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ORIGINAL INVESTIGATION

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Preference for saccharin-sweetened alcohol relative to isocaloric sucrose

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Abstract This experiment tested the reinforcing efficacy of a saccharin-sweetened alcohol solution relative to an isocaloric sucrose drink in rats. One dipper served 10% alcohol plus 0.25% saccharin, and a second, concurrently available, dipper served 14.2% sucrose. During the course of the experiment, access to the two drinks was challenged by increasing the schedule requirement (variable-interval) that determined when a lever press would operate the dipper. There were two main findings. First, the rats continued to consume significant amounts of alcohol despite access to the isocaloric sucrose solution. Second, schedule-requirement increases that decreased sucrose-reinforced responding failed to decrease saccharin-sweetened alcohol reinforced responding. These results extend and replicate earlier findings from studies in which alcohol was mixed with sucrose, and the alcohol mixtures held a caloric advantage over the competing sucrose solutions. The experiment also included controls for differences in baseline response rates and for the influence of saccharin on preference. In the baseline response-rate control conditions, the two reinforcers were 10% sucrose and a mixture of 10% sucrose-plus-quinine. The results showed that the persistence of sweetened-alcohol reinforced responding could not be explained by differences in baseline response rates or the reinforcing properties of saccharin. Rather, the findings were consistent with the idea that the rats were defending baseline levels of alcohol-plus-saccharin consumption.

Key words Alcohol self-administration · Choice · Animal model · Behavioral economics · Substitutability · Ethanol · Sucrose · Quinine · Variable-interval schedule · Lever press · Rats

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Introduction

In experiments with rats, the reinforcing value of solutions of alcohol plus water depended on whether the competing reinforcer was water or sucrose. When the competing reinforcer was water, the rats preferred alcohol (e.g., Samson et al. 1982). However, when the competing reinforcer was sucrose, responding reinforced by alcohol (e.g., 10% concentration) markedly decreased, even when the sucrose concentration was as low as 1% (e.g., Schwarz-Stevens et al. 1991). Moreover, these relations were equally strong for specially bred, alcohol-preferring, P rats (Schwarz-Stevens et al. 1991). In an effort to develop a procedure in which alcoholic drinks remained potent reinforcers relative to sucrose and other caloric sources, experiments with sweetened alcohol were initiated (e.g., Heyman and Oldfather 1992; Heyman 1993; Petry and Heyman 1995). The basic technique had three steps. First, using a lever press operated dipper procedure, high baseline levels of alcohol-plus-sucrose consumption were established. Second, a 10% sucrose solution was introduced at a concurrently available dipper. That is, one lever operated the sweetened-alcohol dipper and the other lever operated the sucrose dipper. Third, access to one or both drinks was challenged by increasing the schedule requirements or by providing large pre-session meals of chow and sucrose (Heyman and Oldfather 1992; Heyman 1993). There were two main findings. Responding reinforced by alcohol-plus-sucrose was more resistant to change, and schedule requirement increases that decreased responding reinforced by sucrose increased responding reinforced by alcohol-plus-sucrose. These behavioral changes were consistent with the idea that the rats were defending baseline levels of alcohol consumption. In contrast, the rats did not sustain baseline levels of sucrose consumption. The experiment described in this report tests the generality of these findings. In particular, it tests whether the results depend on the caloric differences between the sweetened-alcohol and sucrose solutions.

In the sweetened-alcohol experiments, the alcohol mixtures were calorically richer. For example, when the choice was between 10% sucrose and 10% alcohol mixed in 10% sucrose, the calorie advantage for the alcohol drink was about 2.4:1 (0.96–0.40 kcal/ml; Heyman and Oldfather 1992). To test whether this difference contributed to the greater persistence of responding reinforced by sweetened alcohol, the solutions were made isocaloric. One dipper served 10% alcohol sweetened with 0.25% saccharin, and the second dipper served 14.2% sucrose. Thus, the caloric content of the alcohol drink decreased and the caloric content of the competing sucrose solution increased. In addition, there were three other new test conditions.

The schedule challenge was more demanding. Responses were reinforced according to variable-interval schedules. In earlier experiments with this procedure, the schedule values were varied over a six-fold range, from 5 to 30 s (e.g. Files et al. 1995). In the experiment reported here, the range is 18-fold, from 5 to 90 s. Second, there was a control group to determine if differences in baseline response rates contributed to the greater persistence of responding reinforced by the alcohol mixtures. Third, there was a control group to evaluate the reinforcing value of saccharin (without alcohol) relative to sucrose.

On the basis of the earlier experiments, it was anticipated that caloric differences would not account for the persistence of responding reinforced by sweetened alcohol. However, there are no published, systematic evaluations of preference for alcoholic drinks versus isocaloric foods. In previous studies of preference for sweetened alcohol, sucrose rather than a non-caloric substance, like saccharin, was added.

Thus, the experiment seeks to answer three questions: will rats continue to consume significant levels of saccharin-sweetened alcohol when they also have access to an isocaloric, 14.2%, sucrose solution? Second, will responding maintained by 10% alcohol-plus-saccharin be more resistant to change than responding maintained by isocaloric sucrose? Third, is there any evidence that initial response rate levels explain the persistence of responding reinforced by sweetened alcohol?

Materials and methods

Alcohol experiment

Subjects

Eight male Wistar rats served as subjects. At the start of the experiment they were approximately 8 months old and weighed on average 365 g. Following experimental sessions, they were fed 12 g chow, an amount which kept body weights relatively constant for the course of the study. These eight rats and the two other groups were trained to lever press with an autoshaping procedure (e.g., Gamzu and Williams 1971).

Apparatus

The experiments were conducted in eight standard operant chambers (MED Associates: 28 cm, 20.5 cm, 26 cm). Two levers, left and right, were inserted into the front wall, 7 cm above the floor, and 1 cm from each side. The levers (5 cm wide) were operated with a force of about 0.25 N. Just below each lever (2 cm) was an opening into which a 0.1-ml dipper could be raised. Each dipper sat in its own trough, so that it was possible to serve two different solutions. Experimental events were arranged and recorded with an IBM compatible personal computer that used MED-PC software (Tatham and Zurn 1988).

Procedure

At each lever, an independent variable-interval schedule determined when responses were effective. For example, once the interval for the left side dipper elapsed, the next left lever press operated the left dipper (making the drinking cup available). Similarly, right lever presses were reinforced once the right side timer elapsed. The list of intervals for each schedule approximated a Poisson distribution (Fleshler and Hoffman 1962). Importantly, the two variable-interval timers ran independently of one another. For example, while the subject was responding on the left lever, the right timer could elapse and set up a reinforcer for a right lever response. However, as is usually the case in concurrent-interval-schedule experiments, responses just following a switch from one to the other lever were not eligible for reinforcement until a brief delay elapsed (1.5 s in this experiment). This contingency eliminates adventitious switching (Herrnstein 1961). Reinforcement consisted of 3-s access to the dipper, which was long enough for the rat to empty the cup (0.1 ml). Reinforcement was followed by a 1.5-s blackout, and then the timer that had elapsed was restarted with a new interval (drawn at random), and the process started anew.

Pre-experimental induction of alcohol consumption

Prior to the experimental conditions, the rats were induced to drink alcohol. The goal was to establish rapid and large increases in alcohol intake. Initially, one dipper provided water and the other dipper provided alcohol mixed with 10% sucrose. Alcohol concentration was initially set at 2.5% and then increased in 2.5 and 5% steps to 25% (v/v). Each concentration was kept in effect until response rates were stable (about five to ten sessions per concentration). The criterion was the absence of an increasing or decreasing trend for three consecutive sessions. During this phase of training, median alcohol consumption levels varied from 2.50 to 4.75 g/kg per 30-min session.

In the next phase of training, alcohol was reduced to a 10% concentration, and sucrose was substituted for water in the second dipper. During a pilot study (results not reported here), the sucrose concentrations in the second dipper were 19% and 24%. Finally, the two solutions were made isocaloric. Sucrose was removed from the alcohol solution and replaced by 0.25% saccharin, and the concentration of the competing sucrose solution was set at 14.2%. Each mixture provided 0.56 kcal/ml.

The pilot study lasted 63 sessions. This means that the results presented here were preceded by a 4-month period during which the animals consumed large amounts of alcohol daily (typically about 2.5–3.0 g/kg per 30-min session). Throughout, new solutions were prepared each day and kept in sealed flasks until the start of the experimental session.

Alcohol-plus-saccharin preference: phase 1

In the initial condition, the programmed inter-reinforcement intervals were on average 5 s for both sweetened alcohol and sucrose. After responding stabilized, the schedule requirements for the sucrose solution were increased. The first increment was by a factor of 6–30 s, and the second increment was by a factor of 3–90 s. While the sucrose interval requirement was increased, the average interval requirement for sweetened alcohol remained at 5 s. For

Table 1 Order of conditions and number of sessions. Sucrose versus alcohol-plus-saccharin (first schedule refers to sucrose)

Schedule requirement (s)	Sessions
VI 5 VI 5	7
VI 30 VI 5	11
VI 90 VI 5	7
VI 5 VI 5	7
VI 5 VI 30	8
VI 5 VI 90	9
Sucrose versus sucrose-plus-quinine (first schedule refers to sucrose)	
VI 5 VI 5 (no quinine)	18
VI 5 VI 5 (plus quinine)	16
VI 5 VI 30	6
VI 5 VI 90	9
VI 5 VI 5	11
VI 30 VI 5	10
VI 90 VI 5	7
Saccharin versus water and saccharin versus sucrose (VI5s VI5s throughout)	
Condition	Sessions
14.2% sucrose vs water (alternating sides)	4
Saccharin vs water	4
Saccharin vs 14.2% suc	4
14.2% suc vs saccharin	4
Water vs saccharin	5
1.25% sucrose vs saccharin	8
Water vs saccharin	8

example, in the third condition of phase 1, the programmed time between reinforcers was 18 times longer for sucrose than for sweetened alcohol.

Alcohol-plus-saccharin preference: phase 2

In phase 2, the interval requirements for the alcohol solution were increased. First, the sucrose schedule was set back to 5 s, re-establishing baseline conditions. Next, the schedule for alcohol-plus-saccharin was increased to 30 s and then to 90 s.

Each condition was in effect for at least five sessions and until response rates appeared stable. The stability criterion was the absence of an increasing or decreasing trend in either sucrose or alcohol-plus-saccharin response rates over the last three sessions. Table 1 summarizes the order and number of sessions in each condition. In phase 1 and phase 2, experimental sessions were 60 min long.

Data analysis

The dependent variable of most interest was response rate, or, more specifically, the relationship between changes in response rate and changes in the schedule requirements. The method of analysis of variance (ANOVA) was used to analyze this relationship. Response and reinforcement rates were calculated from the last three sessions of each condition.

Response-rate control group

Subjects

Eight male Wistar rats served as subjects. At the start of the experiment the subjects were about 2 months old and weighed on average 267 g. Following daily experimental sessions, they were fed enough chow (6–12 g) to keep them at their initial body weights (250–275 g). These weights were maintained in order to produce response rates that approximated those at the sucrose lever in the alcohol study.

Apparatus

The equipment was the same as used in the alcohol study.

Procedure

In the initial condition of the experiment, each dipper served 10% sucrose, and at each lever, responses were reinforced according to a variable-interval 5-s schedule. Once response rates stabilized, 0.0003% quinine was added to the sucrose solution on the side of the chamber (right) that had previously served alcohol-plus-saccharin. This concentration was chosen because pilot sessions showed that it reduced response rates to levels that approximated those maintained by alcohol-plus-saccharin. Thus, response rates in the initial condition of this experiment approximated those of the initial condition of the alcohol experiment. Next, the interval requirement for the sucrose side was increased, using the same values as in the alcohol experiment: 30 s and 90 s.

Response-rate control: phase 2

Following phase 1, the interval requirement for sucrose reinforcement was reset to a mean of 5 s, and then the interval requirement for the quinine side was increased.

Saccharin experiment

Subjects

Eight male Wistar rats served as subjects. At the start of the study, they were about 6 months old and weighed on average 312 g. During the course of the study they were fed 12 g chow after the experimental sessions. This led to an average weight gain of 9 g over the 6-week duration of the experiment.

Apparatus

The equipment was the same as used in the alcohol study.

Procedure: saccharin, sucrose, and water preference tests

The goal of these experiments was to evaluate the reinforcing efficacy of saccharin relative to sucrose and water. Two sucrose concentrations were used, 1.25% and 14.2%, and saccharin concentration was 0.25%, as in the alcohol study. For some of the preference tests, side biases were evaluated (by switching the contents of the left and right dippers). Table 1 lists the order and number of sessions in each condition. Group means were based on the last two or last four sessions of each condition (as described in Results section), and paired *t*-tests were used to determine differences in preference.

Results

The results were graphed in two ways: in terms of the reinforcer for which the interval requirement was increased, and in terms of the reinforcer for which the interval requirement remained the same (VI5s). Figure 1 summarizes the main findings for schedule requirement

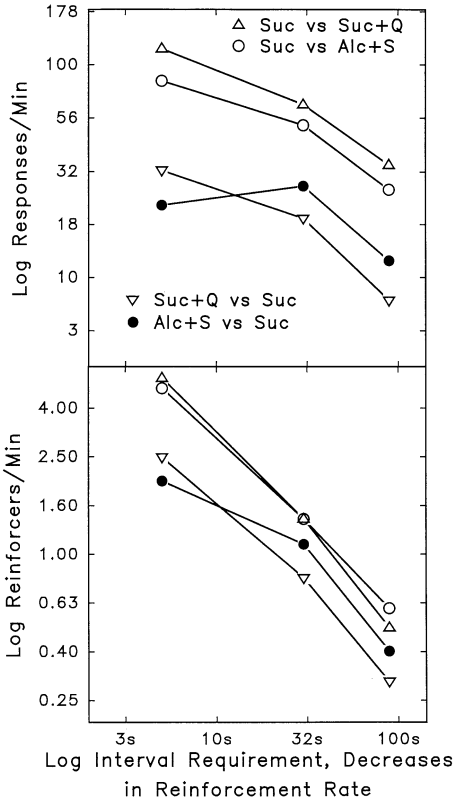

Fig. 1 Response and reinforcement rates as a function of same-side schedule requirements. The interval requirements were on average 5, 30, and 90 s for the data shown in the graph. At the competing, concurrent schedule, the interval requirements were on average 5 s. The label to the left of "vs" refers to the reinforcers for the data shown in the graph. The label to the right of "vs" refers to the competing reinforcers. The data were averaged from the last three sessions of each condition. The coordinates are logarithmic

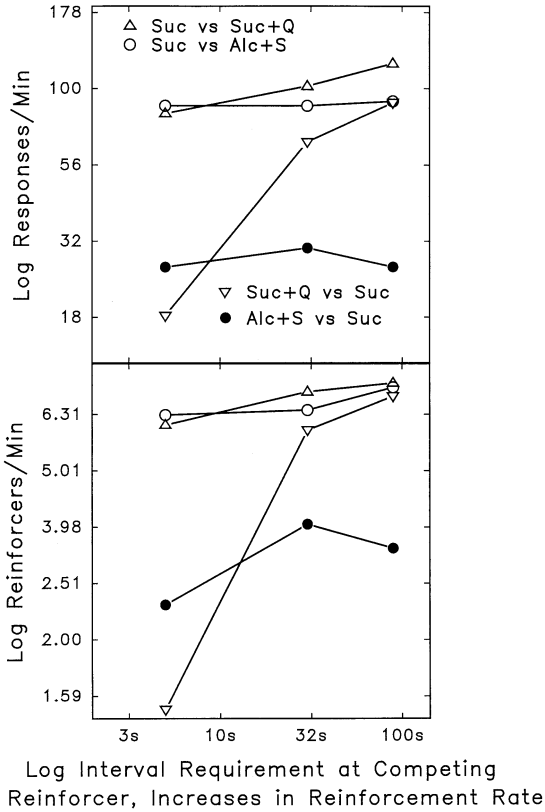

Fig. 2 Response rate and reinforcement rates as a function of other-side schedule requirements. For the data shown, responses were reinforced according to a variable-interval 5-s schedule. At the competing, concurrent schedule the variable-interval requirements averaged 5 s, 30 s, and 90 s (as shown on x-axes). The label to the left of "vs" refers to the data shown in graph. The label to the right of "vs" refers to the reinforcers at the competing, concurrent schedules. The coordinates are logarithmic

increases. The average programmed interreinforcement intervals and response and reinforcement rates are scaled logarithmically. See the figure caption for other details.

The top panel shows that when the reinforcer was sucrose or sucrose flavored with quinine, increases in schedule requirements decreased response rates, as expected. The omnibus *F*-values were: $F(2,14)=66.9$, $P<0.001$ for sucrose reinforced responding in the quinine experiment, $F(2,14)=20.0$, $P<0.001$ for decreases in sucrose reinforced responding in the alcohol experiment, and $F(2,14)=13.9$, $P<0.001$ for decreases in sucrose-plus-quinine reinforced responding. Contrast tests (Rosenthal and Rosnow 1985) confirmed that the decreases in response rate entailed a significant linear component, but no significant higher order (non-linear) components. Thus, when responding was maintained by sucrose or quinine-adulterated sucrose, decreases in reinforcement rate (same-side schedule increases) resulted in systematic, monotonic decreases in response rate. The *F*-values for the linear contrasts were: $F(1,7)=112.6$, $P<0.001$ for sucrose reinforced responding in the quinine experiment, $F(1,7)=43.2$, $P<0.001$ for sucrose reinforced responding in the alcohol experiment, and $F(1,7)=15.8$, $P<0.006$ for quinine-adulterated sucrose.

However, when the reinforcer was alcohol-plus-saccharin, increases in schedule requirements did not invariably decrease responding (the filled circles in Fig. 1). For the 5- to 30-s increment, responding increased in seven of the eight rats [contrast test: $F(1,7)=12.8$, $P<0.01$]. That is, decreases in reinforcement rates were accompanied by increases in responding. However, when the schedule was increased from 30 to 90 s, responding decreased, and the slope of the line joining the data points shows that the proportional change in responding was about the same as in the sucrose conditions. The decrease in response rate under the 90-s schedule was significant as measured relative to the 30-s condition [contrast test: $F(1,7)=12.2$, $P<0.01$], and although seven of eight rats showed decreases relative to the VI5s condition, this change did not reach significance at the 0.05 level according to a contrast test (rather, $P=0.06$). The omnibus *F*-test was also significant even though the changes were bitonic [$F(2,14)=9.1$, $P<0.01$].

The bottom panel of Fig. 1 shows changes in reinforcement rate for the reinforcer associated with the in-

Table 2 Average alcohol consumption levels. The first schedule refers to the requirement for sucrose reinforcement

Schedule requirement	Alcohol consumption g/kg per h
VI 5 VI 5	3.3
VI 30 VI 5	4.1
VI 90 VI 5	3.8
VI 5 VI 5	2.6
VI 5 VI 30	1.5
VI 5 VI 90	0.5

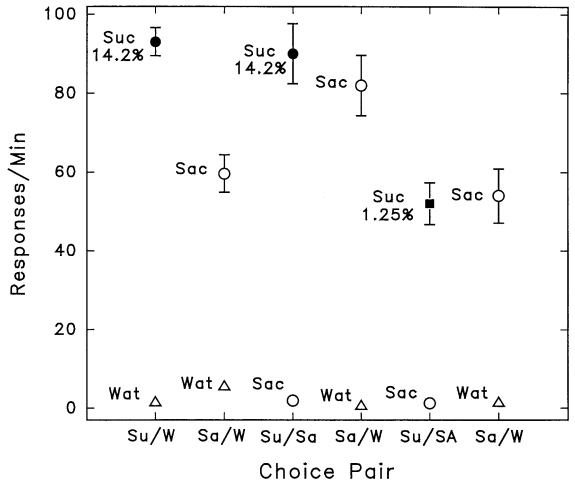

Fig. 3 Responding in the saccharin-preference experiment. The x-axis lists the various choice combinations: "Su" stands for sucrose, "W" stands for water, "Sa" stands for saccharin (O.25%). The data were averaged from the last two or four sessions (see text). The *error bars* indicate standard errors of the mean (some were too small to depict on this graph)

terval requirement increases. These changes, for the most part, simply reflect the programmed inter-reinforcement intervals. However, the filled circles show that at the 30-s interval there was less of a decline in sweetened-alcohol reinforcement rate. This is because responding at the sweetened-alcohol lever increased rather than decreased.

Figure 2 shows response and reinforcement rates for the reinforcer associated with the unchanged schedule (which elapsed on average every 5 s). The x-axes correspond to increases in relative reinforcement rate, and changes in response rates and reinforcement rates reflect changes in access to the competing reinforcer. In contrast, the x-axes in Fig. 1 correspond to decreases in relative reinforcement rate, and the data points reflect changes in the schedule depicted by the x-axes.

In the quinine-response-rate control study (the triangles), increases in the schedule requirement for the competing reinforcer increased response rate, as expected. The omnibus *F*-values were $F(2.14)=14.4$, $P<0.001$ for sucrose and $F(2,14)=12.7$, $P<0.002$ for quinine-adulterated sucrose. Contrast tests showed that these increases entailed a significant linear component [$F(1,7)=13.7$, $P=0.008$ and $F(1,7)=29.9$, $P=0.001$, respectively]. However, in the alcohol experiment, response rates did not systematically change. The filled circles show that alcohol-plus-saccharin reinforced responding remained at about the same level independent of the competing sucrose reinforcement rate [$F(2,14)=1.2$, $P=0.33$], and the open circles show the same sort of relationship for sucrose reinforced responding when the schedule value for alcohol-plus-saccharin was increased [$F(2,14)=0.3$, $P=0.78$]. Thus, there were behavioral interactions when sucrose was adulterated with quinine, but not when alcohol was adulterated with saccharin.

The bottom panel shows that reinforcement rate increased even though the schedule values did not change. This was in part due to increases in response rate and in part due to changes in the pattern of responding that accompanied the decrease in drinking at the competing schedule.

Table 2 lists the amount of alcohol consumed. The amounts were determined from the number of alcohol-plus-saccharin reinforcers and the specific density of alcohol (0.79).

Figure 3 shows average response rates for the group of rats that was given the saccharin versus water and saccharin versus sucrose preference tests. Side is not indicated, because left and right response rates for a given solution were about the same (for example, *t*-tests on side differences were not significant). Each data point shows the average response rate from the last two sessions of each condition (for conditions in which there was a side change, the data point is the average of four sessions, with left and right response rates combined). The error bars indicate the group standard-error (some were too small to display).

The basic finding was that saccharin's capacity to reinforce behavior depended on the nature of the alternative drink. When the competing dipper provided water, saccharin maintained high rates of responding (between 60 and 80/min on average). However, when sucrose was the competing reinforcer, responding at the lever that provided saccharin was sporadic and usually less than 2/min.

Sucrose solutions maintained high rates of responding. The average rate was over 90 responses/min for the 14.2% concentration and over 50 responses/min for the 1.25% concentration. The 14.2% solution was tested against saccharin and water; it was equally reinforcing relative to these two substances (see Fig. 3).

Discussion

The results from the saccharin-preference study (Fig. 3) show that the reinforcing efficacy of the alcohol-plus-saccharin solution depended on the presence of alcohol; the results from the quinine, response-rate control group show that the persistence of responding reinforced by sweetened alcohol cannot be explained by differences in initial response rates. This is the first demonstration that rats will drink substantial amounts of alcohol when they also have access to an isocaloric food. For example, Ta-

ble 2 shows that in baseline conditions, the rats consumed about three times as much alcohol as in comparable studies that used alcohol mixed in water (e.g., Samson et al. 1988), and blood alcohol measures in sweetened alcohol experiments (e.g., Heyman 1995; Heyman et al. 1996) have been higher than usually reported in rat self-administration studies. The remainder of this Discussion section will focus on the question of why responding reinforced by sweetened alcohol was more resistant to change than was responding reinforced by sucrose. This issue will be addressed in two stages. First, persistence will be redescribed as an instance of "regulated preference." Second, the factors that may have mediated regulated preference will be discussed.

In earlier experiments with the sweetened-alcohol procedure, response rates changed so as to maintain the initial, baseline levels of alcohol consumption (e.g., Heyman 1993). In the present experiment this was not possible because interval schedules set the maximum possible reinforcement rate. Nevertheless, the relationship between changes in schedule requirements and changes in response rate can be explained in terms of the motivation to maintain baseline levels of alcohol consumption. In interval schedules increases in schedule requirements are typically accompanied by decreases in response rate and vice versa. This yields a monotonic relationship between reinforcement rate and response rate, and the relationship has a characteristic "shape" that is well described by the matching law (Herrnstein 1970), a quantitative model of reinforced behavior. However, in the alcohol study the typical rate relations generally did not occur. This has also happened in experiments in which the subjects obtain their full daily ration of the reinforcer in the experimental session (e.g., Hursh 1978; Collier 1983). The dynamics are simple enough. If the subject is motivated to obtain a certain consumption level, it can only do so by responding more when schedule values are increased and responding less when schedule values are decreased (assuming the appropriate initial conditions). This logic implies that in the VI5s schedules the rats obtained their "ideal" or preferred amount of sweetened alcohol, and in the VI30s schedule, response rates increased so as to return sweetened-alcohol consumption back to the level of the VI5s condition.

However, when the schedule requirement was increased from 30 to 90 s, responding maintained by alcohol-plus-saccharin decreased below baseline levels. There are at least three possible explanations. First, as the length of the interval increases, changes in response rate have increasingly less influence on reinforcement rate (and thereby consumption). For example, in the limiting case (an interval of infinite length), responding cannot affect reinforcement rate. Thus, response rates may have stopped increasing because under a VI90s schedule changes in responding have little influence on consumption level.

Second, the reinforcing value of alcohol may require a threshold level of consumption. For example, the rewarding effects of many self-administered drugs depend on the rate at which their blood levels increase (e.g., McKim 1991). The precise relations between blood levels and reward value for alcohol have not been determined. However, 0.1 ml of 10% alcohol/90 s works out to about 0.5 g/kg per h in this experiment, which is not much above the clearance rate of 0.3 g/kg per h (Wallgren and Barry 1970). Thus, it is not unreasonable to suppose that the reinforcing nature of the alcohol-plus-saccharin drink changed when it was delivered on a VI90s schedule.

Third, given that the strength of a reinforcer has some limit, decreases in the frequency of sweetened-alcohol availability must eventually lead to a decrease in behavior. However, these three accounts (which are not mutually exclusive) should not obscure the point that responding maintained by sweetened alcohol was more resistant to change than was responding reinforced by sucrose. [See Nevin (1992) for a discussion of factors that influence response rate resistance to change.]

It was also the case that the rats in the alcohol experiment and quinine experiment were different ages and weights. This raises the possibility that these factors may have influenced the relationships between responding and reinforcement rate. However, the rats were mature, and there is neither a theoretical nor empirical basis for believing that mature rats should respond differently to changes in schedule values as a function of age and weight (not counting, of course, decrepitude).

To summarize this section of the Discussion: there were two atypical findings: increases in response rate when relative reinforcement rate decreased (Fig. 1), and the absence of an increase in response rate when relative reinforcement increased (Fig. 2). Both are explained by the idea that the rats were motivated to preserve baseline levels of alcohol consumption.

An implication of the idea that alcohol consumption regulated preference is that sucrose and sweetened alcohol were relatively poor substitutes for one another. For example, if the two reinforcers were interchangeable then changes in the schedule requirements for one reinforcer should have brought about marked shifts in responding maintained by the competing reinforcer, as in the quinine experiment. Put another way, in concurrent schedules, behavioral interactions are a measure of reinforcer substitutability. Thus, an understanding of the substitutability relations should help explain the persistence of responding reinforced by sweetened alcohol.

Although taste influences preference (e.g., baseline data in the quinine study), it does not appear to influence substitutability. For example, in experiments in which taste was the only differentiating factor (e.g. Rachlin et al. 1976), reinforcers were highly substitutable, and in this experiment, the rats readily consumed quinine-adulterated sucrose rather than sucrose when schedule values changed. An alternative hypothesis is that post-ingestive factors influenced substitutability. For example, a number of experiments have shown that food and water do not readily substitute for one another (e.g., Hursh 1978; Green and Rachlin 1991). Alcohol and sucrose differ in

both their metabolic and pharmacological consequences. There is evidence that the pharmacological differences may be relevant to substitutability.

Alcohol calories do not produce as much weight gain in rats and humans as do calories from non-alcohol caloric sources (e.g., Larue-Achagiotis et al. 1989; Lands and Zakhari 1991). However, given the delay between intake and weight gain, it seems unlikely that this difference would influence consumption patterns in rats. Also, when rats were on restricted diets, alcohol and non-alcohol calories substituted for one another on about a one-to-one basis (e.g., Richter 1941). Thus, the relationship of calories to weight gain does not seem a plausible basis for the failure of sucrose and sweetened alcohol to substitute for one another.

In support of the pharmacological view, the benzodiazepine inverse agonist, Ro15-4513, decreased alcohol consumption at doses that failed to decrease sucrose consumption (Petry 1995). Put another way, it was possible pharmacologically to differentiate responding maintained by sweetened alcohol and responding maintained by sucrose. This result may be relevant as it was obtained in an experiment in which the conditions were similar to those of the present study.

The basic finding was that identical environmental manipulations differentially influenced behavior as a function of whether the reinforcer maintaining responding was sucrose or a mixture of alcohol-plus-saccharin. Moreover, as in earlier experiments, behavior maintained by the sweetened-alcohol solution was more resistant to change, and there was evidence that the rats were motivated to maintain baseline levels of sweetened-alcohol consumption. The question of why sucrose did not substitute for sweetened alcohol, whereas it did substitute for quinine-adulterated sucrose, does not appear to be answered by differences in taste or differences in the relationship between calories and weight gain. Rather, the simplest explanation of the results is that preference was in part controlled by alcohol's pharmacological effects.

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