The photo-lickerandum: A device for detecting the licking response, with capability for near-instantaneous programming of variable quantum reinforcement¹

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A combined operandum-feeder is described that eliminates the necessity of passing an electrical sensing current through S while detecting and reinforcing tongue-licking responses. A glass nozzle for dispensing liquid reinforcers is situated just above a small separation in a loop of photo-conducting Sterite tubing; licks at a tiny area below the nozzle break a light beam and are detected via a photo-resistor and associated circuitry. Data are presented from a study in which rats worked at the operandum on a mult FR 40 ext schedule; performance and records are comparable to those obtained via conventional electronic sensing. Applications of the photo-lickerandum and an associated variable-quantum reinforcing system are suggested.

OVERVIEW OF THE TONGUE-LICK RESPONSE

Integrand and Adjunct Reinforcement

The tongue-licking behavior of rodents has been subjected to a diversity of experimental treatments of both an operant and Pavlovian nature. From the standpoint of operant scheduling, the behavior has been studied under either or both of two contingency arrangements that we have labeled *integrand* and *adjunct*. Ordinary drinking (from, say, a dipper or the tube of a water bottle—or from any source that provides *direct consummation*) exemplifies the integrand, “wet-licking” contingency. An adjunct contingency is the case where an animal licks (e.g., at a contact sensor) but is reinforced only indirectly or remotely in either the temporal or spatial sense. Examples of such “dry-licking” are to be seen in the reports of Hulse (1960), Segal and Oden (1965), and Gibson, Reid, Sakai, and Porter (1965), where rats’ licks were reinforced by, respectively, a drop of sugar water, a dry-food pellet, and electrical intracranial stimulation. The mixed contingency—where both integrand and adjunct reinforcement can occur—is well exemplified by the work on “schedule-induced polysipsia” (see, e.g., the reports of Falk, 1961; Stein, 1964; Segal & Deadwyler, 1964; Segal & Oden,

1965; cf., too, these reports with Premack, 1962). In the combined case, the animal consumes liquid at and by each of his tongue licks, but after every *n*th lick or *n*th interval, etc., some other reinforcer is delivered.

The case we are dealing with in this report is the simple adjunct contingency first developed and reported by Hulse (1960). In brief, the animal licks at a tiny area on a smooth surface of one end of a bevelled cylinder, which area is situated a few millimeters under and more distal to an orifice from which small, discrete quanta of liquid are “injected” directly into an animal’s mouth. When an animal is responding to a continuous schedule on a Hulse “lickerandum,” and short latencies of reinforcement are programmed (in, say, the neighborhood of 75 msec; see Justesen, Levinson, & Daley, 1967), the adjunct case most nearly approximates the integrand. Even so, the rat’s tongue movement is not directly instrumental in taking liquid into the mouth and, by operational fiat, is construed as dry licking. The institution of high-demand, intermittent scheduling, moreover, would clearly place the animal in a dry-licking situation.⁴

Respondent Properties

The rat’s tongue lick, as indicated earlier, possesses a respondent character in addition to its operant properties. Hulse (1966), for example, has studied the phasic reflexive aspect of the tongue lick as a function of unconditional stimulus magnitude. He found that increasing the volumes of discrete water presentations to the tongue led to increases in the number of licks in reflexive bursts elicited by the water. Further, DeBold, Miller, and Jensen (1965) and Patten and Deaux (1966) have shown that this reflexive burst is amenable to classical conditioning. The respondent component of the tongue lick is therefore an invariant accompaniment of any reinforcing contingency—integrand or adjunct—that involves near-immediate presentation of liquid to the rat’s tongue. With the Hulse lickerandum system, responses detected immediately following reinforcement are respondent in nature but may not be differentiated from prior, purely instrumental licking. This point is particularly important in interpreting effects of low-demand, fixed-ratio (FR) schedules. At nominal FR-7, for example,

because 8 to 10 reflexive licks might be elicited by a liquid reinforcer, a rat would actually (and minimally) be in a continuous schedule. These precautionary observations having been stated, we turn to a short review of relevant studies.

Review of Pertinent Studies

The operant tongue lick has been brought under control of a diversity of reinforcement schedules. Responding to variable-interval schedules from VI 12-sec to VI 5-min has been reported by Stricker and Miller (1965), Stricker (1966), and Justesen, Levinson, and Daley (1967), fixed-interval schedules from FI 30-sec to FI 60-sec by Stricker and Miller and by Justesen et al, and fixed-ratio schedules by Hulse, Snyder, and Bacon (1960) and by Justesen et al. The most demanding schedule employed was FR 50, this in the last study cited.

In most of the studies cited, scheduling was a subordinate interest, and cumulative records have been presented only in the Justesen, Levinson, and Daley report. In these records, both similarities and differences with respect to rat bar-pressing records are observable. The differences primarily lie in higher rates and in persistence of responding immediately after reinforcement. The immediate “postreinforcement pause” that typically occurs with fixed-ratio and fixed-interval schedules based upon the bar press is absent. However, after the postreinforcement (and presumably reflexive) burst of licks has been run off, pausing frequently does occur—therefore, this difference is likely more apparent than real.

Ferster and Skinner have written of the pecking of pigeons and the bar pressing of rats that “...such responses are not wholly arbitrary. They are chosen because they can be easily executed and because they can be repeated quickly and over long periods of time without fatigue. In a bird such as the pigeon, pecking has a certain genetic unity; it is a characteristic bit of behavior which appears with a well-defined topography [1957, p. 7].” These statements appear to be equally true of the licking behavior of rats. In unpublished dissertation research in our laboratories by Manaster (1969), it was found that a rat working at a conventional lickerandum (Justesen et al, 1967) on a (nominal) FR-7

Fig. 1. A Tappan R-3-L microwave oven is shown with door open. Within the oven is a 14.5 x 9.5 x 10 in. high Plexiglas operant chamber with solid overhead and walls, and grid floor. A white arrow points to the portion of the photo-lickerandum assembly that is seen by an experimental animal when the oven door is closed. The assembly is outlined in black and is flanked by a 6-in. ruler.

frequency to dc translation of potentials that might spell noxious electrical stimulation within the microwave field. Other studies recording tongue licking have depended upon a metallic contact through which a low-intensity sensing current flows when touched by a S's tongue. As such a "drinkometer" circuit would be incompatible with concurrent presence of microwaves, a photosensor for detecting interruptions of a light beam was assembled along with a liquid feeder, the result being the "photo-lickerandum."

Apparatus

The photo-lickerandum assembly is shown in Fig. 1 as mounted on the open "oven" door of a Tappan microwave range. The assembly has been outlined in black and has a white arrow pointing to it. A 6-in. ruler is mounted adjacent. When the chamber door is shut, the fluid-delivery orifice of the unit is located $3\frac{3}{4}$ in. (9.5 cm) above the grid floor of an inner Plexiglas chamber.

Figure 2 is a schematic representation of the photo-lickerandum showing both the part that mounts within the microwave chamber and the part mounted without. Two nylon screws secure the inner and outer portions together and to the door

schedule maintained responding across 24 h without satiating. The animal was food- (but not water-) deprived 29 h prior to onset of the 24-h measure and received 50-microliter reinforcers of 5% dextrose in isotonic saline; although responding was not continuous, its global rate was highly uniform throughout the 24-h span. Moreover, when the animal was observed under the same span of scheduling, after 12 and 0 h of prior deprivation, responding was not only commensurately delayed in onset but, again, was highly uniform in terms of global rate and presented no evidence of satiation. The import of these observations is that the lickerandum affords access to a positively reinforced operant uncontaminated by satiation effects—an avenue, that is, to protracted intervals of operant performance not obtainable in rats working on conventional schedules of positive reinforcement.

As a consummatory behavior, a phasic reflex, and an operant behavior—all occurring in a common topography—the licking response is thus a most interesting and potentially useful endpoint for behavioral and physiological studies.

Fig. 2. Scale drawing (in both inches and centimeters) of photo-lickerandum assembly.

DEVELOPMENT OF A PHOTO-OPERANDUM

We chose the lick response to permit "real time" observations of reflexive and operant behaviors under microwave irradiation (see King, 1969). It was necessary to fabricate an operandum-feeder assembly entirely from dielectrical materials, this in order to avoid animal-to-metal contact and possible radio

Fig. 3. Exterior of Tappan microwave oven. The reservoir of sugar solution and the valves and a hypodermic syringe controlling dispensing of liquid reinforcer are shown. Located near the center of the oven-door grille is the exterior portion of the photo-lickerandum assembly. The blower fans shown at the top provide a constant influx of cooled air to the oven's interior.

grille. A 90-deg semiloop of Sterite photoconducting rod transmits light from a GE 313 miniature lamp via a Drake 5100-182 projection lens unit, through an aperture of air, to another 90-deg semiloop of photoconducting rod that ramifies with a Clairex CL604L photo-resistor. The light beam from the lamp passes through the air gap just below the feeder nozzle. The feeder nozzle itself is formed from Pyrex, with a 1/32-in.-diam channel for fluid ejection. A third nylon screw, located on the outer portion of the photo-operandum, plugs a bleeder channel to the input side of the nozzle. The remainder of the photo-lickerandum assembly is formed from Plexiglas.⁵ When the S correctly positions itself at the assembly so as to accept liquid from the nozzle, its tongue movements will be registered through breakings of the light beam; conversely, a position such that tongue movements break the light beam ensures that the S's mouth is correctly situated to accept the fluid from the nozzle.

The signal from the photo-resistor is coupled to a Lehigh Valley Electronics Model 321-01 variable-resistance gate. By paralleling the input to this gate with a 5,000-ohm rheostat, one can quickly adjust make-and-break tongue-contact thresholds that are unaffected by ambient illumination or—in the event frequent reinforcement by large quanta reinforcers

is programmed—residual liquid that may accumulate under the nozzle in the path of the light beam. Aqueous solutions within the Sterite aperture will scatter some of the emitted beam, but increasing the sensitivity of the gate renders all but opaque solutions “invisible” to lick-detection circuitry. In all of our work, only small quanta reinforcers have been programmed, thereby preventing accumulation of liquid at the nozzle.

The outside portion of the photo-lickerandum and the means through which reinforcer fluid is delivered to the feeder nozzle are shown in Fig. 3. The projector that emits light is shown to the right of the 1/8-in. (internal diam) Plexiglas conduit through which fluid travels into the nozzle. The photo-resistor, partially obscured by a valve, is to the left of the conduit.

A rectangular steel plate (covering the side of the oven grille to the reader's left in Fig. 3) holds the apparatus that delivers a precise quantum of reinforcer fluid to the feeder nozzle. Seen at the reader's upper left is a Lehigh Valley Electronics constant-pressure reservoir from which fluid travels through 1/4-in. (internal diam) rubber tubing to an Asco No. 82624 electromagnetic fluid valve below. The fluid is conducted from this valve to the valve at the right via a Plexiglas manifold of 1/2-in. (internal diam) tubing. Within the manifold area, one or more 1-ml glass

syringes with No. 16 needles provide the pumping force to move a quantity of fluid into the reinforcer delivery system. The plunger of each syringe is driven by a 24-V dc solenoid and returns to original position by spring pressure. The fluid delivery cycle begins with the opening of the right valve and simultaneous driving of a plunger. This action forces fluid into the 1/8-in. Plexiglas conduit. Within the chamber, the fluid emerges as a discrete droplet (or with large volumes, a continuous streamlet) from the feeder nozzle. The left valve is timed to open momentarily during the replenishment stroke of the syringe.

Because of an hydraulic-overshoot characteristic of Asco valves, when the right valve closes, the fluid retreats slightly back into the channel of the feeder nozzle—thus, the animal's tongue does not normally come into contact with liquid during licks when no reinforcement is scheduled.

Figure 4 shows several syringes, hand-drawn phantoms, to indicate where additional syringes may be added to the system. The wing-screw and associated lock-nut shown at the bottom of each syringe-solenoid determines how far each individual syringe plunger will travel and, thus, what the quantity of reinforcer will be. By changing the setting of the screw, the amount any given syringe pumps to the feeder nozzle may be precisely predetermined, and different syringes may be used to vary fluid amounts within a session, or two or more syringes may be used together to deliver varying amounts. For example, the four syringes could be set to deliver, respectively, 10, 20, 40, and 80 microliters of fluid and thus by binary combination, delivery could be made of 15 different quanta of fluid ranging from 10 to 150 microliters, with no time out needed within a session to change mechanical settings.

The operant programming and recording apparatus used to implement these measures were standard solid-state or electromechanical modules or units obtained from the Foringer, Gerbrands, Grason-Stadler, and Lehigh Valley electronics companies.

Fig. 4. Close-up of valves and multiple syringes of the liquid dispensing system. Three of the syringes (Nos. 1, 2, and 4) are hand-drawn phantoms. The three syringes were not needed in the study reported, but the phantoms illustrate their locations when near-simultaneous pumping of differing reinforcer quantities is desired.

BEHAVIORAL OBSERVATIONS

The Ss reported on in this paper were adult male albino rats, Sprague-Dawley strain, obtained from Simonsen of Minnesota. Each of six animals was fed to 85% of its ad lib feeding weight 1 h after daily experimental sessions lasting 60 min. The reinforcer solution was 16% dextrose (with 0.1% sodium benzoate as preservative) in distilled water.

Rats were shaped to lick at the photo-lickerandum by delivering a 35-microliter reinforcer when they approached the nozzle. When a rat moved close enough to the nozzle for his licking to be recorded, each breaking of the light beam was followed by reinforcement. As soon as the animals properly addressed the nozzle, the schedule was shifted to fixed-ratio 5 (FR 5) for one to six sessions, then to FR 10.

Once responding to FR 10 was well instituted, the six animals were presented

a multiple schedule, with a 525-Hz tone stimulus presented during reinforced segments for three animals and during nonreinforced (extinction) segments for the other three animals. The ratio requirement was subsequently increased to 40.

After one or two sessions on the final schedule, sustained responding generally occurred only during reinforced periods, and few responses were made during nonreinforced periods. Figure 5 presents data from one rat that typify its responding (and the responding of the

other five rats) to the multiple schedule. As indicated by Fig. 5, responding did not always begin immediately at onset of the discriminative stimulus, but when it did begin, it was usually sustained at a high rate through delivery of the reinforcer, as may be seen at a in the record. In contrast, several responses occurred at b, when no reinforcement was available, but the responding was not sustained. During reinforced segments, pausing sometimes occurred but always in the middle of ratio runs—not before the first 10 responses were run off following reinforcement or during the last 10 of the required 40. The responding immediately after reinforcement was higher in rate than was responding later in the ratio, as may be verified by comparing slopes and as was frequently noted by observers who could “hear” the rate change when attending to stepping sounds of the cumulative recorder. One may parenthetically note that these rate-accelerated responses comprise the reflexive burst of tongue licks elicited by the positing of reinforcer solution on the tongue; with suppression of detection of the burst component—via, for example, rate-sensing circuitry—one could obtain a “pure” operant signature of the lick response. We were, at this juncture, indifferent to such purity.

DISCUSSION

Comparison of Photo- and Conventional-Lickeranda

The photo-lickerandum is a reliable

Fig. 5. Cumulative record of a rat's responding to a mult FR 40 ext schedule. Hatch marks on both cumulative response and event-marking tracings indicate reinforcement. There is a sustained downward deflection of both tracings when the extinction component is in effect.

sensing device for licking behavior of rats, and responses detected by this method show the same functional relationships to the independent variables employed as have studies in which the sensing device was a metallic contact. The fixed-ratio response segments, for instance, are closely comparable to the records published by Justesen et al (1967). The multiple schedule was well discriminated by the rats, the results being similar to those found by Alvord (1968) in guinea pigs licking to a conventional (Justesen et al, 1967) lickanderum.

Applications

There are several experimental situations, beyond that of our microwave research, where it may be desirable to detect the licking response by nonelectrical means. In liquid taste-discrimination and solution-preference studies, for example, there is always the likelihood of confounding from conventional drinkometer sensing currents that, in passing through an animal's tongue, may polarize or artifactually stimulate gustatory receptors. Hulse's (1960) modification of the drinkometer to sense via an alternating current may overcome these possible sources of confounding, but the question was and will be academic until ac sensing is directly and empirically validated against a nonelectrical means of lick detection.

Another application, one where electrical lick sensing would be forbidden, is where other externally applied currents would be concomitantly presented to a S. The sources of noxious current to a shock grid, for example, would likely couple to the sources of the sensing current, thereby placing high voltages at an animal's tongue.

Finally, so long as Murphy's law prevails in the laboratory setting, equipment can and will fail and will do so at the worst times. The drinkometer sensor that begins to feed amperes instead of microamperes through an animal's body is a low-probability event, but a traumatic one that can be reduced to zero through photo-detection.

Variable Quantum Reinforcement

In an extended bench check, in which electronically generated pulses were used to simulate rapid and continuous licking responses, we established that the multiple-syringe manifold system delivered variable quanta of volume-determinate reinforcers in a trouble-free and highly reliable manner. Although we have no plans at present to explore the effects of, say, response- or time-dependent shifts of reinforcement quantity in either the tongue-licking or standard bar-pressing situation, we recognize that other investigators may wish to do so, thus our mentioning of this potential use.

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NOTES

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2. Also affiliated with the Department of Psychology and the School of Education, the University of Missouri at Kansas City.
3. Also affiliated with the Department of Psychiatry of the University of Kansas Medical Center, Kansas City, Kansas.
4. We stress these distinctions not to the end of burdening an already overburdened technical language with new terminology but to make clear some operations whose equivocation would spell confusion in the discussion to follow. In the remainder of this report, unless otherwise noted, we shall be referring to adjunct, dry-licking contingencies based upon Hulse's methodology.
5. After 18 months of virtually continuous daily use, the Plexiglas base of the photo-operandum is showing signs of erosion, presumably from gnawing by our rats. We have fabricated a new base from an epoxy compound but have not as yet had an opportunity to evaluate it. Nonetheless, we would suggest the use of harder and tougher dielectrical materials than Plexiglas in fabricating that portion of the base exposed to the teeth of rat Ss.