's (1986) finding that rats can be induced to consume ethanol. The procedure essentially "addicted" rats to ethanol, suggesting that current ethanol intake is a function of past consumption. The rats consumed an appreciable amount of ethanol-sucrose commodity but did not prefer it to a similar sucrose commodity when both were freely available. However, imposing a budget to limit total daily intake resulted in dramatic reductions in sucrose consumption while hardly affecting ethanol-sucrose intake. The result suggests that ethanol is very reinforcing until a minimum intake level (presumably near the free-choice level) is attained.

Second, we found that changes in current price affected behavior. This was true for both nonethanol as well as ethanol commodities. Where comparisons were made, responses to ethanol price changes were typically smaller than responses to nonethanol price changes, a result that again suggests that ethanol is very reinforcing. In experiment A, a 100 percent increase in ethanol's price only reduced its consumption by marginal amounts. Over time, responses to the price change tended to become smaller, suggesting that long-run elasticities are not larger than short-run elasticities. In experiment B, a 400 percent increase in ethanol's price dramatically reduced ethanol consumption. These results suggest that human addicts may also be susceptible to dramatic changes in price. As such, public policy makers might consider using increased taxes as a mechanism to minimize addiction. Using the techniques employed in this study, future research might attempt to directly test rational addiction theory by comparing responses to anticipated future changes in price for addictive and nonaddictive commodities. However, this entails complicated stimuli to signal future price changes to rat subjects.

References

Becker, Gary S., Michael Grossman, and Kevin M. Murphy. 1991. Rational addiction and the effect of price on consumption. *American Economic Review* 84:237–41.

———. 1994. An empirical analysis of cigarette addiction. *American Economic Review* 84:396–418.

Becker, Gary S., and Kevin M. Murphy. 1988. A theory of rational addiction. *Journal of Political Economy* 96:675–700.

Chaloupka, Frank J. 1991. Rational addictive behavior and cigarette smoking. *Journal of Political Economy* 99:722–42.

Grossman, Michael, Frank J. Chaloupka, and Charles C. Brown. 1996. The demand for cocaine by young adults: A rational addiction approach. NBER Working Paper no. 5713. Cambridge, Mass.: National Bureau of Economic Research.

Grossman, Michael, Frank J. Chaloupka, and Ismail Sirtalan. 1995. An empirical analysis of alcohol addiction: Results from the Monitoring the Future panels. NBER Working Paper no. 5200. Cambridge, Mass.: National Bureau of Economic Research.

Kagel, John H., Raymond C. Battalio, and Leonard Green. 1995. *Economic choice theory: An experimental analysis of animal behavior.* New York: Cambridge University Press.

Kagel, John H., Raymond C. Battalio, Howard Rachlin, Leonard Green, Robert L. Basmann, and William R. Klemm. 1975. Experimental studies of consumer demand behavior using laboratory animals. *Economic Inquiry* 13:22–38.

Samson, Herman H. 1986. Initiation of ethanol reinforcement using a sucrose substitution procedure in food- and water-sated rats. *Alcoholism: Clinical and Experimental Research* 10:436–42.