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11 Income Alters the Relative Reinforcing Effects of Drug and Nondrug Reinforcers

Marilyn E. Carroll

Income is an important factor to consider in evaluating demand for drugs. Income is defined as the amount of funds, resources, and/or time (or number of opportunities) to obtain goods over a specified time period. The income variable becomes especially interesting when considering how resources (income) are apportioned over various consumer choices. Income can change the choice between two reinforcers depending on the price of those goods (Lea, Tarpy, and Webley 1987). This paper will focus on how income affects choices between drug and alternative nondrug substances. Several assumptions are made, such as, (i) drugs function as reinforcers for operant behavior and can be studied by methods of behavior analysis, behavioral pharmacology, and behavioral economics; (ii) principles derived from these three methods of analysis apply to animals and humans in similar ways (Carroll and Rodefer 1993; Carroll, Rodefer, and Rawleigh 1995; DeGrandpre et al. 1993; Johanson 1978; Griffiths, Bigelow, and Henningfield 1980); (iii) animal and human behavioral economic models seem to have validity in epidemiological findings (Bickel and DeGrandpre 1995), in human laboratory studies (Bickel and DeGrandpre 1995, 1996), and in treatment approaches (e.g., Higgins 1997; Bickel and DeGrandpre 1996); and (iv) drug reinforcers are affected by income in the same way as nondrug reinforcers (e.g., food), indicating that income effects are guided by general principles.

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11.1 Choice between Different Food Conditions

A number of laboratory studies have demonstrated effects of income on food choice in animals. For example, Silberberg, Warren-Boulton, and Asano (1987) allowed monkeys to work for food and varied income by changing the intertrial interval (ITI) from 60 to 70 seconds for low income to 15 seconds for high income. When monkeys were given a choice between large bitter food pellets and small standard food pellets, their choice was for large bitter pellets when income was low, and it shifted to small standard pellets when income was high. The devaluation of the large bitter pellets as income increased indicated that they were an inferior good. In contrast, the small standard pellets would be considered a normal good because their consumption increased at the same percentage rate as income increased. Under these conditions, income elasticity would be equal to 1. This experiment was replicated in rats by Hastjarjo, Silberberg, and Hursh (1990), extending the finding to another species. Hastjarjo and Silberberg (1992) also extended their results in rats from qualitative differences between different-sized reinforcers to a choice between size and delay of reinforcer delivery. Thus, the choice was between one food pellet presented immediately or three pellets presented after a delay (e.g., 10 seconds). Income was varied by offering approximately 60 free-choice sessions in the low income condition and 100 free-choice sessions in the high income condition.

11.2 Choice between Different Drug Conditions

Parallel experiments have recently been conducted in human subjects given a choice between their own brand of higher-priced cigarettes and a nonpreferred brand of lower-priced cigarettes (DeGrandpre et al. 1993). Income was varied by the amount of money ($15) allocated to the subjects to spend during the experimental session. As in the Silberberg et al. (1987) study, under low income conditions subjects preferred the less-expensive other brand to their own brand. However, when income was high, the preference was reversed, and the more expensive own brand was preferred. Thus, the own brand appeared to be a normal good and the other brand was functioning as an inferior good. These studies illustrate that goods are not endowed with certain properties that are inherently reinforcing, but that the reinforcing effects of these goods are dependent upon the economic context in which they are presented (e.g., availability of other choices, income).

11.3 Choice between Different Types of Food

Shurtleff, Warren-Boulton, and Silberberg (1987) examined the effects of income on choice between food and a noncaloric reinforcer (saccharin) in rats. Income was altered by changing the reinforcement rate from 36 to 240 per

hour. When income was low, food was preferred to saccharin, and when income was high, the preference was reversed to favor saccharin. They suggested that their results may be explained by the minimum needs hypothesis (Kagel, Dwyer, and Battalio 1985), which states that goods are ranked based on how much they are needed for bodily functions. Satiation may occur at different rates for different goods. Thus, preference may have switched from food to saccharin because the need for food was satiated before the hedonic need for saccharin or a palatable taste was satiated.

11.4 Choice between Drug and Nondrug Reinforcers

Only a few studies have investigated the effect of income on choice between a drug and a nondrug reinforcer. An early study by Elsmore et al. (1980) manipulated income by changing the ITI (2 to 12 minutes) and maintaining a constant session length, although it was not originally described as an income study. They offered baboons a choice between self-administered heroin injections and food, each presented at constant magnitudes. In this study there was a closed economy for food and heroin (i.e., the daily food and heroin supply were earned within the experimental session). The income elasticities for both drug and food were positive, but because the income elasticity for food was greater than that for heroin, there was a relative preference for food under low income conditions and for heroin under high income conditions.

11.5 Demand for Drug as a Function of Income and Access to an Alternative Nondrug Reinforcer

The comparison of drug self-administration and consumption of nondrug reinforcers was continued in two studies of rhesus monkeys in which income was varied by changing session length (20, 60, and 180 minutes) (Carroll and Rodefer 1993; Carroll et al. 1995). Either orally delivered phencyclidine (PCP), a dissociative anesthetic (Carroll and Rodefer 1993), or ethanol (Carroll et al. 1995) were available under concurrent fixed-ratio (FR) schedules with saccharin or water. A fixed ratio (FR) is the ratio of the number of required responses for one reinforcement. For example, a fixed number (4, 8, 16, 32, 64, or 128) of lip-contact responses on solenoid-operated drinking spouts were required for the delivery of 0.6 ml of liquid. Each FR value was held constant until responding was stable for at least five days. Variation of the FR allowed for price changes (responses/mg) and construction of demand curves. Drug and saccharin concentrations were held constant. Table 11.1 summarizes the design of these experiments. Since drug and saccharin were available only during the experimental session, a closed economy was used for these goods. However, water was freely available during the intersession period, or under an open economy; thus, the animals were not liquid deprived.

The results of these studies showed that PCP, ethanol (ETOH), and saccharin

Table 11.1 Income Study Design

	FR Value					
Low income (20 min)						
PCP or ETOH	4	8	16	32	64	128
Versus water	32	32	32	32	32	32
PCP or ETOH	4	8	16	32	64	128
Versus saccharin	32	32	32	32	32	32
Medium income (60 min)						
PCP or ETOH	4	8	16	32	64	128
Versus water	32	32	32	32	32	32
PCP or ETOH	4	8	16	32	64	128
Versus saccharin	32	32	32	32	32	32
High income (180 min)						
PCP or ETOH	4	8	16	32	64	128
Versus water	32	32	32	32	32	32
PCP or ETOH	4	8	16	32	64	128
Versus saccharin	32	32	32	32	32	32

Notes: Saccharin versus water counterbalanced. FR given in mixed order. PCP study preceded ETOH study.

were functioning as reinforcers because the behavior maintained by these substances greatly exceeded that maintained by the vehicle, water. Water data are not shown in succeeding figures because intake was very low and did not vary systematically with the experimental manipulations. The effect of saccharin on the demand for PCP is shown in figure 11.1. There was a reduction in PCP deliveries (intake) at all FR and income conditions when saccharin (versus water) was concurrently available (left panels), which is consistent with previous studies of the effects of saccharin on PCP-reinforced behavior (Carroll 1985; Carroll, Carmona, and May 1991). These differences were more apparent when plotted as responses over the range of FR values (right panels). P_{max} values were calculated as estimates of the price (FR) at which maximum responding occurred (Hursh 1991). The equation for determining P_{max} is stated in the logarithmic units of price (P) and consumption (Q): $\ln(Q) = \ln(L) = b[\ln(P)] - a(P)$. L is the initial level of demand at minimal price, and b is the initial slope of the demand curve with increases in price. P_{max}, or price yielding maximal response output, is $P_{max} = (1 - b)/a$. The b parameter is usually negative and near zero; thus, elasticity changes are expressed as changes in a. Level shifts or movements of the entire curve up or down on the y-axis are seen as changes in the L parameter. This equation accounts for 90 to 99 percent of the variance in consumption in studies analyzed thus far (Hursh 1991; Hursh et al. 1988, 1989). Under the three income conditions P_{max} was shifted to the left, indicating that concurrent saccharin reduced the PCP price (FR) at which maximum responding occurred.

Table 11.2 indicates that P_{max} increased only slightly but nonsignificantly with income, but the magnitude of the leftward shift was relatively constant

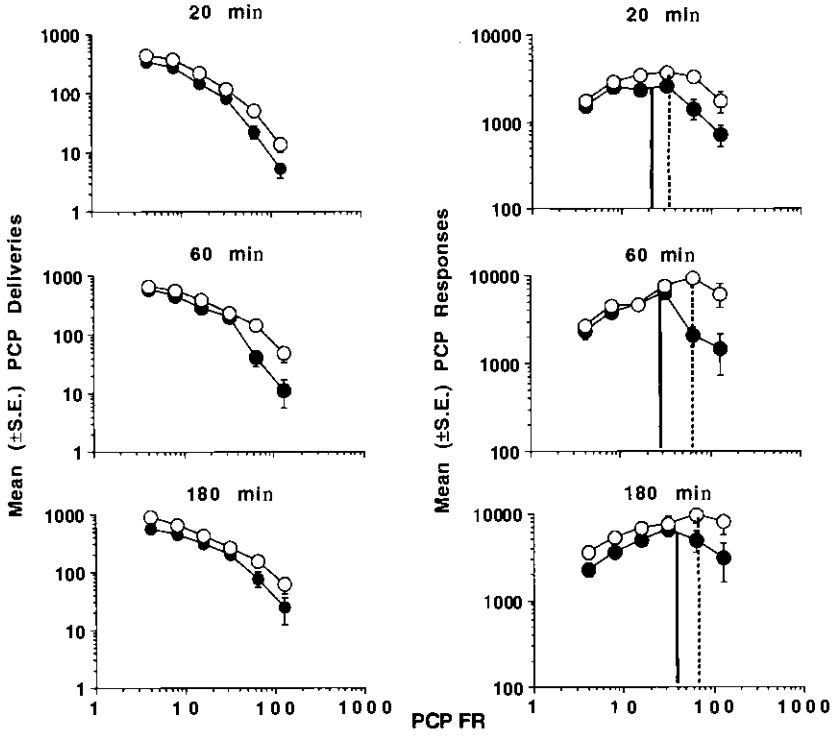

Fig. 11.1 PCP demand curves with concurrent saccharin or water under three income conditions

Note: Mean (± S.E.) PCP deliveries (left panels) and lip contact responses (right panels) are shown as a function of drug price or FR requirement for drug deliveries (4, 8, 16, 32, 64, and 128). Saccharin or water deliveries were concurrently available under an FR 32 schedule. *Solid symbols* refer to PCP deliveries or responses when saccharin was concurrently available, and *open symbols* refer to PCP deliveries or responses when water was concurrently available. In the right panels, the vertical lines that intersect the *x*-axis refer to P_{max} values (see table 11.2), which are estimates of the unit price at which maximum responding occurred (Hursh 1991). *Broken lines* refer to the concurrent water conditions, and *solid lines* refer to the concurrent saccharin conditions. Each point represents a mean for six monkeys over the last five days of stable behavior. Standard errors of the mean were calculated for the five-day means of each group of monkeys.

regardless of income level. Overall, income had little interaction with saccharin's suppressant effects on PCP intake. Similar findings occurred when this experiment was replicated with ethanol and saccharin or when water was concurrently available under the same FR and income conditions (Carroll et al. 1995, fig. 1, table 1). Figure 11.2 shows the same parallel shift downward of the demand curves and leftward shift of the P_{max} values due to concurrent saccharin as discussed for PCP.

The effects of income are illustrated in figure 11.3, where they are represented in Engel curves (Engel, Kollat, and Blackwell 1972), in which consumption is plotted as a function of income. As income increased, consumption

Table 11.2 P_{max} Values under Conditions of Concurrent Saccharin or Water Availability and Income Level

Income Level (min)	P_{max}[a] With Saccharin	With Water
PCP		
20	20.75	32.00
60	24.10	46.88
180	28.00	49.17
ETOH		
20	22.6	75.9
60	33.8	44.2
180	23.9	34.0

[a] P_{max} is the FR value at which maximum response output occurs (Hursh 1991).

increased. The reduction in responding at low income became more pronounced as the FR increased. Table 11.3 shows the percent reductions in PCP and saccharin deliveries as income decreased from the highest (180-minute) to the lowest (20-minute) level. Saccharin intake was much more dramatically affected than PCP and ethanol intake under all FR values. In many cases, the reduction in saccharin was nearly twice that of the drug. Income effects did not vary consistently under the concurrent water versus concurrent saccharin conditions. However, the consistent relationship between FR and income is apparent from the increased percent reductions in drug intake as FR increased.

11.6 Effects of Income on Relative Preference for Drug and Nondrug Reinforcers

The effect of income on the relative preference for drug and saccharin is illustrated in figure 11.4. Income elasticities for both drug and saccharin were positive, but since the slopes were different, the curves crossed, revealing different relative preferences as a function of income. Data for all FRs are presented for the conditions in which either PCP (left panels) or ethanol (right panels) was concurrently available with saccharin. Saccharin was always available under FR 32, but the FRs for PCP or ethanol were varied from 4 to 128. Data with concurrent water are not presented as water intake was negligible and did not change with income. At the FR 4 and 8 conditions (upper left), PCP and saccharin were consumed in equal amounts under the 180-minute income condition; however, as income was reduced to 20 minutes, PCP deliveries were almost four times as high as saccharin deliveries. At FRs 16 and 32, saccharin deliveries were nearly twice as high as PCP deliveries at the high income level, but this preference was completely reversed at the low income level (center left). At FRs 64 and 128, PCP deliveries were very low compared to saccharin deliveries, but the magnitude of the saccharin preference de-

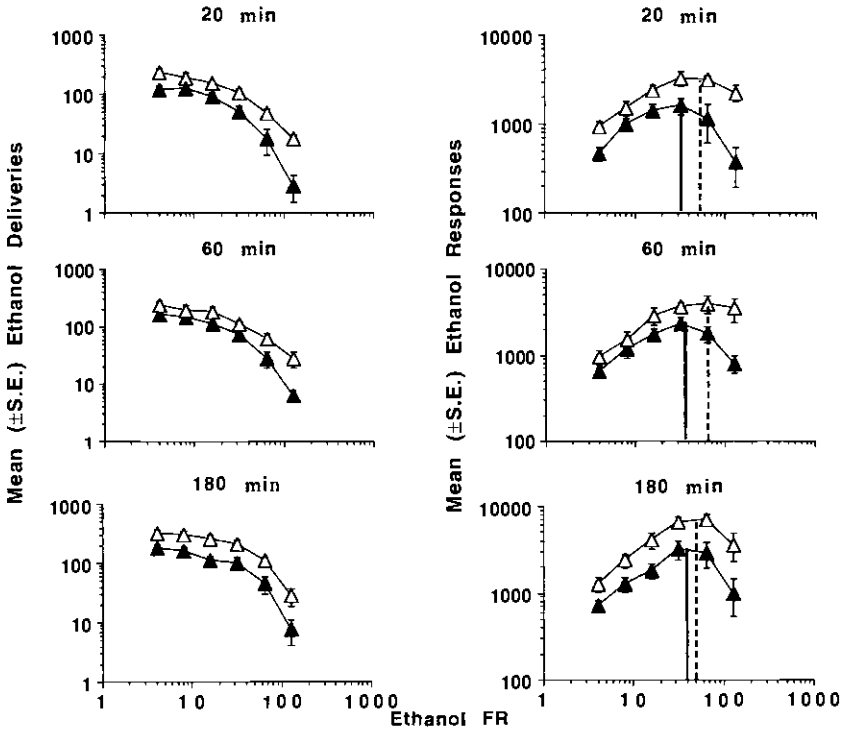

Fig. 11.2 Ethanol demand curves with concurrent saccharin or water under three income conditions

Note: Mean (± S.E.) ethanol deliveries (left panels) and lip contact responses (right panels) are shown as a function of drug price or FR requirement for drug deliveries (4, 8, 16, 32, 64, and 128). Saccharin or water deliveries were concurrently available under an FR 32 schedule. *Solid symbols* refer to ethanol deliveries or responses when saccharin was concurrently available and *open symbols* refer to ethanol deliveries or responses when water was concurrently available. In the right panels, the vertical lines that intersect the *x*-axis refer to P_{max} values (see table 11.2), which are estimates of the unit price at which maximum responding occurred (Hursh 1991). *Broken lines* refer to the concurrent water conditions, and *solid lines* refer to the concurrent saccharin conditions. Each point represents a mean for eight monkeys over the last five days of stable behavior. Standard errors of the mean were calculated for the five-day means of each group of monkeys.

creased substantially as income decreased (lower left). Thus, saccharin maintained responding at higher FR values than PCP, but saccharin-maintained responding was more readily reduced by decreasing income than was PCP-maintained responding.

The relationships between income and ethanol versus saccharin preference was similar to that described for PCP (fig. 11.4, right panels). At FRs 4, 8, and 16, saccharin was preferred to ethanol at the high income level, but the preference was reversed at the low income level. At FRs 32, 64, and 128, ethanol intake was low and saccharin was preferred at all income levels, although the magnitude of the saccharin preference diminished with decreased income.

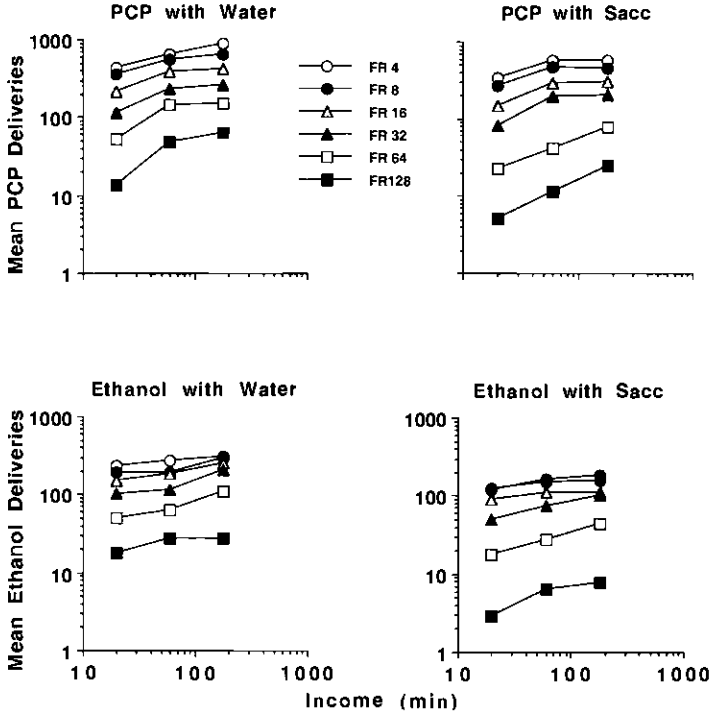

Fig. 11.3 Engel curves for PCP and ethanol with concurrent water or saccharin at six FRs

Note: Engel curves are presented for the PCP (upper panels) and ethanol (lower panels) income studies. Drug consumption is plotted as a function of income (session length) when water (left panels) or saccharin (right panels) was concurrently available. Each line represents a different FR condition. Each point represents a mean of six (PCP) or eight (ethanol) monkeys over the last five days of stable behavior. Standard errors of the mean were calculated for the five-day means of each group of monkeys.

Table 11.3 Percent Reductions in PCP or ETOH and Saccharin Deliveries as Income Decreased from 180 to 20 minutes

FR	Saccharin	PCP w/Saccharin	PCP w/Water	Saccharin	ETOH w/Saccharin	ETOH w/Water
4	89.0	39.9	51.0	72.2	35.0	38.9
8	92.9	40.2	44.8	83.1	46.3	50.0
16	92.8	51.7	49.5	81.1	41.1	49.0
32	92.7	60.0	56.7	82.4	59.3	54.8
64	90.1	71.7	65.9	79.6	77.9	61.7
128	88.4	78.6	78.0	76.0	[a]	[a]

[a]Intake too low and variable to calculate.

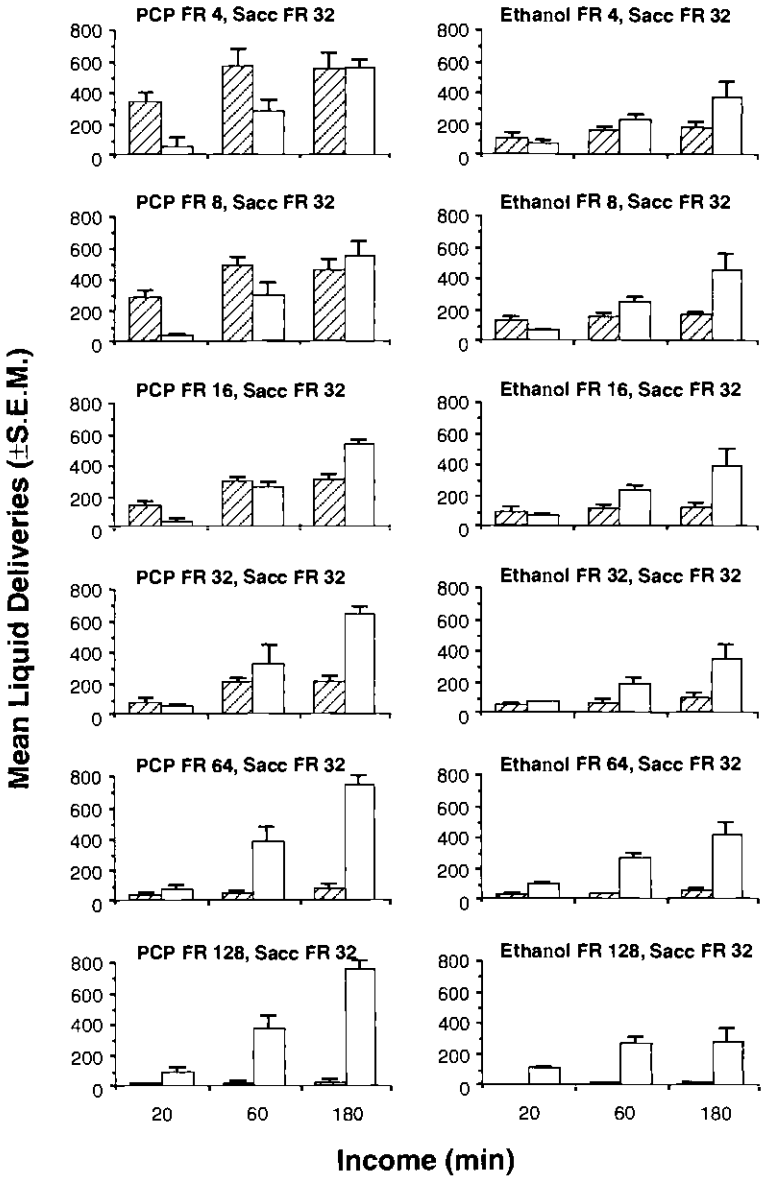

Fig. 11.4 Relative preference for PCP or ethanol versus saccharin at three income levels

Note: Mean (± S.E.) liquid deliveries are presented as a function of income level (20, 60, and 180 minutes) for all six drug FR conditions. Saccharin was always available under an FR 32 schedule. Left panels represent PCP data; right panels refer to ethanol. *Striped bars* indicate drug deliveries, and *open bars* refer to saccharin deliveries. Water deliveries are not shown as they were negligible and did not vary as a function of FR or income. Each bar represents a mean for six (PCP) or eight (ethanol) monkeys over the last five days of stable behavior. Standard errors of the mean were calculated for the five-day means of each group of monkeys.

Overall, saccharin intake was lower in the ethanol study. This was not due to the effects of ethanol because at FR 128 there was little ethanol intake. It may have been due to intrasubject variability, although five of the monkeys participated in both studies.

Individual monkey data are shown in figure 11.4, which illustrates the time course of responding and development of preferences for ethanol or saccharin under different income levels. Individual data were selected as those closest to the group mean. In general, there was a trend for the ethanol-reinforced responding to be completed during the first 20 minutes of the session regardless of session length. However, saccharin drinking continued at a fairly steady rate and did not begin to level off until about 120 minutes. Thus, the saccharin preference that emerged under most income conditions was due to sustained saccharin drinking for a longer time rather than more rapid saccharin drinking. Individual cumulative intake data for PCP and saccharin showed a similar pattern (data not presented). These data suggest that the direct effects of PCP or ethanol on drug-maintained behavior were minimal, as monkeys were able to continue responding for saccharin long after drug intake had stopped.

11.7 Drugs and Nondrug Reinforcers as Superior versus Normal Goods

In figure 11.5, PCP, ethanol, and saccharin consumption are plotted (all under FR 32 conditions) as a function of income to determine whether drug and saccharin are normal or superior goods. As income increases, intake of a superior good occurs at a rate that is proportionally greater than the increases in income. Drug and saccharin consumption are plotted against the curves (*dashed lines*) that would be expected if increases in intake were proportional to increases in income. With both PCP and ethanol under most FR conditions, the drugs functioned as normal goods. Intake increased with income, but under many conditions, increases in intake were proportionally less than increases in income. When saccharin was available with PCP it appeared to function as a superior good, as increases in intake were proportionally greater than increases in income.

11.8 Using Behavioral Economic Measures to Compare Reinforcing Effectiveness of Drug versus Nondrug Reinforcers

When comparing the reinforcing effects of PCP or ethanol and saccharin, there are some data that suggest the drugs are more effective reinforcers. For example, when income was decreased from 180 to 20 minutes, the proportional (percent) reductions in drug intake were less than those found with saccharin intake. Also, although the saccharin FR was not manipulated in the income studies, it was changed across the same range of FRs that were used in a previous study (using a 180-minute session) with the ratio of price to quantity the same for each commodity. The negative slope of the demand curve for

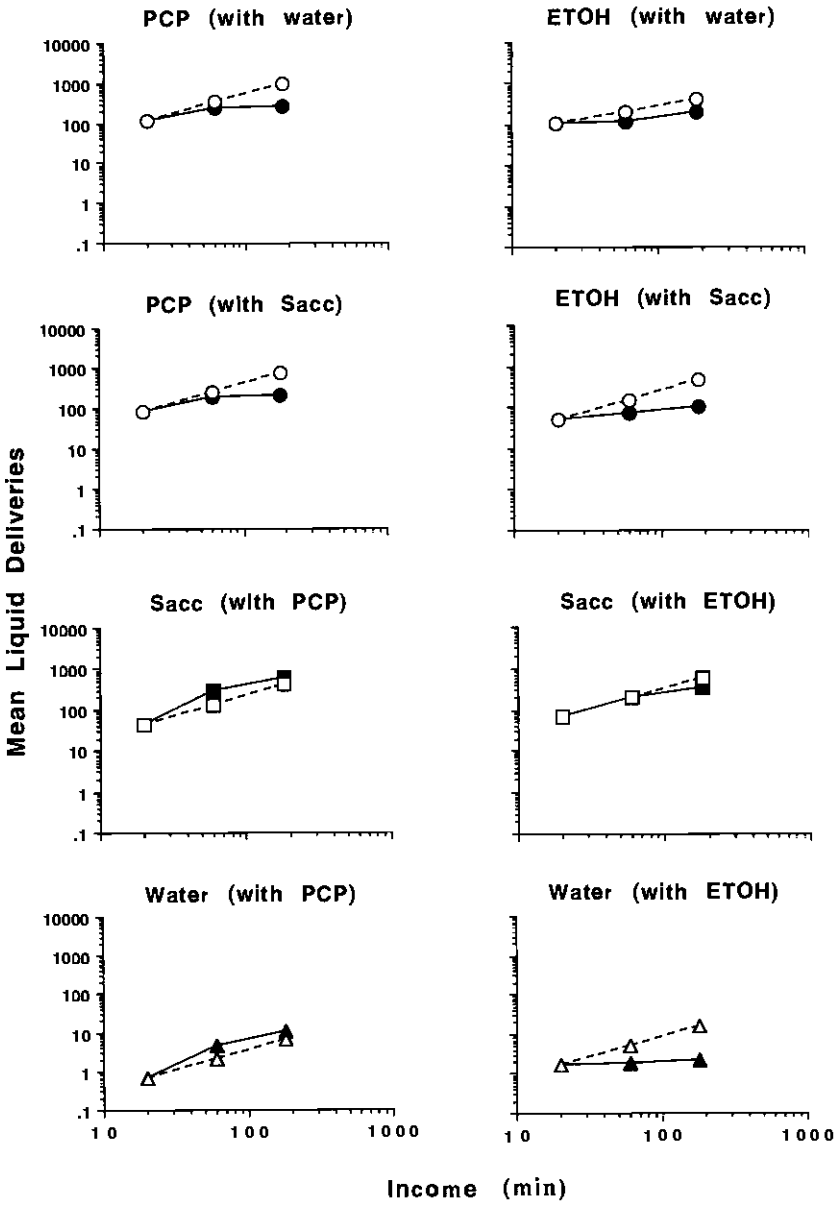

Fig. 11.5 PCP, ethanol, saccharin, and water deliveries as a function of income and compared to hypothetical curves for normal goods

Note: Mean (± S.E.) PCP (left panels) and ethanol (right panels) deliveries are plotted as a function of income (20-, 60-, and 180-minute sessions). The first row illustrates drug intake when water was concurrently available. The second row indicates drug intake with concurrent saccharin. The third row represents saccharin intake with concurrent drug. The last row indicates water intake with concurrent drug. All data are for the FR 32 condition. Dotted lines represent hypothetical curves that would represent normal goods. Each point represents a mean of six (PCP) or eight (ethanol) monkeys over the last five sessions of stable behavior. Standard errors of the mean were calculated for the five-day means across the number of monkeys in each group.

saccharin was greater (−7.8) than that for PCP (−3.6) (Carroll et al. 1991) or ethanol (−2.3) (Carroll and Rodefer 1993), suggesting that saccharin was a more elastic and less efficacious reinforcer than the drugs. Finally, saccharin intake was more vulnerable than drug intake to decreases in income. When income was reduced from 180 to 20 minutes, the relative preference for drug versus saccharin was reversed, and drug intake exceeded saccharin intake at the low FRs. Silberberg et al. (1987) suggest that superior goods are like luxuries while normal goods tend to be necessities, and this is consistent with previous findings that the elasticity of demand for luxury items is greater than that for necessities.

In contrast, there are data that suggest that saccharin is the more efficacious reinforcer, such as higher intakes under the higher income conditions and equal FR (FR 32) conditions. It can also be argued that saccharin intake increased more readily with increases in income, and under some conditions, saccharin functioned as a superior good. These differences may be related to different rates of satiation for a commodity that satisfies the need of a drug-dependent individual versus a commodity that fulfills some hedonic need.

11.9 Substitution of Nondrug Reinforcers for Drugs

The clinical relevance of using alternative nondrug reinforcers for prevention and treatment of drug abuse is that they may substitute for drug reinforcers and maintain alternative lifestyle patterns to drug taking. The drug-saccharin-income data also provide some quantitative evidence of substitution using behavioral economic measures. Substitution occurs when as the price of one good (e.g., drug) increases and consumption shows corresponding decreases, intake of another fixed-price good (e.g., saccharin) increases. Figure 11.6 shows saccharin deliveries as a function of increases in PCP or ethanol price (FR 4, 16, 64) for the three income levels. Under all conditions there was a positive slope, indicating substitution of saccharin for drug. Slopes are indicated in parentheses, and with both PCP and ethanol, the slopes increased with increases in income. However, with the exception of the 60- and 180-minute income conditions with PCP, the slopes were less than 1. Thus, the substitution effect was relatively weak under low income conditions and when ethanol was self-administered.

11.10 Discussion

Overall, it appeared that income is a major economic variable affecting drug-rewarded behavior. Decreasing income reduced intake of both drug and nondrug reinforcers. However, the effect was much greater on the nondrug reinforcer. Thus, income changes can reveal the relative reinforcing strength of drugs versus nondrug substances. This differential response to lowered income resulted in a change in preference from the nondrug item at high income to

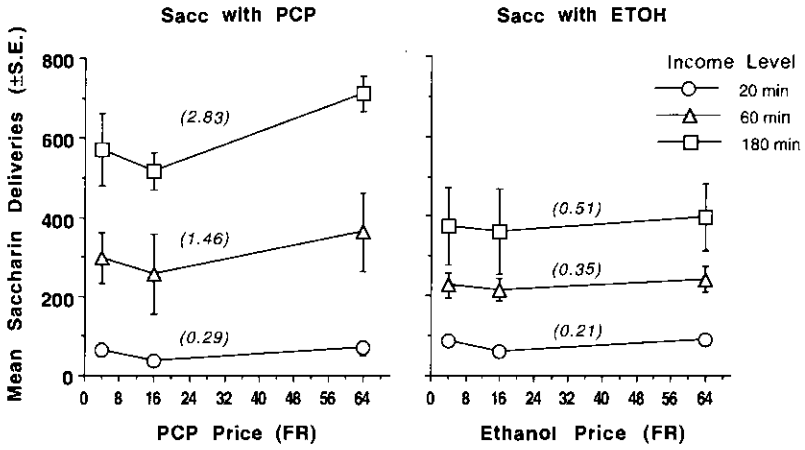

Fig. 11.6 Substitution: Saccharin deliveries plotted as a function of PCP and ethanol price under three income conditions

Note: Mean (± S.E.) saccharin consumption is plotted as a function of the PCP (left panel) and ethanol (right panel) FR schedule value (4, 16, 64) for the three income conditions. Numbers in parentheses refer to the slopes of each line. Each point represents a mean of six (PCP) or eight (ethanol) monkeys for the last five sessions of stable behavior. Standard errors of the mean were calculated for the five-day means across the number of monkeys in each group.

drug at low income. These results were consistent with a report of Shurtleff et al. (1987), who found a saccharin-food preference reversed to a food-saccharin preference at low income, and the data suggest that the drug is functioning as a necessity like food.

The results from the PCP and ethanol versus saccharin studies described here were not in agreement with the Elsmore et al. (1980) data, which showed preference for the nondrug (food) at low income and the drug at high income. This may have been due to the fact that in the Elsmore et al. (1980) study, food was presented in a closed economy, and food was the necessity, while heroin was the luxury item. In the drug-saccharin studies, food was available postsession or in an open economy, while drugs were available only during season (closed). The status of the economy (open versus closed) is another important economic variable that may bear on the effectiveness of treatments (e.g., alternative nondrug reinforcers) for drug abuse.

Differences between these studies may have been due to the closed versus open economies, dose levels, unit prices of food versus drug, or the specific pairs of commodities that were offered. Intake of the drugs (e.g., ethanol, heroin, PCP) as well as the dietary substance (food, saccharin) all increased as income increased, indicating they were normal goods, or in the case of saccharin, a superior good. In contrast, in studies that used different forms of the same commodity, such as food (Hastjarjo et al. 1990; Hastjarjo and Silberberg 1992; Silberberg et al. 1987) or cigarettes (DeGrandpre et al. 1993), one sub-

stance emerged as a normal good and the other as an inferior good (intake decreased as income increased). Further work is needed to determine the economic characteristics of the nondrug alternatives (e.g., inferior or normal versus superior, elasticity of demand) that are optimal in reducing drug self-administration.

Changing income also had effects on economic variables that were previously found to alter drug self-administration. For example, decreasing income reduced the intensity of demand for ethanol (Carroll et al. 1995) and PCP (Carroll and Rodefer 1993). Another effect was the interaction of income with the unit price for the drug. Lowering income produced a greater suppression in drug intake when the price of the drug was high compared to when it was low. Income did not interact, however, with the suppressant effect of an alternative nondrug reinforcer on drug intake. Concurrent saccharin (versus water) reduced the maximum unit price (P_{max}) at which maximum PCP- (Carroll and Rodefer 1993) and ethanol- (Carroll et al. 1995) reinforced responding occurred, but the magnitude of these shifts was similar at all income levels.

As shown previously (Carroll 1985; Carroll et al. 1991), saccharin dramatically reduced drug intake, and this effect was proportionally greater at the higher FRs or unit prices. The overall effect of saccharin was to reduce the intensity of demand for drugs. As reported earlier (Carroll et al. 1991; Comer et al. 1994), saccharin appeared to function as an economic substitute for drugs under all income conditions. It should be noted that substitution effects have not been large in these studies, possibly due to the fact that at the fixed prices used for saccharin (e.g., FRs 16, 32), a ceiling effect occurred. Thus, alternative nondrug reinforcers as well as income manipulations are variables with considerable impact on drug-reinforced behavior; however, these variables appear to function independently. It should be noted that income dramatically affects saccharin intake, reducing it by 80 to 90 percent when changes are made from high to low income; however, even when only small amounts of saccharin were consumed, the reduction in concurrent drug intake was similar to when greater amounts were consumed when income was high. This finding is consistent with an earlier report in which the FRs for concurrent PCP and saccharin were both varied instead of keeping saccharin at a fixed price (Carroll et al. 1991). The resulting suppression of the PCP demand curve was the same regardless of whether saccharin intake was low due to FR increases or remained high at the fixed price.

In conclusion, the choice between a drug and nondrug reinforcer is highly dependent on the prevailing economic context. Choice will be affected by the unit prices of the different commodities, as demand for drug reinforcers is less elastic than for the nondrug reinforcers. Changes in income may also dramatically alter the relative preference for drug and nondrug reinforcers, although income has a relatively small effect on total drug intake (Carroll et al. 1995; Carroll and Rodefer 1993; DeGrandpre et al. 1993). The optimal economic

conditions for reducing drug intake are low income, high drug price, and most important, the availability of an alternative nondrug reinforcer.

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