*AN INEXPENSIVE ELECTRO-FISTULAR SWIVEL
FOR NEGATIVE FEEDBACK CONTROL OF
SELF-STIMULATION¹*

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A swivel was developed for concurrent intraorganismic fluid injection and intracranial electrical stimulation of the unrestrained rat. Effects of various intragastric injections on bar-pressing maintained by electrical stimulation of the hypothalamus were studied. In some subjects, intragastric injections of either water or milk decreased the rate of responding. This decrease resulted from pauses in responding rather than from decreases in the local rates of responding. The decrement in responding occurred at a lower gastric volume during milk injection than during water injection. In other subjects, however, neither water, milk, nor 32% sucrose injections affected the rate of self-stimulation.

The maintenance of responding by electrical stimulation of the lateral hypothalamus has been viewed as a positive feedback system because of the lack of satiation for this stimulation (Olds, 1958*b*). A functional correlation between certain drive states and self-stimulation (Olds, 1962) has, however, been suggested. The conventional method for studying this covariance between primary drives and the effectiveness of electrical stimulation of the brain (ESB) as a reinforcer, has been to compare the rate of responding of a subject under two drive levels. This method has demonstrated that the rate of responding for ESB at certain hypothalamic sites is directly related to the level of food deprivation (Olds, 1958*a*; Hodos and Valenstein, 1960), the level of circulating androgens in the male rat (Olds, 1958*a*), and the estrous cycle of the female rat (Prescott, 1966). Increased food deprivation has also been found to raise the rate of self-stimulation at other limbic sites (Brady, Boren, Conrad, and Sidman, 1957). By tube feeding deprived subjects within a single testing session, Hoebel and Teitelbaum (1962) demonstrated an immediate decline in rate of responding by rats with electrodes placed in the lateral hypothalamus. The common

characteristic of all these studies is that drive level was changed during a discrete session between two test periods.

With the development of simple surgical techniques for chronic implantation of gastric tubes (Epstein and Teitelbaum, 1962), oral fistulas (DeBold, Miller, and Jensen, 1965), esophageal fistulas (Mook, 1963) and intravenous cannulas (Weeks and Davis, 1964) in the albino rat, new approaches to the study of self-stimulation behavior are possible. With a preparation in which ESB is administered to an animal concurrently with appropriate intraorganismic injections, the drive level of an animal working for ESB can be varied continuously during the testing session. Such a preparation allows good control over such parameters as rate and amount of injection, and eliminates extraneous handling of the animal.

The present report describes a swivel and animal-coupling system developed for concurrent brain stimulation and intraorganismic fluid injection in the unrestrained rat. The swivel is designed so that the liquid dispensing system rotates in unison with two electrically independent electrode leads. Exploratory findings using this swivel with self-stimulating animals implanted with chronic intragastric fistulas are reported. The focus of the experiment was to study the possibility of bringing self-stimulation behavior under negative feedback control, and to examine the previously reported covariance between hunger and rates of self-stimulation.

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METHOD

Apparatus

The swivel (Fig. 1-A and B) is a modification of one described by Johnson, Trehub, and Pietskowski (1966). The electrode contacts are made onto two ball-bearings² which are insulated from each other (P, F, and G) but which rotate together on a hollow-core bolt (O and S) containing the injection tubing (N); the fluid injection system is thus maintained independently and twisting of the electrode lead is prevented. The hollow-

core bolt system is constructed from common electrical hardware such as tip jacks and banana jacks.³

The swivel is most easily assembled in two sections. (1) The hollow core swivel system: the springs from the vacuum tube protective covers (R) are soldered to the outside rims of the ball-bearings (C). This connection may be

²Precision bearings available from PIC Design Corp., 477 Atlantic Ave., East Rockway, N.J.

³Banana jacks and tip jacks fitting a $\frac{5}{16}$ -in. mounting hole were used for this swivel. The following components were used from the various jacks. Allied Electronics (Chicago, Ill.) stock numbers and Fig. 1 labels are included for all components used: O—non-insulated banana jack (A 9185); S—threaded bolt from insulated banana jack (24 A 9169); B—insulated plastic cap, and G—plastic insulating washer from insulated tip jack (24 A 9163).

Fig. 1. A. Cross-section view of the electro-fistular swivel. B. Exploded perspective view of the swivel. (A) concentric layers of Thermofit tubing, (B) plastic cap from insulated tip jack, (C) ball-bearing, (D) nuts from banana or tip jacks, (E) lead from stimulator, (F) Thermofit or electrical tape insulating sleeve, (G) plastic insulating washer from insulated tip jack, (H) $\frac{3}{8}$ -in. outside diameter protective vinyl spaghetti tubing, (I) solder lug, (J) electrode lead, (K) spacer, (L) stainless steel needle tubing, (M) wire binding, (N) polyethylene tubing, (O) non-insulated banana jack, (P) insulating washer, (Q) Plexiglas swivel mount, (R) spring from vacuum tube protective cover, (S) threaded bolt from insulated banana jack.

made either with a liquid metal such as Epoxy Liquid Steel or with acid-core solder. The heat necessary in making an acid-core solder connection will not damage the ball-bearings. The protective vinyl spaghetti tubing (H) is friction-fitted into the non-insulated banana jack (O) and the hollow bolt of the insulated banana jack (S). The following pieces are then placed on the non-insulated banana jack (O): a solder lug, the insulating washer from the insulated tip jack (G), and another solder lug. The second solder lug must be reamed out to fit over the protruding lip of the insulating washer. In this way it will be insulated from the metal parts of the hollow-core bolt that conduct the electricity from the top ball-bearing to the bottom solder lug. A few threads of the non-insulated banana jack (O) are filed away, and electrical tape (F) is wrapped around the area. Thus, when the bottom ball-bearing is positioned as shown (Fig. 1-A), it too will be insulated from the non-insulated banana jack (O). Complete insulation is accomplished by a cardboard washer (P) placed on top of the journal of the bottom ball-bearing. The journal is then firmly attached to the banana jack (O) by a nut. The two parts of the hollow-core bolt (O and S) are now joined by a nut (D). This part of the swivel is inserted through a hole in the Plexiglas swivel mount (Q) as shown in Fig. 1-B, and the top ball-bearing, with its attached spring, is positioned on top of it and secured with a nut. The springs (R) thus suspend the swivel on the Plexiglas (Q). Figure 1-B, an exploded perspective drawing of the swivel, should help visualize the spatial relations of the swivel, especially the connection of the springs to the ball-bearings. The friction of the springs on the Plexiglas is much greater than the friction of the ball-bearings. Hence, the hollow-core bolt turns with the protective vinyl tubing friction-fitted into it.

(2) The inner fluid transport and electrical stimulating system: concentric layers of Thermofit⁴ (A), a heat shrinkable tubing, are shrunk around the polyethylene tubing⁵ (N) at its distal ends so that the fluid transport

system will be reinforced and will fit snugly into the protective tubing (H). After the fluid transport system has been inserted into the protective vinyl tubing, electrode leads are threaded into the protective tubing through appropriately placed holes. The fistulated animal is connected to the fluid transport system by a short length of hypodermic needle tubing (L). Since the protective vinyl tubing is bound (M) to the reinforced ends of the polyethylene tubing, the turning of the animal is translated into the rotation of the swivel, and the delicate polyethylene tubing is protected from being crimped or torn.

In its assembled form, the fluid transport system receives fluid through a short length of hypodermic needle tubing (F-Fig. 2). The swivel rotates easily around the needle tubing with no leakage. The springs attached to the ball-bearings allow overall resiliency of motion to the swivel as it follows the movements of the animal. The swivel can be dismounted easily for servicing by unscrewing the plastic cap (B) and the first nut. Because the tube springs (R) are not attached to the Plexiglas mount, the top ball-bearing may be lifted off the banana jack bolt (S).

The dimensions of some of the components should vary depending on the type of fistular preparation used with the swivel. The dimensions used with the intragastric fistula are as follows: protective vinyl tubing, $\frac{3}{16}$ -in. outside diameter (OD), $\frac{1}{16}$ -in. inside diameter (ID); PE-50 polyethylene tubing, 0.038-in. OD, 0.023-in. ID; 24-gauge hypodermic needle tubing, 0.022-in. OD.

In this experiment, the swivel was mounted on the cover of a standard rat chamber. Figure 2 shows the swivel in functional relation to the injection apparatus. A solenoid-driven syringe is connected to the input of the swivel through a two-way Aupette⁵ valve (D). Fluid is drawn from a reservoir (C) during the spring return of the solenoid arm. The injection syringe is held firmly between a bracket (G) and a clamp (B). Care must be taken in choosing the spring for the solenoid arm return. It should be strong enough to return the solenoid arm but weaker than the maximum lift of the solenoid. In this experiment, a 24 v dc continuous duty Guardian solenoid with a 66-oz lift was used. A layer of oil (A) was floated in the syringe barrel to prevent freezing of the syringe.

⁴Thermofit is a heat shrinkable tubing available in various sizes from Schaal Associates, 11 Adams Street, Burlington, Mass.

⁵Available from Clay Adams Co., New York, New York.

Fig. 2. Electro-fistular swivel with injection apparatus: (A) a layer of light vegetable oil to prevent freezing of the syringe piston, (B) clamp, (C) to fluid reservoir, (D) Aupette valve, (E) solenoid, (F) hypodermic needle tubing, (G) metal bracket, (H) cover of training chamber, (R) vacuum tube spring attached to a ball-bearing of the swivel.

Two reliable methods of coupling the animals to the injection system were developed (Fig. 3-A and B). If the bare polyethylene fistula is brought through the acrylic cement cap on the animal's head, it will break off with minimal flexing. A durable female unit can be formed, however, by molding several concentric layers of Thermofit tubing (B) around the polyethylene fistula (Fig. 3-A). The Thermofit may be coated with Epoxy cement before shrinking to form a more durable unit. A length of needle tubing has to be inserted in the polyethylene fistula (C) while shrinking the Thermofit to prevent it from

collapsing. The tubing should be shrunk with a low wattage soldering-iron or cautery to prevent splitting. The end of the fluid transport tubing from the swivel is formed into a male unit that can be attached to the female unit on the animal's cap. The connection is bound by shrinking a sleeve of Thermofit around the protruding collars as shown in Fig. 3-A. The animal can be disconnected easily from the injection apparatus by cutting at the joint with wire strippers. This coupling system was used throughout the present experiment.

The second connecting system is a direct generalization of the system used with a type of commercial electrodes (Fig. 3-B). The plastic couplers (D) used with these electrodes have been bored out to accommodate the polyethylene fistula.⁶ A commercially produced threaded collar (E) is used to connect the couplers.

Subjects

Four experimentally naive, 120-day old, Sprague Dawley male rats weighing 280-330 g were anesthetized with sodium pentobarbital and implanted with chronic intragastric fistulas by the method described by Epstein and Teitelbaum (1962). During the same operation bipolar stainless steel electrodes were surgically implanted. Each pole of an electrode was 0.009 in. in diameter and insulated except at the tips. The stereotaxic coordinates were chosen so as to place the electrode tips in the lateral hypothalamus; the coordinates (deGroot, 1959) were: Rat 1: A-4.6, L-1.5, H-3.0; Rat 2: A-5.8, L-1.7, H-2.5; Rat 3: A-4.8, L-1.9, H-3.0; Rat 4: A-5.0, L-1.8; H-3.0. After five days of post-operative recovery all subjects except Rat 3 were placed on a daily 22-hr food-deprivation schedule for approximately one week before experimentation. This deprivation schedule continued for the duration of the experiment. During experimentation, a 2-hr feeding period was allowed immediately after each test session. Rat 3 was maintained on free-feeding throughout the experiment. Water was available in the home cages at all times, except before Session 3, when Rats 1 and 2 were deprived of water for 6 hr.

⁶Plastic couplers were made to specifications by Plastic Products Co., P.O. Box 1204, Roanoke, Va.

Fig. 3. Two methods of coupling fistulated animals to the fluid injection system: (A) stainless steel needle tubing, (B) Thermofit tubing, (C) polyethylene tubing, (D) plastic coupler, (E) coupler connector collar, (F) wire binding, (G) spacer, (H) protective vinyl spaghetti tubing.

Procedure

During the first session, each rat was trained to lever-press on a continuous reinforcement schedule (CRF) for ESB. After learning the response, the subjects were allowed to respond for 45 min. Each reinforcement consisted of a 0.3-sec train of 60-pulses per sec, biphasic, 0.1-msec pulses from a Grass S-4 stimulator. Voltage was continuously monitored on a cathode ray oscilloscope. Current intensities were initially chosen for each rat to sustain responding. These currents were used in subsequent sessions. The intensities used were 70 μ A, 80 μ A, 76 μ A, and 120 μ A (all currents measured zero to peak) for Rats 1 through 4 respectively. Each successive testing session was separated by a day. During Session 2 each rat was allowed to self-stimulate on a CRF schedule without intragastric injections for 1 hr. The animals were connected to the injection apparatus during this session. During Session 3, Rats 1 and 2 were allowed to self-stimulate on a CRF schedule; superimposed on the CRF responding for ESB, intragastric injections of water were administered on a fixed-ratio five (FR 5) schedule. The lengths of these and subsequent injection sessions were determined by the volume of the injected fluid and the readiness of the animals to maintain responding. When the injected volume clearly surpassed the maximum volume that would

normally be ingested by similarly deprived animals (25 to 30 ml for both food and water) and no change in responding had occurred, the session was terminated. Animals that showed a change in responding during injection sessions were continued until the nature of the change had been determined. For Rats 3 and 4, instead of water, a commercial milk solution (undiluted Metrecal) and a 32% sucrose (32 g sucrose per 100 g water) solution were injected, respectively. Rats 1 and 2 were given an additional session during which the Metrecal milk was injected on FR 5 superimposed on the CRF responding for ESB. The individual injections consisted of 0.065 ± 0.005 ml of fluid. The nutrient density of the milk injections was 0.92 Cal per ml and that of the sucrose solution, 1.28 Cal per ml. The general experimental apparatus consisted of a single-lever operant conditioning box used in conjunction with conventional programming and recording devices.

RESULTS

Figure 4 consists of the cumulative records of Rats 1, 2, and 4. Two characteristic types of responding were found from the sites studied. Two rats showed some form of modulation of self-stimulation due to the intragastric injections and two did not.

Rats 1 and 4 showed no change in the rate

Fig. 4. Cumulative records for sessions 2 to 4 for Rats 1 and 2, and for sessions 2 and 3 for Rat 4. The records of the control sessions represent only the second half of a 1-hr self-stimulation session. Each record is labeled with the treatment administered during that session and the terminal injected fluid volumes for all subjects. For Rat 2 the injected volume at the first protracted pause in responding is given. The downstrokes on the records of Rat 2 represent brain stimulations given independently of the animal's behavior. Each excursion of the cumulative recorder pen represents 550 bar-presses.

of responding as a result of either the intra-gastric water, milk, or sucrose injections. The self-stimulation session for Rat 1 was terminated when the quantity of injected fluid had greatly exceeded what had previously been reported (Hoebel and Teitelbaum, 1962) to have produced inhibition of self-stimulation. Since neither a 51-ml stomach load of water nor a 34-ml load of milk inhibited self-stimulation, it was concluded that the intragastric injections were not modulating the self-stimulation at this site. For Rat 4, the sucrose injection session was extended to see if self-stimulation would terminate with an extreme intragastric load of high caloric density. The subject was still self-stimulating when the stomach load had reached 59 ml. This represented a weight increase of 21% over pre-

session weight. Since there was no apparent change in average response rate despite the large gastric load, the session was terminated with the hope of preserving the animal. The rat was extremely bloated, and the abdominal skin was expanded tautly. The animal was found dead in its cage next morning. The abdominal cavity was opened and the gut was found to be engorged with fluid. Death probably resulted from dehydration due to the hypertonic sucrose solution drawing water from the tissues and extracellular fluid into gastrointestinal cavities.

Rats 2 and 3 demonstrated a pattern of responding that was noticeably affected by the injection procedures. Since the cumulative records of Rat 3 were similar to the corresponding records of Rat 2, they have not

been included in Fig. 4. For both animals the decrease was a result of pauses in responding rather than a change in the local rate of responding. The first protracted (at least 2-min) pause in responding for Rat 2 during the water injection session occurred at a stomach load of 45 ml; with the milk injection, the first such pause occurred at a load of 22 ml. For Rat 3, which had been maintained on a free-feeding schedule, the first protracted pause during milk injection occurred at a load of 9 ml. When such pauses in responding had lasted for at least 2 min, brain stimulations independent of the animal's behavior were administered to see if the subjects would come back to the bar. Responding resumed with these administrations during both water and milk injection sessions, but subsequent pauses occurred at increasingly shorter intervals.

During the control sessions, Rats 1 and 4 could be differentiated from Rats 2 and 3 by their predominant mode of responding. The main behavior pattern of Rats 2 and 3 was vigorous biting of the bar; Rats 1 and 4 responded primarily with their front paws and exhibited few oral responses. Furthermore, though Rats 1 and 4 exhibited no changes in overall responding, they did show increasingly erratic responding during the later parts of the injection sessions. Rats 2 and 3 actively avoided the bar by crouching at the other end of the training chamber.

Histological verification of electrode locations was not accomplished because of a post-experimental epidemic in the rat colony. However, the high control rates of self-stimulation are comparable to those found with lateral hypothalamic placements.

DISCUSSION

Apparatus

The present experiment demonstrated the durability and reliability of the electro-fistular swivel. Several points about the use of the swivel need to be made, however. The action of the ball-bearings was quite frictionless as long as care was taken to allow none of the injected fluid to get into them. If some fluid did accidentally get into the ball-bearings, the swivel remained useable during that session, but cleaning with a light oil such as electrical contact cleaner was necessary for

continued performance. For accurate fluid injection, the fluid transport system had to be clear of air bubbles. During initial tests of the injection apparatus, the volume per injection was reproducible to less than 2%. During experimental testing, however, Rat 1 received 51 ml of injected fluid with approximately 720 solenoid movements, while Rat 4 received only 59 ml with 1000 movements. This represents about 18% less injected fluid than would be expected on the basis of Rat 1. This error is believed due to the inability of the solenoid to force effectively all the fluid into the stomach against a back-pressure developed by the enormous intragastric load. Because the size of the stomach would affect such an error, the error should have been more prominent in Rat 4, since it weighed 40 g less than Rat 1. Because the swivel can be used independently of the present injection method, more reliable pumps or stronger solenoids should be used to prevent such errors.

Although the swivel has been used only with intragastric and intraoral fistulas, it could readily be used with other preparations if the fistula outlet were anchored to a dental cement cap on the subject's skull. Also, by using this swivel with the intraoral electrode described by DeBold, *et al.*, (1965) and a touch sensor, the intraoral licking response of the unrestrained animal can be recorded without the harness previously used by Pattern and Deaux (1966). Since the fluid injection system of the swivel can be used independently of the electrode contacts, it is useable also where only intraorganismic injections of the unrestrained animal are wanted. Thus, by using intraorally fistulated animals and the fluid injection part of the swivel, delay of reinforcement can be closely controlled in a free-operant situation.

Data

The exploratory data demonstrated the ability of both food and water to bring responding for ESB from certain hypothalamic sites under negative feedback control. That this control commenced much sooner for the milk injected animals than for the water injected one, and for the freely fed animal before the deprived animals, suggests that some quality of the nutritive solution was crucial to the early cessation of responding.

It is interesting that those areas that were sensitive to milk injections were also sensitive to water injections. The sensitivity of self-stimulation to nutritive injections has been explained by increased ventromedial nucleus (VMN) activity and its subsequent inhibition of certain lateral hypothalamic areas (Hoebel and Teitelbaum, 1962). Physiological evidence for such a mechanism has been presented (Anand, Dua, and Singh, 1961; Anand, Chhina, and Singh, 1962; Anand, Chhina, Sharma, Dua, and Singh, 1964; Oomura, Kimura, Ooyama, Maeno, Iki, and Kuniyoshi, 1964; Oomura, Ooyama, Yamamoto, and Naka, 1967). Anatomical connections between the VMN and lateral hypothalamus have also been described (Szentágothai, Flerkó, Mess, and Halász, 1962). It is possible that the inhibition due to water injections resulted from stomach distention, mediated by the afferent gastric receptors described by Paintal (1954). The potent effect of stomach distention on increasing VMN activity has been demonstrated by Sharma, Anand, Dua, and Singh (1961).

Hoebel and Teitelbaum (1962) reported on animals in which the interpolated intragastric injection of milk decreased lever pressing relatively uniformly and on animals in which responding was maintained but interrupted repeatedly by other activities such as grooming. Rats 2 and 3 exhibited the second type of response modulation; *i.e.*, periods of cessation of responding; rather than indulging in extraneous behavior during these pauses, however, they would actively orient away from the bar. When responding was reinstated by administering brain stimulations independent of the animal's behavior, the pre-stopping rate was resumed. Hence, in our animals, the intragastric injections did not modulate the average rate of responding but the duration and frequency of bouts of responding. In this sense it is similar to some other response measures, such as rate of licking (Hill and Stellar, 1951; Davenport, 1961; Stricker and Miller, 1965), that do not vary with level of deprivation.

The inability of intragastric injections to assume a negative feedback control over self-stimulation from certain hypothalamic sites was also demonstrated. Rat 1 received large amounts of both food and water with no consequent decrement in responding. Rat 4

exhibited a striking maintenance of performance despite an enormous and probably aversive hypertonic stomach load. The maintenance of self-stimulation under conditions that upset body-fluid balance beyond physiological limits demonstrates the potency of ESB either as a very strong reinforcer or as a stimulus that can increase the pain threshold of an animal. It is probable that rewarding ESB has both properties. Olds (1961) and Valenstein and Beer (1962) demonstrated that animals would withstand painful shock to the feet to obtain ESB. Furthermore, Andy (1958) has reported that self-stimulation at certain sites does increase the pain threshold of the animal.

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