

A FAILURE TO OBSERVE SCHEDULE-INDUCED  
POLYDIPSIA DURING SCHEDULES OF BRAIN  
STIMULATION REINFORCEMENT

by

DONALD GORDON RAMER

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Department of Psychology

The University of British Columbia  
2075 Wesbrook Place  
Vancouver, Canada  
V6T 1W5

Date October 1, 1975

ABSTRACT

An attempt was made to observe schedule-induced polydipsia in rats whose lever pressing was reinforced with electrical brain stimulation. Eleven food-deprived, water-sated rats drank freely available water excessively during sessions in which Noyes food pellets were delivered intermittently. When brain stimulation reinforcement was substituted for food reinforcement, drinking dropped immediately to near zero. Delivering brain stimulation according to a variety of schedules, pairing brain stimulation with food reinforcement, providing saccharin solution in addition to water, and substituting an air stream for water each failed to produce schedule-induced polydipsic licking during brain stimulation reinforcement sessions. These results suggest that food ingestion is a necessary stimulus for schedule-induced polydipsic drinking. Theories of schedule-induced polydipsia are discussed and evaluated.

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## INTRODUCTION

### Schedule-Induced Polydipsia

When small food pellets are delivered intermittently to food, but otherwise undeprived rats, and water is freely available, a curious phenomenon develops. Within several daily sessions of a few hours each, the animals will reliably and consistently drink a small draught of water following the ingestion of each pellet. If a large number of pellets is delivered during a session, the amount of water consumed is extraordinarily large, often being several times the normal daily intake. This phenomenon was first reported by Falk in 1961 and was called schedule-induced polydipsia (SIP). One reason it is described as "schedule-induced" is to distinguish it from other types of polydipsia, such as food-deprivation polydipsia in gerbils (Kutscher, Stillman, and Weiss, 1968).

Since 1961 SIP has attracted a good deal of experimental investigation. The phenomenon seems worthy of study because of its nonadaptive nature. Rats normally consume 25g of food and 36 ml of water each day under ad lib feeding conditions (Collier and Knarr, 1966). Food deprivation decreases water intake (Falk, 1964). Following 22 hr food deprivation, rats have been observed to ingest a 1:1 ratio of water to food, and maintain this proportion in their stomach contents during feeding (Lepkovsky, Lyman, Fleming, Nagumo and Dimick, 1957).

During conditions which produce SIP, this ratio has been observed to reach 7:1, concurrent with extreme cellular tissue overhydration (Stricker and Adair, 1966). Food-deprived rats can scarcely afford the energy required to heat copious amounts of water from ambient temperature to body temperature before expelling it. Falk (1972) has further discussed the nonadaptiveness of an animal drinking itself into a dilutional hyponatremia which borders on water intoxication. Falk considers this activity to be "psychogenic".

Many experiments show that SIP occurs under a variety of conditions. Polydipsic rats will drink from any of several different water dispensing devices (Falk, 1966a). The effect will occur with different operant response requirements for the food pellet (Falk, 1969), and in the absence of a specified operant response, when food pellets are delivered freely to the animal (Burks, 1970). Falk (1969) has observed SIP in both sexes of different strains of rats. Furthermore, the effect is not confined to the rat. Schedule-induced polydipsia has also been reported in the rhesus monkey (Schuster and Woods, 1966), chimpanzee (Kelleher, cited in Falk, 1972), and pigeon (Shanab and Peterson, 1969; but see Whalen, 1975).

Schedule-induced polydipsia is not simply elicited by the ingestion of food. The animal must be food deprived for the phenomenon to occur. Falk (1969) found that raising a rat's weight

from 80 to 95% of normal had little effect on the degree of SIP drinking. Above 95%, however, such drinking decreased rapidly even though the animal's operant responding for food pellets on a fixed-interval (FI) schedule was scarcely affected. This inverse relationship between body weight and SIP drinking is particularly interesting because food deprivation normally decreases drinking in the home cage (Falk, 1964).

Intermittency of food pellet delivery is also an important factor in SIP drinking. Schedule-induced polydipsia does not occur during continuous reinforcement (CRF) schedules (Falk, 1966a), except when a CRF schedule alternates with periods of extinction (Keehn and Colotla, 1971). In this case, drinking only occurs at the onset of extinction (EXT). On intermittent schedules, inter-reinforcement time (IRT) and amount of SIP drinking are related in a bitonic fashion. Falk (1966b) has observed SIP to increase as the IRT was increased to 150 sec. An IRT of 300 sec, however, produced less SIP. The importance of such schedule parameter considerations in the SIP phenomenon is another reason for the use of the term "schedule-induced".

It has been suggested that reinforcer magnitude also affects SIP. Delivering two pellets rather than one during both variable-interval (VI) 1-min and VI 2-min schedules greatly reduced the total volume of water consumed within each session (Falk, 1967). However, Keehn and Colotla (1971) found that drink durations following 1-, 3-,

6-, or 9- pellet meals are essentially the same. Only following 21-pellet meals did the drink duration increase. If simultaneous delivery of two pellets in the Falk experiment can be considered to comprise one meal, then volume consumed following each meal was approximately the same. The distinction between pellet and meal will be more fully discussed later.

Schedule-induced polydipsic drinking depends on the type of food used as reinforcement. Noyes 45 mg rat pellets produce the largest amount of drinking. Twenty-two mg portions of liquid monkey diet dispensed according to a VI 1-min schedule engender only slightly less drinking. Forty-five mg sucrose and glucose pellets produce low levels of drinking. Liquid Metrecal and portions of 30% sucrose produce even less drinking (Falk, 1967). Freed (1971) found that SIP drinking was greatly decreased when sweetened nonnutritive pellets were substituted for 45 mg Noyes food pellets. This suggests a relationship between the nutritive value of the food reinforcement and the quantity of water consumed. The dependence of SIP upon type of reinforcement will be more fully discussed later.

Experiments concerned with the SIP phenomenon have typically provided water in the experimental space. The quantity of liquid consumed has been shown to depend in part on type of liquid. Falk (1966c) found that more saline than water was consumed poly-

dipsically. Valenstein, Cox, and Kakolewski (1967) found that rats drank a greater quantity of a solution of saccharin and glucose than of water. Segal and Deadwyler (1965b) obtained greater consumption of solutions of saline and saccharin, and smaller consumption of quinine, than water. The excessive consumption of glucose and perhaps saccharin may be due in part to the food-deprived condition of the animals (cf. Gilbert and Sherman, 1970). Indeed, Keehn, Colotla, and Beaton (1970) found that rats drank saccharin throughout the IRT in addition to during the post-pellet period as normally occurs during SIP.

Schedule-induced polydipsia does not occur only when water is easily accessible. Rats have been shown to work, by pressing a lever for example, in order to produce access to water following pellet delivery (Falk, 1966a).

Schedule-induced polydipsia appears similar to normal drinking except for its excessiveness and its close temporal relation to food ingestion. While rats normally drink approximately 70% of their total water intake closely associated with food (Fitzsimons and Le Magnen, 1969), the reliable drinking and volume consumed after each pellet in SIP situations is absent. The excessive volume of water consumed within a short time demands explanation. From the research on SIP have evolved several explanatory hypotheses. Each of these will be examined.

### Dry Mouth Hypothesis

Schedule-induced polydipsia usually occurs during experimental sessions in which rats receive dry Noyes food pellets. Stein, in 1964, suggested what is perhaps the obvious: rats drink in response to the ingestion of dry food. According to this notion, the rat drinks to eliminate supposedly aversive post-prandial oral effects of the ingestion of dry food pellets (Stricker and Adair, 1966). Thus SIP drinking may serve the function of "gargling" following the ingestion of dry food. Another interpretation, however, is that dry food serves simply as a stimulus for the initiation of drinking (Teitelbaum and Epstein, 1962).

Support for the dry mouth notion is provided by studies in which substances other than Noyes pellets served as reinforcers. Stein (1964) failed to observe SIP when dilute sweetened condensed milk was used. Stricker and Adair (1966) failed to either initiate or maintain SIP in rats when vegetable oil served as reinforcement. In the latter case vegetable oil was substituted for food pellets following the establishment of SIP. Fitzsimons and Le Magnen (1969) found that normal rats consume at least 70% of their total daily water requirement with meals. This holds for both free feeding or scheduled feeding conditions. While normal rats eat and drink in clearly discernible bouts, both recovered lateral hypothalamically lesioned rats and neurologically normal desalivate rats display the typical prandial drinking pattern characteristic of SIP (Kissileff, 1969a; Kissileff and Epstein, 1969).

"Prandial" drinking has typically referred to drinking bouts which immediately follow food ingestion and which involve consumption of less than 0.5 ml of water. "Normal" drinking bouts both precede and follow food ingestion and involve consumption of between 0.5 and 2.5 ml of water.

Vance (1965) provides additional support for the dry mouth hypothesis. If desalivate rats eating dry food are deprived of water, food intake falls more precipitously than does food intake of intact rats which are water deprived. Further, the transition from normal to prandial drinking in the desalivate rat occurs over several days, similar to the initiation of SIP drinking. When the salivary flow is interrupted in recovered lateral rats, their total water consumption increases in the absense of a corresponding increase in food consumption (Kissileff and Epstein, 1969). This increase is due entirely to an exaggeration of the prandial pattern of drinking typical of recovered lateral rats. If a small amount (0.015 to 0.05 ml) of water is injected directly into the mouths of either recovered lateral rats or neurologically normal desalivate rats during ingestion of a food pellet, prandial drinking is abolished. Injections of similar volumes of water directly into the stomachs of these animals produced no significant reduction of prandial drinking. Water intake of normal rats was proportionally reduced by injections of water via either route (Kissileff, 1969b). These findings strongly support the notion that oropharyngeal stimuli associated with the ingestion of dry food control prandial drinking. Normal

drinking appears to be partially under the control of these oropharyngeal mechanisms, as food-associated prandial drinking appears to be one of the major components of normal drinking.

The dry mouth hypothesis has encountered difficulties from several sources. Falk (1969) notes that rats show no performance decrement from beginning of session to end when reinforced with dry food pellets, despite an absence of water in the experimental space. Thus the apparently aversive aftereffects of dry food are not such that they decrease the reinforcing value of the food. When a CRF schedule is in effect, and water is concurrently available, little prandial drinking occurs and SIP does not develop (Falk, 1966a). Schedule-induced polydipsia has been observed when 22 mg portions of liquid monkey diet, one-third water by weight, served as reinforcement (Falk, 1967). Falk (1969) believes that dilute sweetened condensed milk and vegetable oil as used by Stein (1964) and Stricker and Adair (1966) were dispensed in quantities too large to produce SIP. Indeed, Falk (1967) found that liquid monkey diet only produced a high degree of SIP when reinforcement magnitude was small.

#### Adventitious Reinforcement Hypothesis

Schedule-induced polydipsia has also been viewed in terms of adventitious, or superstitious (cf. Skinner, 1948) reinforcement. Clark (1962) suggested that bouts of drinking which occurred during



short IRTs on a VI schedule were often followed by reinforced bar presses. Thus an adventitiously reinforced chain consisting of drink - bar press - food reinforcement could be established. Clark found some evidence for this adventitious chaining notion. When the animals were switched to fixed-ratio (FR) schedules in which the likelihood of a response being reinforced was unaffected by drinking, SIP drinking was greatly attenuated. When the rats were returned to a VI schedule following FR, a pattern of post-reinforcement drinking soon redeveloped.

Other manipulations have provided some support for the contention that SIP is an operantly maintained response. When food pellets are delivered independent of the rat's behaviour, according to either fixed-time (FT) or variable-time(VT) schedules, post-pellet drinking occurs (Segal, 1965; Segal, Oden and Deadwyler, 1965b; and Mottin, 1969). This pattern takes several days to develop, suggesting the establishment of an adventitiously reinforced response. When food reinforcement is withheld, the drinking undergoes extinction. It gradually recovers following reinstatement of the original schedule (Segal, Oden, and Deadwyler, 1965a). Further, the number of licks during EXT appears to be related to the number of licks emitted during "training", on a VT schedule (Mottin, 1969).

There is evidence to suggest that SIP is not established and

maintained adventitiously by reinforcement. Schedule-induced polydipsia is an extremely stable and reliable phenomenon. Superstitious behaviour, on the other hand, has been characterized by its ideosyncratic nature, variability, and instability (Skinner, 1948; but see Staddon and Simmelhag, 1971). Also, the chain of responding during SIP situations is somewhat backwards for an adventitious explanation to hold. Should adventitious reinforcement maintain SIP, drinking should then occur before, not immediately following, food pellet delivery. Schedule-induced polydipsia has been observed in rhesus monkeys to follow food reinforcement which was delivered at one hour, and longer, intervals (Schuster and Woods, 1966). To suggest that drinking which occurs during the period of lowest probability of reinforcement is maintained adventitiously seems to be stretching the point.

Schedule-induced polydipsia has also been observed to occur in situations which punish drinking in close antecedent proximity to food reinforcement. Falk (1964) programmed a changeover delay (COD) during a VI 60-sec food reinforcement schedule. The COD prevented delivery of a food pellet when scheduled food delivery was preceded by a lick at the drinking spout within 15 sec. Despite the fact that drinking was never immediately reinforced, SIP was established and maintained. Segal and Oden (1969) extended this finding by the imposition of a 30 and 60 sec COD on a FT 60-sec schedule. This also failed to prevent SIP.

Schedule-induced polydipsia has been reliably demonstrated during a FR 30 schedule which reinforced every 30th bar press (Falk, 1969). In this case, post-pellet drinking postponed reinforcement, which occurred only following the required thirty bar press responses. It is unlikely that drinking during this condition could be adventitiously reinforced.

The evidence, then, supporting an adventitious reinforcement interpretation of SIP is tenuous.

#### Mediating Behaviour Hypothesis

It has been suggested that SIP occurs to serve as a cue in timing reinforcement availability. Segal and Holloway (1963) found that rats reinforced with food for spacing their key press responses at least 20 sec apart (DRL 20-sec schedule) soon engaged in a pattern of key press - pellet - drinking. Premature responses were not followed by drinking, as were reinforced key presses. When drinking did not occur, responses were seldom sufficiently separated in time to be reinforced. Once rats had developed SIP under a DRL schedule, removing the water bottle (Deadwyler and Segal, 1965) or replacing it with an empty bottle (Segal and Oden, 1965) tended to disrupt the DRL performance, thus decreasing the number of pellets received. These results suggest that SIP plays an important role in the mediation, or timing, of intermittently reinforced responding.

The notion that SIP serves only to mediate responding, however, cannot be seriously entertained. As Falk (1969) has pointed out, that drinking can serve a mediating function does not necessarily imply that it is necessary for this function. Schedule-induced polydipsia occurs on a variety of schedules, including those for which timing would serve no useful purpose, e.g. VI and ratio schedules. Segal and Holloway's experiment confounded food delivery with successful timing. These authors' assumption regarding the necessity of drinking to time IRTs is undermined by the observation that drinking only followed food pellet delivery.

#### Arousal Hypothesis

Wayner (1974) has suggested that the delivery of a food pellet to a hungry rat is an arousing event. On an intermittent schedule, food reinforcement is an unconditioned stimulus which elicits a state of excitement or arousal. Once aroused, the animal will engage in some activity with a higher than normal frequency. Wayner views this state of arousal as being nonspecific; the animal will engage in whatever motor activity his environment will support. According to this contention, one would predict that post-pellet motor activities are interchangeable. For example, a rat could equally be expected to engage in drinking, wheel running, attack, etc. The literature does appear to support this prediction (Falk, 1972).

"Stimulus-bound" behaviours have been shown to bear some similarity to post-pellet behaviours. When electrical stimulation is delivered to the lateral hypothalamus, rats will engage in a variety of motor behaviours including eating, drinking, sniffing, and grooming for the duration of the stimulation. Which behaviour the animal emits is dependent upon stimuli available in the environment (Valenstein, Cox and Kakolewski, 1970). These investigators suggest that stimulus-bound behaviour occurs due to the arousal produced by hypothalamic stimulation.

#### Post-Reinforcement Period Aversiveness

Schedule-induced polydipsia occurs immediately following food pellet ingestion, during the post-reinforcement period. It is well known that periods of low probability of reinforcement, which occur immediately post-reinforcement on periodic schedules, are aversive. During the post-reinforcement period pigeons will respond to terminate a stimulus associated with a high response requirement FR schedule (Azrin, 1961). As well as escape, attack behaviour can be generated by these conditions. Following reinforcement on a FR 50 schedule, when the next reinforcer is not immediately available, a pigeon will attack a restrained pigeon (Gentry, 1968). This phenomenon is not restricted to high ratio requirements. Azrin, Hutchinson, and Hake (1966) were able to demonstrate attack in a pigeon when EXT was introduced following a period of CRF. This attack was only observed following food consumption. A brief feeder flash was insufficient for the elicitation

of attack. Attack has also been produced with various FT schedules in which food was presented non-contingently (Flory, 1969).

Schedule-induced polydipsia and extinction-induced attack share at least one common characteristic. Flory (1969) found that a pigeon's attacking of a nearby restrained pigeon following food delivery varied according to the food reinforcement schedule in effect. In a series of FT schedules, attack frequency increased as the schedule duration increased to about FT 60-sec or FT 120-sec, and then decreased as the schedule length continued to increase. This bitonic function is similar to that observed by Falk (1966b), where SIP increased as FT schedules were extended to about 180 sec. A study by Deaux and Kakolewski (1970) provides physiological evidence to support the notion that emotionality, which is intuitively implicated in attack, might also play a role in eliciting SIP. Rats in this study which were stressed by handling or rotation showed an increase in drinking concurrent with a decrease in eating. Stress induced a rapid increase in serum osmolality, which might explain the emergence of drinking. The aversiveness of the post-reinforcement period may also produce an increase in osmolality, which can be returned to normal by the initiation of drinking.

Amphetamine and pentobarbital are commonly thought to increase and decrease emotionality, respectively. Falk (1964) and Segal, Oden and Deadwyler (1965c), however, have found rather paradoxical effects

of these drugs on SIP. Amphetamine, which according to the emotionality hypothesis would be expected to increase SIP, in fact does the opposite. The effect of this drug is difficult to evaluate, however, because it also decreases home cage water consumption and normal food deprivation drinking (Falk, 1964). Pentobarbital, which is assumed to decrease emotionality, and thus would be expected to decrease SIP, does so by shortening drink durations. Drinking still occurs following the ingestion of each food pellet. These findings cannot be considered to support an emotionality interpretation of SIP.

To use an ill-defined concept such as emotionality as an explanation of the SIP phenomenon creates more problems than it solves. It might be more instructive to look at phenomena which share properties of SIP and post-reinforcement aversiveness.

#### Adjunctive Behaviour

During the post-reinforcement period, animals have been shown to engage in a variety of behaviours. Post-reinforcement drinking, escape, and attack have been discussed. Several other behaviours also occur during the post-reinforcement period on intermittent schedules. If the water spout is replaced by a drinking tube which emits a steady stream of air, or a small burst of nitrogen contingent on a lick at the tube, the post-reinforcement period will be filled with bouts of licking at the tube (Mendelson and Chillag, 1970; Taylor and Lester, 1969). Licking in both these cases resembles SIP water licking, except that

it occurs for a much longer duration, often filling the entire IRT.

This is possibly due to an apparent lack of satiation. Rats reinforced with food on a VI 1-min schedule for bar pressing exhibited much more wheel-running than during CRF or EXT conditions (Levitsky and Collier, 1968). Villarreal (1967) found that rhesus monkeys during a FT 15-min schedule of food reinforcement would chew on wood shavings, which lined the bottom of the chamber, following the ingestion of the pellet. He called this behaviour "schedule-induced pica". These animals would manipulate, chew, and store the wood shavings in their cheeks as well as ingest them. This activity resembled SIP in that it rapidly declined at shorter IRTs and disappeared during EXT.

Some of these schedule-induced activities apparently compete or interfere with SIP. Freed and Hymowitz (1969) noticed that rats' SIP drinking became disrupted when the animals started chewing on the cellulose material lining the bottom tray. When this easily manipulable material was removed, SIP was immediately re-established. Villarreal (1967) found that his rhesus monkeys either preferred to drink during the post-reinforcement period, or alternated between drinking and chewing wood shavings. Segal (1969) reported similar results with rats. When both a drinking tube and a wheel were available, post-reinforcement drinking was the most frequent response. When the water spout was removed, wheel running increased in frequency.

It appears from these studies that a number of other behaviours



may be substituted for SIP. These activities share similar temporal patterns, and may be considered excessive when compared to baseline rates. The similarities shared by these post-reinforcement behaviours have given rise to the currently most prevalent conception of SIP. As all of these behaviours can be construed as adjuncts to the reinforcement schedule, they can be considered to belong to a class called adjunctive behaviour (Falk, 1969, 1971, 1972).

Falk makes a compelling argument for the utility of regarding SIP as an adjunctive behaviour. There are indeed many correspondences among these post-reinforcement, or schedule-induced, behaviours. For example, all these activities occur during the period immediately post-pellet, when, with the exception of CRF, probability of reinforcement is lowest. It must be noted that SIP and other adjunctive behaviours, do not occur during CRF. As Falk points out, SIP is controlled either by the recency of pellet delivery, or the period of lowest probability of reinforcement, or both. There is currently insufficient evidence to make a definitive statement regarding this distinction.

According to Falk,

"...adjunctive behaviour is behaviour maintained at high probability by stimuli whose reinforcing properties in the situation are derived primarily as a function of schedule parameters governing the availability of another class of reinforcers."  
(Falk, 1972, p. 172).

Water thus gains its ability to reinforce drinking by virtue of the concurrently available food reinforcement schedule.

Falk suggests that a behaviour which has been classified as adjunctive must display certain characteristics. The frequency of the response which occurs during the IRT must increase to an excessive level, at which it remains stable, during repeated presentation of the reinforcing stimulus. This stimulus must not act as a conditioned or unconditioned stimulus which elicits the response, nor must it reinforce that response. The strength of the behaviour should be a bitonic function of the rate of presentation of the reinforcing stimulus. Finally, the behaviour should occur with highest probability immediately following presentation of the reinforcing stimulus.

With respect to SIP, post-pellet drinking increases at a steady rate to a stable asymptotic level. This drinking is not under direct control of the contingencies maintaining bar pressing for food, but rather is indirectly controlled by the variables associated with bar pressing and ingestion of food.

Falk relied heavily on the ethological analysis of displacement behaviour (Tinbergen, 1952) in the formulation of his definition. Displacement activity occurs when an ongoing species-specific, goal-directed behaviour pattern is interrupted. For example, black-headed gulls have been observed to start nest building when their brooding behaviour is interrupted (Moynihan, 1953). Interrupting, or thwarting, an ongoing goal-directed behaviour pattern occurs when the stimuli necessary to maintain that behaviour are removed. In the SIP situation,

rats engaged in a high rate of consummatory (eating) behaviour are thwarted in this activity due to the intermittency of the reinforcement schedule. Their consummatory behaviour thus becomes displaced. Drinking serves as a convenient displacement because it contains some of the elements of eating. Bar pressing for food, one of the elements of consummatory behaviour, engages the animal in a high rate of motor behaviour. When this behaviour is interrupted, the animal's motor behaviour might be displaced to wheel running, or any other conveniently available activity involving elements of motor or consummatory behaviour. The "explanation" of SIP as an adjunctive behaviour is currently the most popular hypothesis.

#### Purpose of Present Research

If SIP is an adjunctive behaviour, it must meet all of the conditions which Falk considers characteristic of adjunctive behaviour. Interchangeability of both adjunctive behaviours and reinforcing stimuli seems to be an integral part of the adjunctive hypothesis. The hypothesis would presumably predict that any reinforcing stimulus which maintains a high frequency of consummatory, or goal-directed, operant behaviour would, once removed, result in the production of adjunctive behaviour. Past research has yielded both successes and failures in demonstrating SIP with different substances serving as reinforcement. Falk (1969) suggests that these discrepancies have occurred because of a failure to observe all the criteria necessary to produce adjunctive behaviour. For example, the IRT must be sufficiently long, the substance

must be sufficiently reinforcing, the animal must be highly motivated, and so on.

The present study employed electrical stimulation of the brain (ESB) as the reinforcing stimulus. If SIP can be classified as an adjunctive behaviour according to Falk's criteria, it should occur following intermittent presentation of ESB. Electrical stimulation of the brain has been shown to maintain a high rate of operant behaviour (Olds and Milner, 1954) and will reliably maintain scheduled responding (Pliskoff, Wright, and Kawkins, 1965). In addition, Hoebel (1968) has shown that such postingestional events as gastric distention, increased blood-sugar level, and cellular osmolality, both when they occur normally and when they are experimentally induced, interact with rates of lateral hypothalamic self-stimulation. Hoebel has demonstrated striking correspondences between lateral hypothalamic activity and feeding. Further, Valenstein et al. (1970) have reliably demonstrated that ESB delivered independent of the animal's behaviour will produce a variety of consummatory behaviours, when the appropriate stimuli are present.

#### GENERAL METHOD

##### Subjects

Two Wistar albino rats (S1 and S2) obtained from Woodlyn Breeding Laboratories, Guelph, Ontario, and nine black hooded rats

(S3 through S11) obtained from Canadian Breeding Laboratories, La Prairie, Quebec, served as subjects. All animals were males weighing between 300 and 350 g at time of surgery.

### Surgery and Histology

The animals were anesthetized with sodium pentobarbital (Nembutal, 50 mg/kg) injected intraperitoneally. Each animal was chronically implanted with a Plastic Products bipolar stimulating 0.25 mm electrode aimed at the medial forebrain bundle at the lateral hypothalamus. The coordinates for implantation were 2 mm posterior to Bregma, 1.8 mm lateral to the sagittal suture, and 8.6 mm ventral to the dura. Electrodes were held in place with acrylic cemented to machine screws imbedded in the skull. The electrodes protruded from the acrylic sufficiently to allow positive connection to a Plastic Products lead.

Following surgery all animals were injected intramuscularly with 0.2 ml penicillin, and allowed at least one week to recover prior to experimentation.

Following termination of the experiment, animals were sacrificed by means of carbon dioxide. Their brains were fixed in formal saline, and then frozen. Forty-u thick sections were cut and stained with thionin.

Histological inspection verified that the electrodes had been implanted throughout the medial forebrain bundle in 10 of the animals.

Rat S3's electrode was located in a more posterior section within the substantia nigra. Fig. 1 illustrates these placements according to the stereotaxic coordinate system used by Pellegrino and Cushman (1967).

### Apparatus

Two experimental chambers were used in these experiments.

Chamber 1 was constructed 3 sides of metal and one of plexiglass and measured 25 cm x 25 cm x 38 cm high. A Scientific Prototype lever was centrally mounted on one metal wall, 6 cm from the grid floor. A ball-type drinking spout protruded 1 cm through a 1.5 cm diameter hole to the left of the lever, 3 cm from the floor. A food cup connected to a food dispenser was mounted to food dispenser was mounted to the right of the lever, 3 cm from the grid floor. This apparatus was enclosed within a ventilated, lighted, sound-attenuating chamber.

A 21 cm x 27 cm x 40 cm high plywood chamber served as Chamber 2. A lever, food cup, and drinking spout were similarly mounted on one wall of this chamber. An additional hole through which a second drinking spout could protrude was made between the first hole and the wall. This hole was covered when not in use. Chamber 2 was also enclosed within a ventilated sound-attenuating box, and illuminated.

Electrical stimulation of the brain was delivered from a 60 Hz sine wave stimulator. A commutator which connected the leads from the power source to the stimulating electrodes allowed the animals unrestrained movement within the experimental space. Experimental

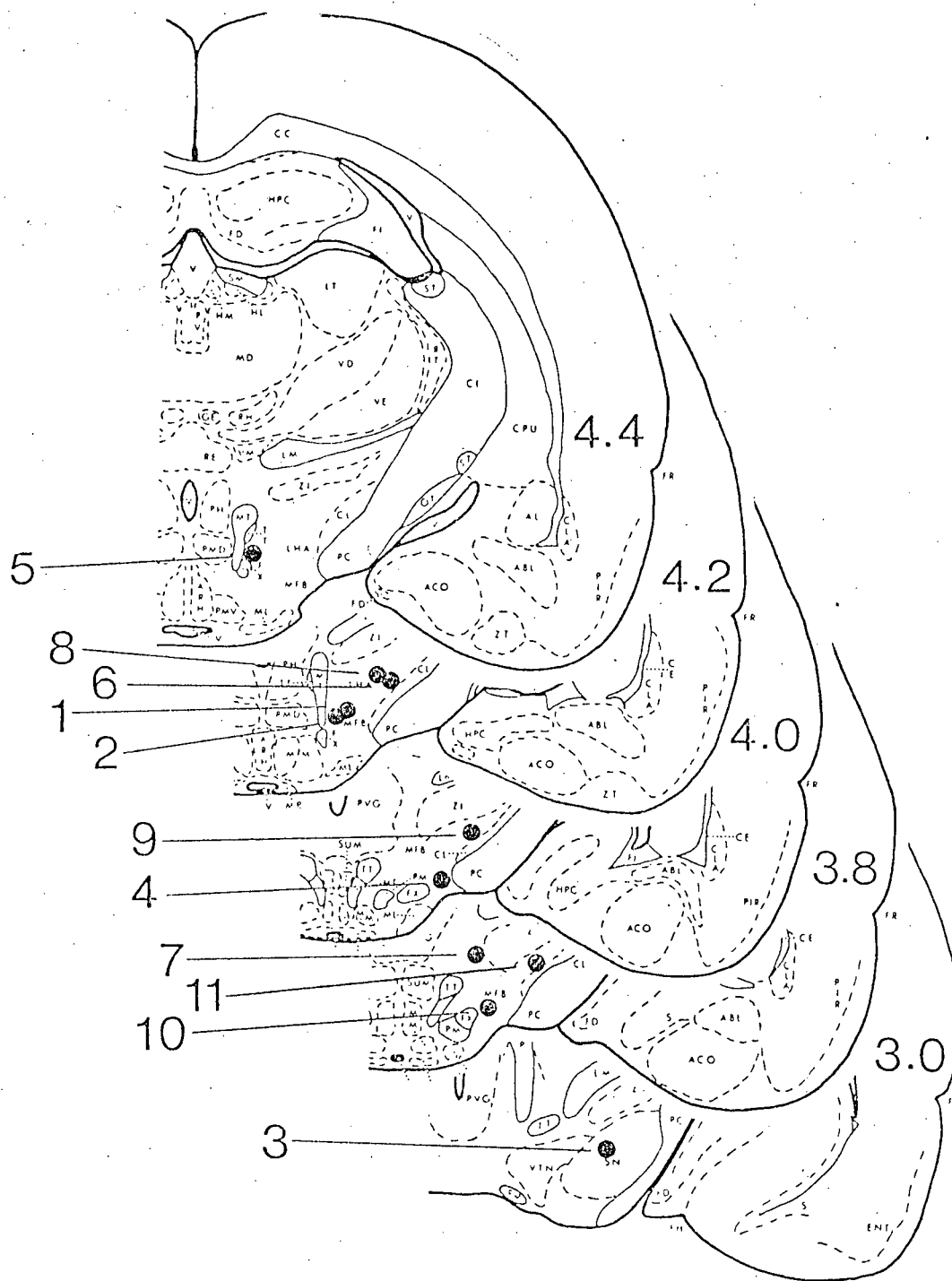


Figure 1: Electrode sites of animals S1 through S11.  
 Drawings were taken from Pellegrino and Cushman (1967).

conditions were programmed and data collected by BRS/LVE solid state and electromechanical circuits.

### Procedure

Following food deprivation to 80% of their free-feeding weight, all animals were screened for self-stimulation. Only those animals that reliably bar pressed for ESB reinforcement were employed in these experiments. Current levels were set at 10  $\mu$ A above the level which would maintain responding on a CRF schedule. This level was maintained for the duration of the experiment. During initial bar press training, ESB was delivered for 0.25 sec contingent on each response. Once bar pressing was reliably established, ESB reinforcement in Chamber 1 consisted of five equally spaced pulses each of 0.25 sec duration, covering a total period of 2.5 sec. Animals tested in Chamber 2 received 2.5 sec continuous current at scheduled reinforcement periods. Except as noted reinforcement was always contingent upon a bar press response. Initially each response produced one ESB reinforcement. Over the first two or three sessions the schedule parameters were changed gradually until ESB reinforcement was delivered according to the appropriate intermittent schedule.

Following bar press training for ESB reinforcement, all animals were trained to bar press for 45 mg Noyes food pellets. Training proceeded in a similar manner as with ESB reinforcement.

All experimental sessions, except for designated exceptions,



were of 90 min duration. Animals received sessions an average of six days per week, at about the same time each day. Each animal was fed Purina rat chow following each experimental session so as to maintain the rat at 80% weight. Water was continuously available in the home cage. Home cage water consumption was monitored on a daily basis.

### EXPERIMENT 1

Schedule-induced polydipsia has been reported to have occurred during ESB reinforcement schedules (Atrens, 1973; Wayner, Greenberg, Fraley, and Fisher, 1973). Atrens observed post-ESB drinking in two rats, and consumption of wet mash in three others. The SIP, however, ceased after several sessions. Wayner et al. were able to maintain SIP, though at a greatly reduced rate, in one of four rats switched to ESB following food reinforcement. These results were not replicated by Cohen and Mendelson (1974), who observed rats to drink excessively following food, but not ESB, reinforcement on several simultaneous VI schedules. In this experiment, rats had the opportunity to work for both food and ESB reinforcers, delivered according to various VI schedules. Although animals received both food and ESB within each session, drinking occurred only following food reinforcement.

The Cohen and Mendelson experiment compared SIP following food and ESB on a within-subject basis. It is possible, however, that rats did not drink following ESB reinforcement because of the large volume consumed in association with food. Although these animals did

not drink immediately post-ESB, they did engage in drinking during each session.

The present experiment sought to determine whether rats drink during sessions of ESB reinforcement in the absence of food. Both food and ESB served as reinforcers in successive blocks of sessions, in order to compare their effects on SIP within each animal. Reinforcement schedules other than those used by Cohen and Mendelson, which also have been shown to produce a high degree of SIP (cf. Falk, 1969), were employed.

### Method

#### Subjects and Apparatus

Rats S1 through S8 were tested in Chamber 1.

#### Procedure

The procedure is summarized in Table 1. Conditions are listed in the sequence in which they occurred. Values of the schedule of reinforcement are given in sec. For example, DRL 20 indicates that a response was reinforced only if it occurred at least 20 sec following the previous response. On FI schedules the first response to occur following the required interval produced reinforcement, e.g. FI 90 means that the first response to occur 90 sec following the previous reinforcement was reinforced. On VI schedules responses produced reinforcement according to the average designated value, e.g. a VI 30 schedule provided, on the average, 2 reinforcements per min.

Throughout all segments of the experiment, bar press responses, number of reinforcements (food and ESB), and water consumed were recorded.

### Results and Discussion

The final three columns of Table 1, "Responses", "Reinforcements", and "Water Consumed", summarize data from the last five sessions within each condition. Where only five sessions occurred within a condition, data from all the sessions are included. Similarly, only data from the single session are included when conditions were alternated daily.

Both ESB and food reinforcement reliably maintained responding in all animals throughout the experiment. Food reinforcement generally maintained a higher response rate, but this was not a consistent trend with each animal. When food pellets served as reinforcement, SIP typically occurred. Only a minimal amount of drinking occurred during sessions in which ESB reinforcement was delivered. Usually there was no measurable water consumption during this condition. At most, 4 ml of water were consumed within one ESB session, while water consumption approached and even exceeded 60 ml during 90 min food sessions. Fig. 2 graphically illustrates these large differences of water consumption during food and ESB reinforcement conditions. These data are from S1 and correspond to the five sessions of ESB and five sessions of food reinforcement followed by daily alternation of these conditions, as depicted by Table 1.

TABLE 1

## Summary of Procedure and Results - Experiment 1

| Subject | Schedule | Reinforcer | Number of Sessions | Number of Responses<br>Mean(Range) | Number of Reinforcements<br>Mean(Range) | Volume of Water (ml)<br>Mean(Range) |
|---------|----------|------------|--------------------|------------------------------------|---|-------------------------------------|
| S1      | DRL 20   | ESB        | 15                 | 453(438-471)                       | 26(28-36)                               | 0.0                                 |
|         |          | Food       | 10                 | 393(370-420)                       | 142(126-157)                            | 58.8(56-64)                         |
|         |          | ESB        | 5                  | 459(336-538)                       | 54(41-66)                               | 0.0                                 |
|         |          | Food       | 5                  | 404(100-538)                       | 120(100-139)                            | 41.2(24-50)                         |
|         |          | ESB        | 1                  | 434                                | 81                                      | 0.0                                 |
|         |          | Food       | 1                  | 363                                | 150                                     | 46.0                                |
|         |          | ESB        | 1                  | 352                                | 90                                      | 0.0                                 |
|         |          | Food       | 1                  | 513                                | 137                                     | 60.0                                |
|         |          | ESB        | 1                  | 406                                | 49                                      | 0.0                                 |
|         |          | Food       | 1                  | 555                                | 140                                     | 62.0                                |
|         | VI 30    | ESB        | 10*                | 352(317-383)                       | 74(55-89)                               | 0.4(0-1)                            |
|         |          | Food       | 7                  | 1714(1306-2342)                    | 186(177-199)                            | 0.0                                 |
|         |          | ESB        | 7                  | 2240(1915-2575)                    | 180                                     | 47.2(41-55)                         |
|         |          | Food       | 7                  | 1653(1047-2752)                    | 182(180-188)                            | 0.2(0-1)                            |
|         | FI 80    | ESB        | 5                  | 1114(945-1398)                     | 67(67-68)                               | 0.0                                 |
|         |          | Food       | 5                  | 1340(1022-1683)                    | 69(69-70)                               | 37.3(35-39)                         |
|         | FI 160   | ESB        | 5                  | 1244(1100-1407)                    | 69                                      | 0.0                                 |
|         |          | Food       | 5**                | 1321(1027-1433)                    | 46                                      | 0.0                                 |
|         |          |            | 5**                | 1965(1765-2227)                    | 46(46-47)                               | 24.9(21-31)                         |
| S2      | DRL 20   | Food       | 15                 | 480(465-510)                       | 50(23-72)                               | 10.5(6-17)                          |
|         |          | ESB        | 10                 | 629(571-696)                       | 36(32-43)                               | 0.0                                 |
|         |          | Food       | 5                  | 486(453-519)                       | 36(26-41)                               | 8.0(6-10)                           |
|         |          | ESB        | 5                  | 412(382-470)                       | 56(33-71)                               | 0.0                                 |
|         |          | Food       | 1                  | 435                                | 62                                      | 11.5                                |
|         |          | ESB        | 1                  | 345                                | 87                                      | 0.0                                 |
|         |          | Food       | 1                  | 405                                | 73                                      | 15.0                                |
|         |          | ESB        | 1                  | 297                                | 122                                     | 0.0                                 |
|         |          | Food       | 1                  | 423                                | 97                                      | 13.0                                |
|         |          | ESB        | 1                  | 417                                | 48                                      | 0.0                                 |
|         | VI 30    | ESB        | 10*                | 194(147-254)                       | 116(91-142)                             | 0.7(0-2)                            |
|         |          | Food       | 7*                 | 219(191-275)                       | 124(110-138)                            | 0.0                                 |
|         |          | ESB        | 7                  | 2052(1789-2349)                    | 180                                     | 22.6(20-25)                         |
|         |          | Food       | 7                  | 1187(595-1814)                     | 178(171-180)                            | 0.2(0-1)                            |
|         | FI 80    | ESB        | 5                  | 1115(1019-1189)                    | 69(68-69)                               | 0.5(0-2)                            |
|         |          | Food       | 5                  | 1636(1414-1849)                    | 70(69-70)                               | 9.7(6-14)                           |
|         | FI 160   | ESB        | 5                  | 1362(1235-1509)                    | 69                                      | 0.2(0-1)                            |
|         |          | Food       | 5**                | 1438(1303-1677)                    | 46(46-47)                               | 0.0                                 |
|         |          |            | 5**                | 1994(1286-2328)                    | 46                                      | 5.4(2-8)                            |
| S3      | DRL 20   | ESB        | 10                 | 238(148-291)                       | 129(102-145)                            | 0.9(0-2)                            |
|         |          | Food       | 10                 | 290(211-326)                       | 104(96-126)                             | 11.1(5-16)                          |
| S4      | DRL 20   | Food       | 10                 | 342(301-371)                       | 146(138-152)                            | 30.3(29-32)                         |
|         |          | ESB        | 10                 | 330(283-352)                       | 94(84-121)                              | 1.9(1-3)                            |
|         | DRL 30   | Food       | 10                 | 254(228-275)                       | 63(50-74)                               | 16.9(15-20)                         |
|         |          | ESB        | 10                 | 230(208-253)                       | 67(61-75)                               | 0.6(0-1)                            |
|         | DRL 40   | Food       | 10                 | 194(181-214)                       | 41(35-51)                               | 8.5(4-14)                           |
|         |          | ESB        | 10                 | 194(163-243)                       | 47(25-62)                               | 0.1(0-1)                            |

Continued

TABLE 1 - Continued

| Subject | Schedule | Reinforcer | Number of Sessions | Number of Responses<br>Mean(Range) | Number of Reinforcements<br>Mean(Range) | Volume of Water (ml)<br>Mean(Range) |
|---------|----------|------------|--------------------|------------------------------------|---|-------------------------------------|
| S5      | FI 30    | ESB        | 10                 | 916(749-1088)                      | 175(166-193)                            | 1.5(0-3)                            |
|         |          | Food       | 10                 | 1684(1275-2185)                    | 168(163-171)                            | 24.0(20-29)                         |
|         | FI 90    | ESB        | 10                 | 698(577-804)                       | 59(56-60)                               | 0.7(0-2)                            |
|         |          | Food       | 10                 | 1420(1180-1871)                    | 60(60-62)                               | 6.4(5-8)                            |
|         | FI 30    | ESB        | 10                 | 1274(1061-1402)                    | 173(171-174)                            | 1.2(1-2)                            |
|         |          | Food       | 10                 | 2153(1982-2300)                    | 174(160-180)                            | 16.7(15-18)                         |
| S6      | FI 30    | Food       | 10                 | 1078(950-1189)                     | 181(178-185)                            | 40.4(36-45)                         |
|         |          | ESB        | 10                 | 714(581-862)                       | 175(170-180)                            | 2.5(0-4)                            |
|         | FI 90    | Food       | 10                 | 1614(1325-1845)                    | 62(61-63)                               | 29.0(28-30)                         |
|         |          | ESB        | 10                 | 578(423-698)                       | 60                                      | 1.8(0-3)                            |
|         | FI 150   | Food       | 10                 | 1600(1327-1799)                    | 38(36-39)                               | 22.3(19-26)                         |
|         |          | ESB        | 10                 | 601(514-668)                       | 37(36-38)                               | 2.6(1-4)                            |
|         | FI 210   | Food       | 10                 | 1760(1591-1905)                    | 27(26-27)                               | 16.1(15-17)                         |
|         |          | ESB        | 10                 | 433(397-465)                       | 25(24-26)                               | 0.3(0-1)                            |
| S7      | FI 30    | ESB        | 10                 | 512(436-560)                       | 172(167-179)                            | 0.0                                 |
|         |          | Food       | 10                 | 2315(1623-2693)                    | 188(183-192)                            | 32.4(30-34)                         |
|         | FI 90    | ESB        | 10                 | 558(441-676)                       | 64(63-65)                               | 0.0                                 |
|         |          | Food       | 10                 | 2675(2512-2900)                    | 64(62-68)                               | 21.3(20-22)                         |
|         | FI 150   | ESB        | 10                 | 491(438-530)                       | 37(35-39)                               | 0.0                                 |
|         |          | Food       | 10                 | 2335(2186-2563)                    | 38(36-39)                               | 8.5(7-12)                           |
| S8      | FI 30    | ESB        | 10                 | 1923(1747-2144)                    | 184(158-193)                            | 0.0                                 |
|         |          | Food       | 10                 | 1473(1193-1655)                    | 184(182-186)                            | 32.5(29-34)                         |
|         | FI 90    | ESB        | 10                 | 1473(1141-1665)                    | 63(60-67)                               | 0.0                                 |
|         |          | Food       | 10                 | 2000(1818-2116)                    | 65(62-67)                               | 23.3(20-25)                         |
|         | FI 150   | ESB        | 10                 | 1634(1419-1838)                    | 37(36-38)                               | 0.2(0-1)                            |
|         |          | Food       | 10                 | 1448(1377-1538)                    | 37(36-38)                               | 20.3(19-21)                         |

\* 100% body weight

\*\* 2 hr sessions

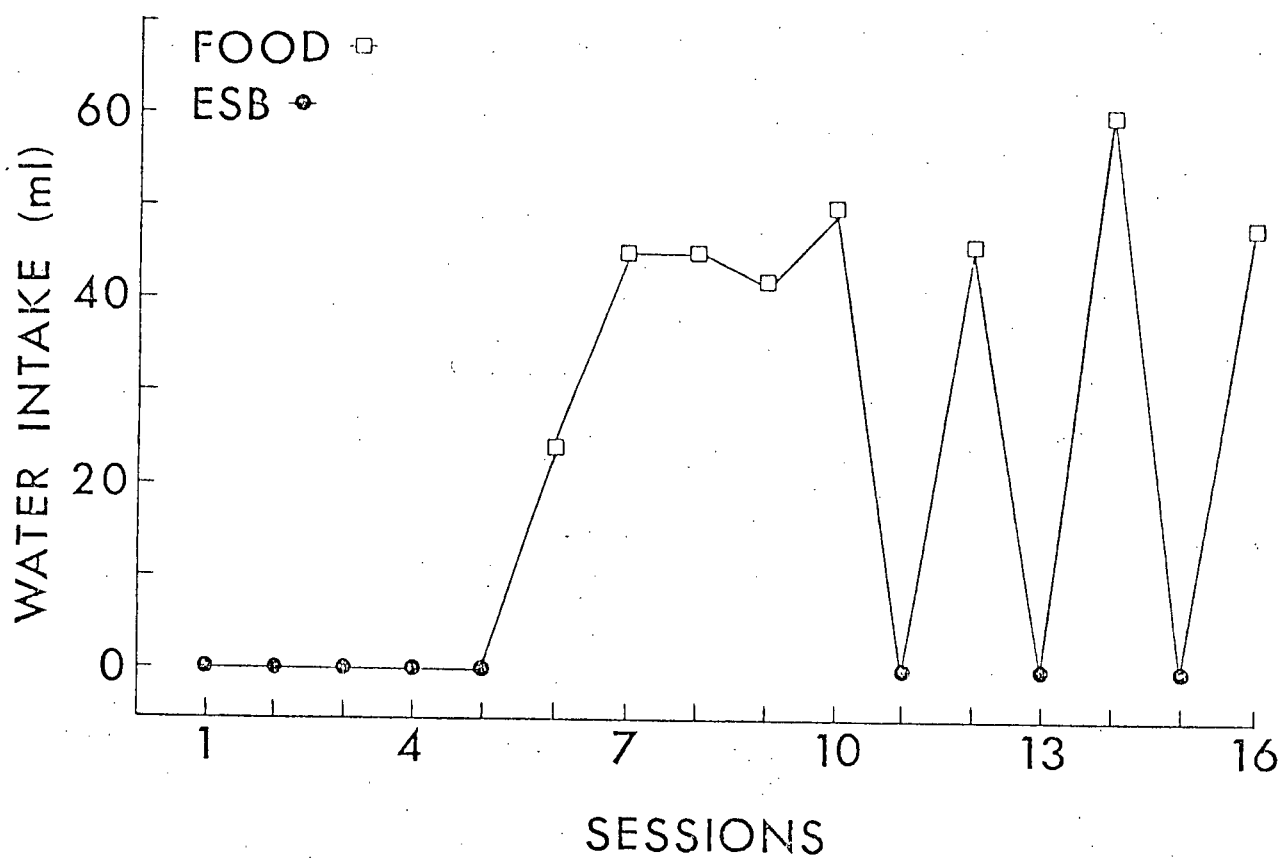
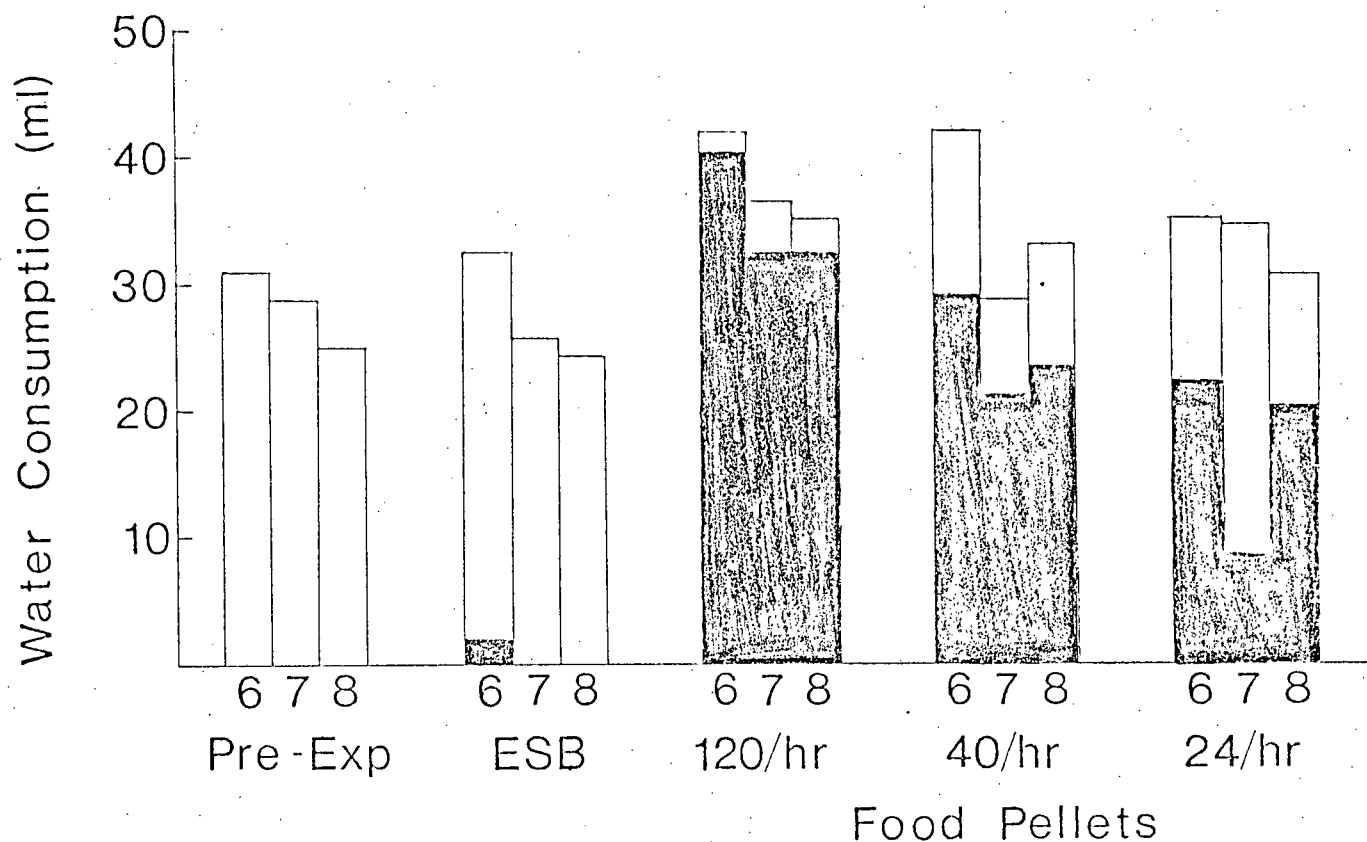


Figure 2: Water consumption of S1 during sessions of ESB and food reinforcement.



**Figure 3:** Mean daily water consumption of S6, S7, and S8 prior to experimentation (Pre-Exp) and during sessions of ESB and food reinforcement. The last three groups of columns represent mean daily water consumption during FI 30-sec, 90-sec, and 150-sec reinforcement schedules, respectively. The shaded areas represent session water consumption.

Animals S1 and S2 were run for several ESB sessions at 100% weight. Consistent with sessions at 80% weight, very little drinking occurred.

Figure 3 shows a comparison of drinking by three animals under several conditions. Total daily water consumption before experimentation differed little from daily consumption when ESB reinforcement sessions occurred. This contrasts with total consumption on days in which food reinforcement sessions occurred. The differences within the last three groups of columns in Fig. 3 suggest that an inverse relationship exists between home cage consumption and experimental session consumption. This relationship has also been described by Falk (1969). Also, the differences of session consumption among these three groups of columns indicates that volume of water consumed may depend on number of pellets delivered. Most of the session water consumption occurred during FI 30-sec food sessions, which delivered 120 pellets per hour. Similarly, least session consumption occurred during delivery of 24 pellets per hour. Lotter, Woods, and Vasselli (1973) found that SIP water consumption and number of pellets delivered were highly correlated ( $r = 0.953$ ), when data from a number of studies were analyzed. Table 2 shows individual subject Pearson correlation coefficients between the number of pellets delivered and volume of water consumed in the present experiment. These coefficients are based on the last five sessions within each condition.



TABLE 2

Pearson correlation coefficients between number of pellets delivered and volume of water consumed, for each animal.

| Subject | r    |
|---------|------|
| S1      | 0.74 |
| S2      | 0.92 |
| S3      | 0.73 |
| S4      | 0.96 |
| S5      | 0.85 |
| S6      | 0.92 |
| S7      | 0.91 |
| S8      | 0.95 |

Water consumption during experimental sessions, then, is highly related to the number of pellets delivered to the animal.

It is apparent from this experiment that SIP does not occur following ESB delivered at least with the present parameters. One might think that, once established, some degree of SIP would be maintained during the first session of ESB reinforcement after food reinforcement. This did not happen.

#### EXPERIMENT 2

The effects of palatibility on SIP have been well documented. Post-pellet drinking increases when the solutions consist of saccharin

and sucrose (Gilbert and Sherman, 1970), saccharin and glucose (Valenstein, Cox, and Kakolewski, 1967), saccharin and saline (Segal and Deadwyler, 1965b), saline and water (Stricker and Adair, 1966), and saccharin and water (Keehn, Colotla, and Beaton, 1970). As far as is known, none of these solutions previously has been made available to rats on a schedule of ESB reinforcement. Experiment 2 sought to determine whether rats would drink a solution more palatable than water following ESB reinforcement. For this purpose, the subjects were provided with simultaneous access to water and a water-saccharin solution both in the home cage and in the experimental chamber.

### Method

#### Subjects and Apparatus

Two naive animals, S10 and S11 were employed in this experiment. These animals were tested in Chamber 2. Two drinking spouts, one containing water and the other a 0.9% solution of sodium saccharin and water protruded through the two openings in Chamber 2. The left-right position of the spouts was randomly alternated on a daily basis.

Bar press responses, reinforcement delivery, and licks detected by a drinkometer circuit connected between the brass grid floor and the saccharin solution drinking spout were recorded by a Gerbrands cumulative recorder. The drinkometer circuit was electrically isolated from the ESB circuit by a series of relays.

### Procedure

Both animals were exposed to the sequence of conditions depicted by Table 3. Rat S11's electrode assembly became loose before a return to the final ESB condition could be made. A FI 90-sec schedule was in effect throughout this experiment. Food or ESB was delivered during each condition according to the parameters described in the General Method. During the EXT condition reinforcement was withheld.

Both animals were provided with free access in the home cage to one drinking spout containing water and another containing a 0.9% saccharin solution. Daily consumption from both spouts was recorded.

### Results and Discussion

Data from the last five sessions within each condition are summarized in Table 3. Rat S10 responded more frequently for food, while S11 responded equally often for both reinforcers. Very little water was consumed by either animal, both in the home cage and during experimental sessions. Both animals drank saccharin solution during all conditions. Least of the solution was consumed during EXT (S10). While both animals consumed a large amount of saccharin solution during ESB, the food condition engendered the greatest consumption.

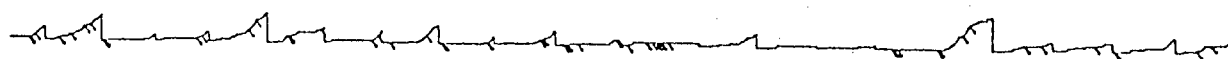
The temporal distribution of bar press responses, reinforcements, and licks at the saccharin spout is illustrated in Fig.4. These cumulative recordings were taken from the first hour of representative sessions of S10.

TABLE 3

Summary of Procedure and Results - Experiment 2

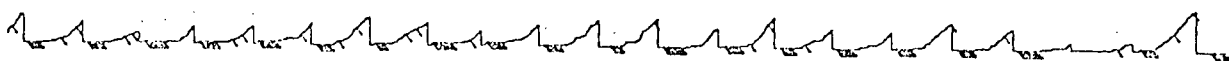
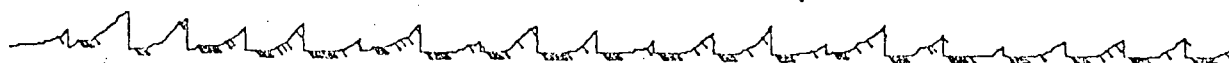
| Subject | Reinforcer | Number of Sessions | Number of Responses<br>Mean(Range) | Number of Reinforcements<br>Mean(Range) | Experimental Session                |  | Home Cage                          |  |
|---------|------------|--------------------|------------------------------------|---|-------------------------------------|--|------------------------------------|--|
|         |            |                    |                                    |   | Volume of Water (ml)<br>Mean(Range) | Volume of Saccharin(ml)<br>Mean(Range) | Volume of Water(ml)<br>Mean(Range) | Volume of Saccharin(ml)<br>Mean(Range) |
| S10     | ESB        | 10                 | 908(768-994)                       | 65(63-67)                               | 0.0                                 | 19.9(16-27)                            | 5.8(1-10)                          | 102.6(81-123)                          |
|         | Food       | 10                 | 1418(1295-1710)                    | 63(63-64)                               | 0.0                                 | 36.2(31-40)                            | 3.2(2-4)                           | 87.2(71-106)                           |
|         | EXT        | 10                 | 46(35-69)                          | 0                                       | 0.2(0-1)                            | 6.0(5-7)                               | 1.8(1-2)                           | 86.0(73-98)                            |
|         | ESB        | 10                 | 966(757-1207)                      | 63(60-64)                               | 0.2(0-1)                            | 18.2(16-20)                            | 3.0(2-5)                           | 73.5(62-100)                           |
| S11     | ESB        | 10                 | 1721(1627-1888)                    | 64(62-66)                               | 0.2(0-1)                            | 20.0(9-28)                             | 2.4(1-4)                           | 190.2(182-215)                         |
|         | Food       | 10                 | 1619(1547-1965)                    | 66(64-68)                               | 0.0                                 | 75.1(68-85)                            | 4.6(1-9)                           | 227.6(187-255)                         |
|         | EXT        | 10                 | 20(3-45)                           | 0                                       | 0.2(0-1)                            | 26.4(24-31)                            | 2.2(2-3)                           | 218.2(150-261)                         |

ESB



100 Rs

FOOD



90 sec

Figure 4: Cumulative recordings of S10 during conditions of ESB and food reinforcement. Each bar press response stepped the pen upwards. The pen was reset at reinforcement delivery. Every eighth lick is represented by a downward deflection of the pen.

Cursory inspection of these data suggest that SIP was established with ESB reinforcement. This conclusion would be wrong on two accounts. First, an examination of the top half of Fig. 4 indicates that drinking occurred intermittently throughout the IRT within this ESB session. This pattern differs from that of normal SIP which occurs only within the post-reinforcement interval. Second, home cage saccharin consumption by S10 was in the range of 80 to 150 ml per day. Rat S11 drank even more saccharin in the home cage. Table 3 shows that home cage saccharin consumption far exceeded drinking during experimental sessions. While S10 drank more during ESB than during EXT, S11 did not.

The lower half of Fig. 4 clearly shows both the typical post-pellet pattern of SIP and instances of drinking at times other than during this period, during the food reinforcement condition. This additional IRT drinking lends support to the point made by Keehn, Colotla, and Beaton (1970) regarding palatability stimulating drinking in addition to that which is schedule induced.

Despite the occurrence of some drinking during ESB sessions, these data must be construed as a failure to demonstrate SIP with saccharin solution during a schedule of ESB reinforcement.

### EXPERIMENT 3

Several reports have suggested that SIP drinking occurs after a stimulus which has been paired with food. Rosenblith (1970) found that rats slowly acquired SIP after conditioned reinforcement. In this study, every third FI terminated in food pellet delivery. A feeder click and light flash, which accompanied food pellet delivery on every third interval, terminated the other two FIs. A similar study by Porter and Kenshalo (1974) found drinking to occur in rhesus monkeys following conditioned reinforcement. During EXT after a DRL 30-sec schedule, two of three rats drank more following a feeder click which occurred contingent upon a successfully spaced response than during similar periods in the absence of a feeder click (Segal and Deadwyler, 1965a). However, a recent study failed to replicate this phenomenon. Allen, Porter, and Arazie (1975) failed to observe drinking in five of six rats following a brief light flash and click which had been associated with pellet delivery.

Conditioned reinforcement procedures can be used to determine which aspect of food pellet delivery is important for the occurrence and maintenance of SIP. Food pellets act as reinforcers, often signal periods of lowered reinforcement probability, elicit various consumatory activities such as sniffing, chewing, and swallowing, and possess sensory qualities such as taste and texture. Conditioned reinforcers possess only these first two attributes, thus allowing a comparison with the latter characteristics to be made.

Experiment 3 was an attempt to produce SIP after ESB using the conditioned reinforcement procedure of pairing ESB with food reinforcement.

### Method

#### Subjects and Apparatus

Rats S4 and S6 of Experiment 1 served as subjects for the present experiment. They were tested in Chamber 1.

#### Procedure

Both animals initially received ten sessions of paired ESB and food reinforcement, followed by five sessions of ESB reinforcement. During the first condition, a food pellet and ESB of the parameters described in the General Method were concurrently delivered contingent on the reinforced bar press. Since it took a portion of a second for the animal to reach the pellet, ESB onset actually preceded ingestion of the food pellet. Both animals were finally returned to the original condition, S4 having first received an additional ten sessions of food reinforcement alone. A FI 90-sec schedule of reinforcement was in effect throughout the experiment.

### Results and Discussion

The data from the last five sessions of each condition are summarized in Table 4. Food and ESB, as well as food alone, reliably



TABLE 4

## Summary of Procedure and Results - Experiment 3

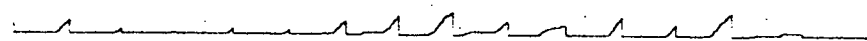
| Subject | Reinforcer | Number of Sessions | Number of Responses<br>Mean(Range) | Number of Reinforcements<br>Mean(Range) | Number of Licks<br>Mean(Range) | Volume of Water (ml)<br>Mean(Range) |
|---------|------------|--------------------|------------------------------------|---|--------------------------------|-------------------------------------|
| S4      | Food + ESB | 10                 | 1060(889-1261)                     | 62(59-66)                               | 9102(8663-10465)               | 18.9(16-20)                         |
|         | ESB        | 5                  | 650(519-777)                       | 57(54-60)                               | 208(6-366)                     | 0.6(0-1)                            |
|         | Food       | 10                 | 924(819-1052)                      | 60(60-61)                               | 6487(5491-7006)                | 13.5(12-15)                         |
|         | Food + ESB | 10                 | 848(685-1049)                      | 60(58-63)                               | 6878(5940-7852)                | 16.4(15-18)                         |
| S6      | Food + ESB | 10                 | 1846(1521-2196)                    | 60(60-61)                               | 7859(7620-8157)                | 25.4(22-28)                         |
|         | ESB        | 5                  | 645(387-982)                       | 59(58-60)                               | 69(15-174)                     | 0.5(0-1)                            |
|         | Food + ESB | 5                  | 2098(1915-2294)                    | 62(60-65)                               | 7066(6771-7803)                | 25.1(23-26)                         |

S4

FOOD + ESB



ESB

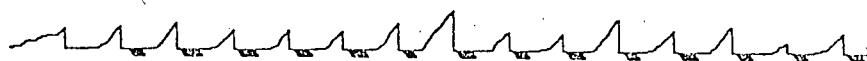


FOOD



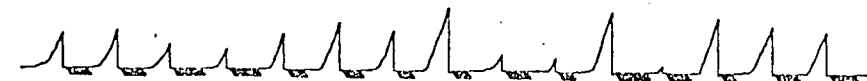
100 Rs

FOOD + ESB



S6

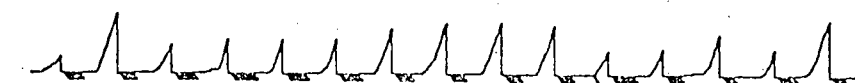
FOOD + ESB



ESB



FOOD + ESB



90 sec

**Figure 5:** Cumulative recordings of S4 and S6. See Figure 4 for additional description.

produced excessive drinking which was consistent across sessions. When food reinforcement was removed, drinking was immediately and greatly reduced. This reduction was apparent in both the volume of water consumed and in the number of licks. Slightly more water was consumed by one animal when ESB was paired with food than when food alone was delivered. A cumulative record from a food and ESB session and an ESB alone session is shown in Fig. 5. These data were taken from the middle portion of a session within each condition, and are representative. While the magnitude of responding generally differed for the food and ESB and ESB alone conditions, the response distribution was similar in both cases to typical FI performance. Drinking occurred almost entirely during the period immediately post-reinforcement, within conditions in which food pellets were delivered. There was seldom any drinking during the ESB condition.

These results agree with those reported by Allen et al. (1975). Should SIP simply be a function of the reinforcing and discriminative properties of food reinforcement (i.e. be schedule-induced), it should have occurred in the present experiment as well as in the first two experiments. The results of these experiments suggest that food is a necessary condition for the occurrence of SIP. More specifically, it appears that some sensory-consumatory aspect of food is important in producing SIP.

#### EXPERIMENT 4

Related to the phenomenon of post-reinforcement drinking is that of post-pellet air licking (Falk, 1971). It is possible that SIP drinking would occur following ESB reinforcement were it not for the extreme hydration which occurs in the absence of food consumption. The present experiment provided rats with an opportunity to engage in a post-reinforcement activity which circumvents this problem. Rats have previously demonstrated both air- (Mendelson and Chillag, 1970) and nitrogen-licking (Taylor and Lester, 1969) following delivery of food pellets. This activity occurred at a much higher rate than water drinking, possibly due to lack of satiation.

#### Method

##### Subjects

Three animals (S5, S6, S7) that had reliably demonstrated food-associated SIP in previous experiments, and one experimentally naive animal (S9) completed the experiment.

##### Apparatus

Chamber 2 served as the experimental space. The drinking spout was connected to a regulated supply of compressed air. During experimental sessions air was constantly delivered to the spout at a pressure of approximately 1.03-2.07 N/cm<sup>2</sup>.

### Procedure

A FI 90-sec schedule was in effect for the duration of this experiment. Although three of the four subjects had previously acquired SIP, none of the animals air licked during the first few sessions with food reinforcement. Consequently the animals were water deprived for 23 hr prior to each session. Following three such sessions during which air licking occurred at a high rate, water was again made freely available in the home cage, and the regular experimental regime ensued. This procedure had to be repeated two or three times before all animals would reliably lick during the food condition. An additional four animals, some of which were employed in previous SIP experiments, failed to continue air licking after a return to free access to water and were excluded from the experiment.

Table 5 summarizes the sequence of conditions of food and ESB alternation. As in the previous experiments, number of bar press responses, reinforcements, and licks at the drinking spout were recorded.

### Results and Discussion

Data were collected from the last five sessions within each condition and summarized in Table 5. Air licking occurred at a high rate during food reinforcement sessions. Licking was almost completely eliminated during ESB reinforcement sessions. These results are consistent

TABLE 5

## Summary of Procedure and Results - Experiment 4

| Subject | Reinforcer | Number of Sessions | Number of Responses<br>Mean(Range) | Number of Reinforcements<br>Mean(Range) | Number of Licks<br>Mean(Range) |
|---------|------------|--------------------|------------------------------------|---|--------------------------------|
| S5      | Food       | 10                 | 1100(813-1362)                     | 60(59-62)                               | 8374(4203-13013)               |
|         | ESB        | 10                 | 1122(1078-1135)                    | 62(62-62)                               | 9(1-14)                        |
|         | Food       | 5                  | 1328(963-1789)                     | 62(60-66)                               | 5800(1972-8562)                |
| S6      | Food       | 10                 | 2179(1634-3078)                    | 61(53-67)                               | 7289(3497-14623)               |
|         | ESB        | 10                 | 1182(1062-1308)                    | 59(54-62)                               | 2(0-6)                         |
|         | Food       | 5                  | 2644(2340-2935)                    | 62(60-66)                               | 6676(4062-13884)               |
| S7      | Food       | 10                 | 2257(1716-2710)                    | 60(58-60)                               | 14228(12950-15510)             |
|         | ESB        | 10                 | 458(414-502)                       | 60(60-61)                               | 10(4-16)                       |
|         | Food       | 5                  | 1716(1619-1930)                    | 61(60-63)                               | 10977(3102-15880)              |
| S9      | Food       | 10                 | 1225(1167-1322)                    | 63(60-65)                               | 3489(2190-4804)                |
|         | ESB        | 10                 | 516(466-614)                       | 50(44-55)                               | 79(6-341)                      |
|         | Food       | 5                  | 1265(1023-1469)                    | 61(53-67)                               | 6576(4005-8589)                |

both within each animal and across sessions within each condition. Fig. 6 illustrates representative results from two of the animals. Each cumulative recording from S9 was taken from the middle of the final day of each condition. The top recording for S7 was taken from the beginning of day nine. The ESB recording for S7 was made during the first day within this condition, as was the third recording, which illustrates a return to air licking following reinstatement of the food reinforcement condition.

S7

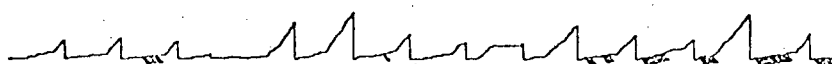
FOOD



ESB



FOOD



100 Rs

S9

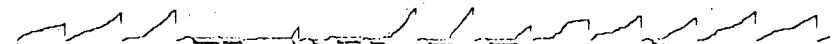
FOOD



ESB



FOOD



90 sec

Figure 6: Cumulative recordings of S7 and S9.  
Additional description is provided in Figure 4.

Close examination of these recordings reveals several interesting points. For example, S7, which showed the highest rate of licking, licked after most, but not all, pellets. This licking occurred for longer durations than SIP water licking and recurred throughout the IRT. The ESB record of this animal indicates no recorded licking. Returning to food reinforcement resulted in a gradual return to air licking which was maintained once reestablished. Rat S9's records, while indicative of the discrepancy of air licking between food and ESB conditions, illustrate the long latency of initiation of air licking following pellet delivery. Usually several bar press responses interpolated between reinforcement and air licking. This pattern was generally consistent with the other animals.

#### EXPERIMENT 5

The failure of the previous experiments to reliably demonstrate SIP or schedule-induced air licking following ESB reinforcement may be either directly or indirectly attributable to the chronically implanted stimulating electrodes. Falk (1964) has shown that small hypothalamic lesions have a marked attenuating effect on SIP. However, the within-subject comparisons of the present study preclude this possibility from preventing the establishment of ESB-associated SIP. Another possibility exists, however. Valenstein, Cox and Kakolewski (1970) found that rather long (10 sec or more) trains of hypothalamic stimulation, which produced various "stimulus-bound"



behaviours resulted in a decrease in normal deprivation-elicited food and water consumption following stimulation. This suppressive effect was referred to as "post-stimulus inhibition". It is unlikely that post-stimulus inhibition occurred in animals in the present experiments. The stimulation duration was much shorter than that used by Valenstein et al. Also, the simultaneous presentation of food and ESB in Experiment 3 did not appear to attenuate post-reinforcement drinking. If anything, this manipulation potentiated SIP.

Experiment 5 was designed to further determine whether ESB acted in any way to prevent the occurrence of SIP. Deprivation-produced drinking served as the response measure.

### Method

#### Subjects

Rats S4, 5, 6, 7, 8, and 10 were water deprived for 22 hr preceding each experimental session. Rat S10 was also deprived of saccharin, normally available in the home cage, for the same length of time.

#### Apparatus

Subjects were tested in Chamber 1 or 2 as indicated in Table 6. The lever was removed from both chambers. Its space was covered by a metal plate.

TABLE 6

Summary of Procedure and Results - Experiment 5

| Subject | Chamber | ESB<br>Schedule | Measure   | Volume     | Number of           |
|---------|---------|-----------------|-----------|------------|---------------------|
|         |         |                 |           | No ESB/ESB | Licks<br>No ESB/ESB |
| S4      | 1       | FT 90           | Water     | 10.3/12.5  | 2209/1889           |
| S5      | 1       | FT 30           | Water     | 14.7/16.5  | 435/449             |
| S6      | 1       | FT 90           | Water     | 14.0/16.5  | 1976/2354           |
| S7      | 2       | FT 90           | Air       | -          | 4611/4311           |
| S8      | 2       | FT 90           | Water     | 15.0/14.3  | 2387/2534           |
| S10     | 2       | FT 90           | Saccharin | 16.8/16.8  | 1511/2658           |

Procedure

Each animal was connected to the stimulator and put in the experimental chamber for 15 min. During the first three daily sessions the animals received no ESB. Stimulation was noncontingently delivered during the next three sessions according to the schedule as described in Table 6. Water, saccharin, or air was available during these six sessions. Volume, where appropriate, and number of licks were measured.

Results and Discussion

Table 6 indicates the volume consumed and number of licks of water, saccharin, and air, averaged across the first three (No ESB) and

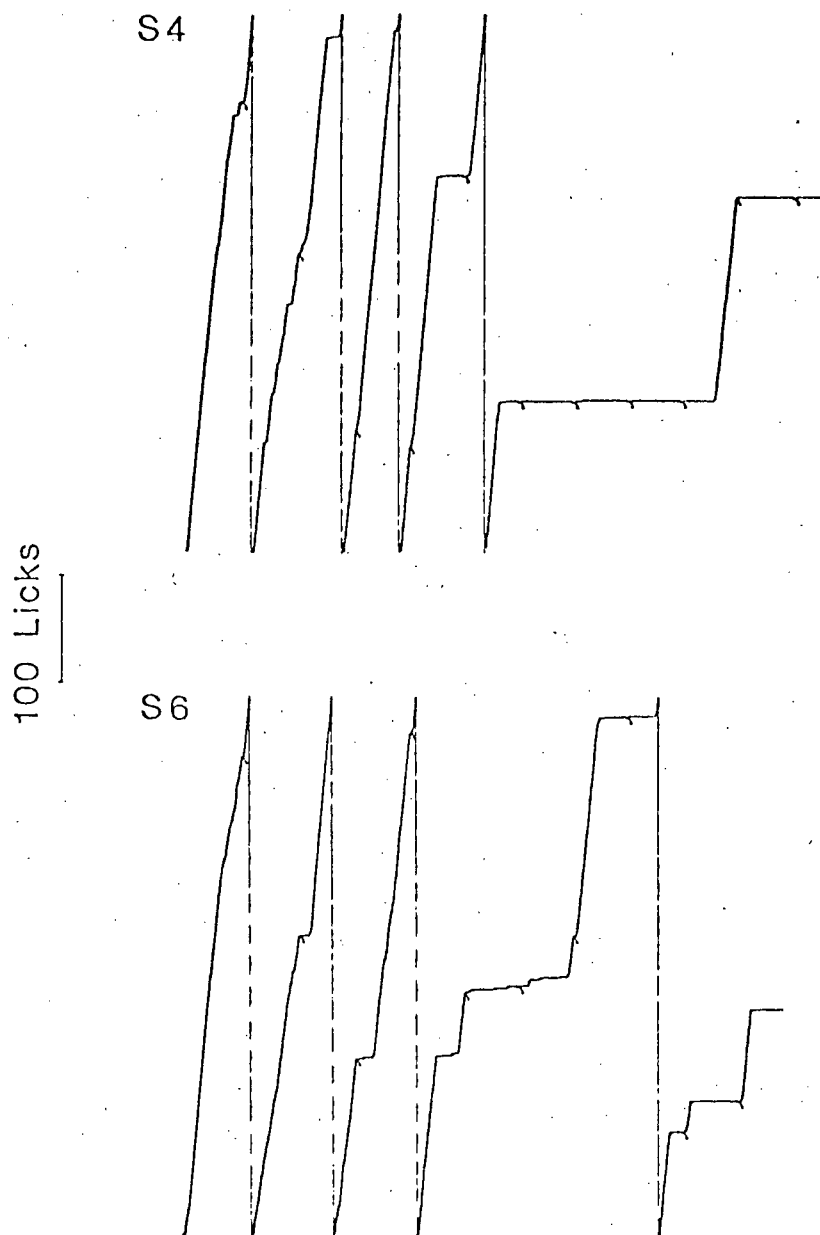


FIGURE 7: Cumulative recordings of S4 and S6.  
Each lick stepped the recording pen upwards.  
Downward deflections of the pen represent ESB delivery.

the last three (ESB) sessions. It is apparent that stimulation produced only minor disruption of drinking. This is true for all three of the measures employed. Fig. 7 further illustrates this point. These recordings are representative of 15 min periods of FT 90-sec ESB delivered to S4 and S6. These cumulative recordings provide examples of instances where stimulation was delivered at the beginning, the end, and the middle of a bout of licking. Post-stimulus inhibition does not appear to be operating here.

It is interesting to note the discrepancy between number of licks and volume, both here and in previous experiments. This may be due to insensitivity of the drinkometer device, or to the variability inherent in licking. Volume, then, would serve as a more reliable measure of drinking.

#### GENERAL DISCUSSION

These experiments have confirmed and extended a previous failure to produce SIP with schedules of ESB reinforcement. Cohen and Mendelson (1974) found drinking to occur following food, but not ESB, reinforcement when these reinforcers were available on various VI schedules within the same session. The present study found similar results when food and ESB reinforcement were available during successive sessions, not simultaneously as in the Cohen and Mendelson experiment.

The present study also employed different reinforcement schedules complementing Cohen and Mendelson's conclusion that SIP is not simply schedule-induced.

In the present attempt to produce SIP with ESB reinforcement, a variety of schedules, including those which maximize post-pellet drinking, was used. The animals were also provided with a solution more palatable than water. Electrical stimulation of the brain was paired with food pellet delivery. An opportunity to lick air, which precludes satiation and is highly related to SIP water drinking, was provided. None of these manipulations resulted in the occurrence of schedule-induced licking in association with ESB reinforcement.

Failure to observe SIP cannot be attributed to post-ESB inhibition of drinking (Valenstein et al., 1970). This was clearly demonstrated in Experiments 3 and 5. It has also been suggested that the location of the water spout relative to the food cup is an important consideration (e.g. Allen, Porter, and Arazie, 1975). For example, the water spout in the Porter and Kenshalo (1974) study, which reported SIP in rhesus monkeys during conditioned reinforcement, was located directly above the food hopper. It is possible that animals pause to drink on the way back from the food cup to the lever. However, rats in the present study developed SIP following food reinforcement despite the water spout's inconvenient location relative to the food cup. Further, the failure to obtain SIP cannot be attributed to the fact that ESB was not reinforcing

or intermittently presented. Nor does it appear that ESB and food differed greatly in reinforcing value as both maintained an approximately equal rate of operant responding. It is also unlikely that SIP failed to occur due to specificity of neural stimulation. As is indicated by Fig. 1, electrode placements were located generally throughout the medial forebrain bundle. Stimulation at a placement outside this area also failed to produce SIP.

Since ESB and food share reinforcing and discriminative functions, it appears that SIP is due to some other aspect of food reinforcers. The sensory-consummatory response differences are the most obvious.

The present results fail to corroborate those reported by Atrens (1973) and Wayner et al. (1973). These investigators, however, did not as has been claimed, unequivocally demonstrate SIP. Atrens reported drinking following ESB reinforcement delivered according to a FI 120-sec schedule in one animal and a VI 60-sec shedule in another. In both cases, however, drinking showed a marked decrement with repeated testing over days. Food deprivation and increasing and decreasing both the IRT and the number of ESB reinforcers per session failed to prevent this drinking from ceasing. Wayner et al. observed post-ESB drinking to occur intermittently in one of four rats, at a magnitude well below that which occurred with food reinforcement. This rat drank more during ESB reinforcement sessions than during EXT. However, drinking during ESB sessions occurred in a few long bursts, atypical of the normal pattern

of post-pellet SIP.

The present failure to find SIP with ESB reinforcement suggests that several of the major hypotheses of SIP are untenable. Schedule-induced polydipsia is unlikely an adventitiously reinforced response. Both food and ESB presumably have the capacity to superstitiously reinforce licking. However, this never occurred, even on a short VI schedule. Nor was any evidence found that the SIP observed with food reinforcement was due to this sort of process. Further, rats in the present study were never observed to use licking to mediate DRL responding, during food or ESB sessions. Post-reinforcement aversiveness, or the arousal or emotionality which has been assumed to occur following removal of the reinforcing stimulus, surely must be assumed to occur following ESB as well as food. Rats in the present study never placated this emotionality by licking, nor were they aroused to drink during the post-ESB period.

The currently most popular account of SIP, which considers it to be a member of a class called adjunctive behaviour, cannot be supported by these data. Falk (1971, 1972) considers adjunctive behaviour to be produced by the reinforcement schedule. The reinforcing stimulus, as well as constituting an important component of consummatory activity, also signals an interruption in this activity. The animal is thus predisposed to "displace" his consummatory behaviour. According to Falk, such displacement is adaptive to the animal since it allows the opportunity

to acquire other reinforcers from the environment when food is not available. This displacement process encompasses a number of possible activities, one of which is drinking. The consistent failure to establish post-reinforcement water, saccharin, or air licking following ESB reinforcement strongly suggests that SIP is a function of other factors in addition to schedule variables.

Thus, at present, there seems to be no obvious way to predict from the adjunctive concept whether the intermittent delivery of a reinforcer will produce a schedule-induced response such as SIP drinking. Since at least certain adjunctive behaviours do not occur with all reinforcers, the adjunctive concept needs to be revised to regain predictive ability. Otherwise, "adjunctive" will simply be a label for the occurrence of certain post-reinforcement behaviours.

A survey of the literature suggests that SIP occurs only during food deprivation, and only when small amounts of food of one sort or another are presented intermittently. Forty-five mg Noyes food pellets produce the largest degree of SIP, followed closely by small portions of liquid monkey diet. Other substances, such as sucrose and glucose pellets, liquid sucrose, and vegetable oil produce little or no SIP (Falk, 1969). Stein (1964) first suggested that dry food acts as a stimulus to initiate drinking. However, it is unlikely that liquid monkey diet, one-third water by weight, produces a dry mouth. Sucrose and glucose pellets are both dry substances, yet neither



produce SIP. Drinking following liquid food and Stein's notion may be reconciled since it is possible that drinking occurs following liquid and dry foods for different reasons. Different liquids, for example, may leave aversive oral aftereffects which are attenuated by drinking. One aversive aftereffect of eating dry foods might be oral dryness. It is possible that different food substances, such as sucrose and glucose pellets, either do not produce oral dryness as presumably do Noyes rat pellets, or they leave more pleasant oral aftereffects. At present, however, little is known of these possibilities.

Rats have most often served as subjects in SIP studies. It is known that rats normally drink 70% of their total daily water intake in close association with the ingestion of food (Fitzsimons and Le Magnen, 1969). Even when rats are prevented by rearing techniques from ingesting food and water in close temporal proximity, SIP occurs (Hymowitz and Koronakos, 1968). This would suggest a strong predisposition for rats to consume food and water together. Food is not the only cue to drinking (cf. Falk, 1961), but in "unnatural" experimental situations rats may rely heavily on this cue (cf. Kissileff, 1969; Kissileff and Epstein, 1969). To add support to this contention, drinking has been shown to depend more upon the number of "bites" than on bite size (Lotter, Woods, and Vasselli, 1973; Reynierse, 1966). One bite consists of one uninterrupted bout of eating. Rats typically consume a small draught of water following each bite, which is usually larger than a 45 mg food pellet. When bite size and frequency are determined

experimentally by intermittently delivering food pellets, drinking changes accordingly. Keehn and Colotla (1971) found that drink durations were essentially the same when a series of 1, 3, 6, or 9 pellets were delivered one immediately after the other at the end of various fixed interval schedules. Rats in this study drank only following the last pellet in the series, and then only a normal SIP amount. The notion that volume of water consumed is related to number of bites, or meals, is strongly supported by the high positive correlations between volume consumed and number of 45 mg pellets delivered per session, reported by Lotter, Woods, and Vasselli (1973) and by the present study.

There is evidence to suggest that SIP occurs in response to food ingestion only in species with a predisposition to eat and drink in temporal proximity. Whalen (1975) failed to observe polydipsia in pigeons. These animals typically meet their daily water requirements in two or three large draughts. It seems reasonable to assume that pigeons would be less likely than rats to utilize food ingestion as a cue to initiate drinking. Whalen's results are also inconsistent with all SIP theories except that of Stein.

### CONCLUSION

The greater than normal post-reinforcement drinking that has been called schedule-induced polydipsia appears to occur in rats only when certain reinforcers such as Noyes food pellets are intermittently delivered. Rats appear to eat food in several bites or meals and to drink a certain amount after each bite. Osmotic cues have been suggested to play a role in the initiation of drinking. If food is delivered periodically in quantities less than the normal bite size the rat still drinks after each bite. The results, if a sufficient number of small bites occur, is a large, sometimes excessive, volume of water intake. No reference to superstitions, mediations, states of emotionality or arousal, post-reinforcement aversiveness, or adjunctive behaviour induced by reinforcement schedules appears necessary.

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