METHODS & DESIGNS

The facts of schedule-induced polydipsia

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The principal empirical relationships between schedule-induced drinking during inter-food-reinforcement intervals and the size and frequency of the inducing reinforcements are reviewed. Data from experiments by Lotter, Woods, and Vasselli (1973), which purport to show the constancy of drinks after various sizes of eating bouts, were replotted to reaffirm the established dependency of drink size on eating bout size. Far from being an artifact of any such eating-drinking constancy, schedule-induced polydipsia remains a closely knit body of facts awaiting systematic theoretical development.

When hungry animals have free access to food and water, they alternate bouts of eating and drinking until satiated (McFarland & Lloyd, 1973). Lotter, Woods, and Vasselli (1973) observed food-deprived rats for daily 1-h periods and found them to engage in approximately 10 such bouts of eating and drinking, during which time they consumed 7 ml of water from a drinking tube and ate just over 200 45-mg Noyes food pellets from a cup. In a further series of experiments, the size of the eating bouts was experimentally fixed by delivery of limited numbers of food pellets (1, 4, or 12) on variable interval (VI) or variable time (VT) schedules, and the amount of water drunk during hourly sessions was measured. Excess drinking (polydipsia) was found with reinforcer amounts of 1 or 4 pellets, but not with 12-pellet reinforcers. The inverse relation observed between water intake and eating-bout size (which Lotter et al. called "bite" size) led the authors to conclude that "the size of the reinforcement is the determining factor in the increased drinking" (p. 481).

The way in which drinking is dependent on reinforcer or eating-bout size was tacitly attributed by Lotter et al. to an interaction of two factors. First, the larger the size of the individual reinforcers, the fewer the number of eating bouts the rat needs to engage in to reach satiation. Ad-lib eating with water available appears to set the lower limit at about 10 bouts of 20 pellets each. Secondly, should the rat drink a fixed amount of water after every eating bout, regardless of its size, then schedule-induced polydipsia would be a somewhat trivial consequence of the increased number of eating-drinking cycles forced upon the

subject by the intermittent delivery of small reinforcers.

With the first of these two factors, there can be little dispute. As the size of the reinforcers declined, rats did engage in more and more eating bouts per hour. And as they ate more times, so they drank more: a correlation of $+0.953$ was found between the volume of water consumed and the number of reinforcements per hour. This high correlation, which is implied by the second factor—the assumed constancy of drink or draft size, independent of reinforcer size—is, however, in itself insufficient to establish that constancy. Notwithstanding, the demonstration that this constancy holds over a range of situations is clearly central to any attempt to explain away the diverse facts of schedule-induced polydipsia by appeal to eating-drinking invariances.

It comes as a momentary surprise to recall that this artifact explanation for schedule-induced polydipsia is an old idea. In fact, it was one of the earliest explanations proposed by Falk (1964) and Stein (1964). Falk pointed out that after each 45-mg pellet delivered on an intermittent schedule that provided 180 pellets over a 3.5-h period, "the animal drinks after he eats as if it were a regular meal. I keep serving him meals and he drinks as if he had 180 natural meals" (Falk, 1964, p. 115). However, Falk apparently did not entertain this simple hypothesis further, for it fails to find a systematic role in any of his later theorizing about polydipsia (e.g., Falk, 1966, 1969, 1971). As it happens, there are quite good empirical reasons to reject it. One main line of evidence that can be brought to bear against it comes from the relationship between the interreinforcement interval and amount of adjunctive drinking. Falk's (1966) original inverted-U function between amount drunk and fixed interreinforcement interval (FI) is somewhat ambiguous, because it confounded session length, and hence opportunities to drink, with

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Figure 1. Drink size per eating bout as a function of the size of the bouts provided the rats. Points plotted are averages of four rats and were calculated from data of Lotter, Woods, and Vasselli (1973). Numerals indicate the experiment number. The dotted line is the least squares equation, $y = 0.0173x + 0.28$.

interreinforcement time. Even so, when Falk's (1966) data are replotted as *rate* of drinking (milliliters/hour) there is a constancy at about 10-11 ml/h over the range of 20-120 reinforcements/h. Here, rate of water intake remains constant, even though the number of eating bouts is changing over a wide range, a fact for which the artifact hypothesis leaves us unprepared. More recently, the actual amount of water consumed per interval has been examined in various FI schedules (Bond, 1973; Flory, 1971; Hawkins, Schrot, Githens, & Everett, 1972), and in all cases an inverted U describes the relationship between amount drunk per interval and the interreinforcement interval. Again, since each interval is associated with precisely one eating bout, the artifact hypothesis is embarrassed because it wrongly predicts no variation in water intake per interval. Moreover, not only the amount drunk, but also the percentage of pellets followed by drinks and the drink duration are sensitive to the interreinforcement interval, as Segal, Oden, and Deadwyler (1965) showed some time ago. All of these data are facts, not artifacts, and as such require systematic interpretation.

Perhaps it is unfair to ask the artifact hypothesis to explain effects that are outside its immediate domain, which is, after all, drinking associated with changes in the amount of each reinforcer, or with different eating bout sizes. Yet here, too, the facts resist relegation to artifactual status. Flory (1971) studied drinking induced by one- or two-pellet reinforcers over a range of fixed interreinforcer intervals. For all animals, water intake per interval was greater for the two-pellet than for the one-pellet reinforcer magnitude.

"Doubling reinforcement magnitude at any of a wide range of fixed interval lengths produced an increase in water intake per interval" (Flory, 1971, p. 222). Similar results were found by Rosenblith (1970), who found a greater amount of water drinking per interreinforcement interval with 250-mg food pellets than with 45-mg food pellets. Bond (1973) compared one-pellet bouts with five-pellet bouts and found that five-pellet bouts invariably produced more copious drafts.

All of the data cited above, save for those of Bond (1973), were extant at the time that Lotter, Woods, and Vasselli (1973) revived Falk's (1964) early suggestion that the size of a postprandial drink was independent of the size of its immediately preceding eating bout, and that invariance of drink duration underlay schedule-induced polydipsia. Yet, what is perhaps the most remarkable fact of all is that in their own experiment, Lotter et al. neglected to notice that their data actually contained strong support for an opposing view, namely, the larger the eating bout, the larger the subsequent drink. Since their animals drank after all or nearly all (95%) of their food reinforcers (E. C. Lotter, personal communication), the mean postprandial draft size can be estimated from the number of pellets delivered, the reinforcement or eating bout size, and the milliliters of water consumed per session. In Figure 1, seven determinations of the mean drink size are plotted from the six subexperiments of Lotter et al. against eating bout size in pellets. It is clear from Figure 1 that as bout size increases, the size of the postprandial drink also increases, perhaps linearly over the range of 1 to 20 pellets. In view of the empirical relationship demonstrated in Figure 1, the authors' statement that "the average drink size remained very constant over the entire experiment ($.46 \pm .04$ ml)" is deceptive. That average hides a systematic variation in drink size.

How did Lotter et al. (1973) miss this relationship in their data? One reason may have been that although drink size increased as bout size increased, this increase was far less striking than the effect of more frequent eating bouts that occurred when bouts were small. For instance, when single pellets were received for leverpressing on a nominal VI 1-min schedule, the animals engaged in 70 single-pellet bouts during the 1-h session (Experiment 2). However, when 12 pellets per reinforcement were received on the same VI 1-min schedule, the animals engaged in only 18 12-pellet bouts (Experiments 3, 4). So, despite the approximately twofold increase in drinking per bout from 0.29 ml to over 0.50 ml shown by Figure 1, there was a nearly fourfold increase in total bouts; hence, about twice the total water intake was recorded at the 1-pellet bout size compared with

the 12-pellet bout size. Perhaps it was overlooking this unequal compensation that led the authors to conclude that "the rat drinks a certain fixed amount of water after every bite [bout] independently of the size of the bite" (p. 478). In any case, it is clear that the application of the invariance hypothesis to the relation between reinforcements/hour and milliliters/hour drunk (Figure 2 of Lotter et al.) should yield a straight line of the form $y = kx$, where y is the hourly water consumption in milliliters, x is the rate of reinforcement in reinforcements/hour, and k is the putative drink constant, 0.46 (Lotter et al., p. 483). Figure 2 shows averaged data points from Lotter et al. along with the predicted (solid) line. The fit is obviously poor. As it happens, however, the data are much better fit by another straight line, $Y = 0.27X + 4$; and although no special significance can be attached to that particular equation, it is what underlies the high product moment correlation found between the variables. Its dotted representation in Figure 2 serves to emphasize the clear divergence of the predicted from the empirical line, which is nothing less than a powerful refutation of the hypothesis of the constancy of the postprandial drink size. With infrequent (large) reinforcers (Experiments 1, 3, 4), the subject overdrinks the constancy equation; then as bouts are constrained to smaller and smaller sizes and their frequency increases (Experiments 2, 5, 6), the subject underdrinks the constancy prediction.

The facts of schedule-induced polydipsia remain unexplained. Empirical relationships between drinking and a variety of reinforcement parameters cannot as yet be accounted for by any simple notion such as the constancy of the postprandial drink. Rather, that drink varies in its probability, its duration, and its amount, depending upon these parameters. Along with a host of related adjunctive behaviors (Segal, 1972), schedule-induced polydipsia continues to await a psychological interpretation for its systematic significance.

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Figure 2. Rate of water consumption (y) as a function of the rate of eating bouts (reinforcements, x). Solid points are means of four rats from six experiments of Lotter, Woods, and Vasselli (1973). The small numerals tag the experiment number. Open triangles are means from data of Stein (1964), open circles are means from data of Falk (1967). The solid straight line is the representation of the equation $y = 0.46x$. The dotted line is the empirical line, $y = 0.27x + 4$, fitted by eye.

(Received for publication October 16, 1974;
revision received December 17, 1974.)