Brain Stimulation Reinforcement: Implications of an Electrode Artifact

Beninger et al. (1) concluded that the lever pressing of rats reinforced directly with electrical brain stimulation reinforcement (BSR) (i) does not show a sharp decline when BSR is terminated and (ii) is as easily brought under the control of a lean intermittent schedule of BSR as it is under a schedule of food reinforcement. These conclusions, which I dispute, conflict with numerous empirical reports (2) and suggest that three major theoretical accounts (3, 4) aimed at understanding these “anomalies” of BSR are unnecessary.

The authors’ conclusions are partly based on their inability to replicate my finding (5) that if a response-dependent BSR was preceded by a brief warning signal (a cue light) rather than immediately following the response, (i) the acquisition of control by an intermittent schedule [such as fixed ratio (FR), 200; variable interval (VI), 2 minutes; or fixed interval (FI), 3 minutes] was facilitated and (ii) a higher response rate was maintained on time-based schedules. I have found that the effect of the warning signal in my experiment depends upon an artifact.

The artifact is caused by an electrode and plug assembly (Plastic Products, Inc.) that has the potential for movement-produced electrical discontinuity and graded conductance change at the interface. As a result, preceding the BSR with a brief warning signal imposed a chain schedule: the signal functioned as a discriminative stimulus (S\textsuperscript{D}) for the animal’s postural adjustment which, because of the artifact, allowed an increase in conductance and charge, and consequently a greater magnitude of reinforcement. This was shown by data for four rats that acquired lever pressing reinforced by signaled BSR in both components of a multiple VI 1-minute, VI 1-minute schedule. A constant voltage stimulator was employed. After behavior stabilized, BSR was signaled in one component and unsignaled in the other. Substantially more current passed when the BSR was signaled rather than unsignaled (Fig. 1). The asymptotic response rate was 8 to 20 percent higher in the component associated with signaled BSR. Reversal of the component stimuli with respect to signaling of BSR produced the same result. When a new “captive” collateral (Plastic Products, Inc.) was substituted for the older model plug and collar, current flow for signaled and unsignaled BSR was nearly the same and the response rate for the two schedule components did not differ. The ability of the signaled BSR to maintain higher response rates is thus an artifact of the older model plug assembly (6). Furthermore, without the artifact making the signal an S\textsuperscript{D} in a chain schedule, the signaling procedure is as poor as or worse than simple response-contingent BSR (7) in bringing about lever pressing on an intermittent schedule. The efficacy of a chain schedule in establishing schedule performance with BSR was first shown by Pliskoff et al. (8) with multiple trains of stimulation per reinforcement. My own experiment (5) shows that a single train of BSR can serve as reinforcement in the terminal link of an intermittent chain schedule.

Beninger et al. (1) claim to show in their third experiment that performance typical of that with food reinforcement is produced with simple response-contingent BSR and that a special procedure such as chaining is therefore unnecessary. But their response rates of 5 per minute are exceedingly low for a random interval (RI) 45-second schedule. Even the highest rates reported (10 per minute) are considerably lower than the 20 per minute found in my experiment with a substantially leaner VI 2-minute schedule. Beninger et al. reported rapidly declining response rates as the RI value was increased. Perhaps this discouraged attempts to maintain responding on such schedules as FR 200, VI 2 minutes, and FI 3 minutes, as shown in experiments in which a chaining procedure was used (5, 8). Only evidence (with cumulative records) of such schedule performance should be taken in support of the assertion that chaining is unnecessary.

Imposing a chain schedule with BSR prevents the occurrence of the rapid extinction effect (REE) (9)—a sharp drop-off in responding when extinction is programmed after continuous reinforcement (CRF) training—during the transition from CRF to the intermittent schedule. The REE is peculiar to BSR because BSR is ordinarily applied in the last and only link of a chain schedule, whereas food reinforcement requires many links in a chain of consumatory behavior. In 1934, Skinner (10) asserted in the language of the day that “in a chain of reflexes not ultimately reinforced, only the members actually elicited undergo extinction.” In other words, responses after the break are protected from extinction because S\textsuperscript{D}’s for them are not presented. On the other hand, S\textsuperscript{D}’s before the break are presented and their responses are extinguished. Consequently, the REE reflects the breakage of the all-important last and only link of a one-link chain. When extinction after CRF with food reinforcement occurs, many links after the break are “not elicited” and the operant is thereby better protected from extinction. Similarly, the response decrement in extinction after CRF training is slower when a foodlike chain is arranged than when BSR is directly contingent on the operant (11). Almost all successful attempts to maintain behavior on an intermittent schedule of BSR have employed a chain that protects the operant.

Microelectrode techniques were employed as described (1). A similar result has been reported in rabbit superior cervical ganglion by H. Kobayashi and B. Libet, J. Physiol. (London) 208, 353 (1970). In our experiments, membrane resistance was measured by using hyperpolarizing current pulses (−100 pA, 30 to 60 msec). Changes in input resistance as small as 10 percent were detectable.


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from extinction during the transition from CRF to the schedule (12).

Accordingly, it is not BSR per se that makes schedule control difficult, but its property of being applied in the last link of a one-link chain. Other applied reinforcers pose similar problems in rats and ducklings (13) as well as humans (14). Carlisle (15) found that rats pressing to turn on a heat lamp reinforcer in a cold chamber performed well on a CRF schedule, but poorly on an intermittent schedule unless a chaining procedure was used.

Whereas most of the experiments since 1958 in which the older electrode and plug assembly was used remain valid, conclusions from those in which information about BSR onset was varied should be questioned, because the information would act as an S0 for postural adjustment leading to increased reinforcement. Some examples of those experiments follow: Stein’s (16) conclusion that stimulus need not be an S0 for it to be a conditioned reinforcer. The finding by Steiner et al. (17) that a pattern of BSR which rats produce in a self-stimulation test is aversive when “played back” independent of behavior; Faircloth’s (18) conclusion that BSR is more reinforcing when it is self-initiated; Bollinger and Gerall’s (19) finding of a decrease in brain-electrode impedance associated with the acquisition of self-stimulation; and my conclusion with Lordo (20) that rats prefer signaled to unsigned BSR.

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References and Notes
6. The artifact would also be manifest with a constant-current stimulator since the artifact entails electrical discontinuity.
9. Beninger et al. (1) assert that the REE does not occur, but they used RI 45-second as the maintenance schedule rather than the CRF with which the “anomaly” was first described [J. Olds and P. Milner, J. Comp. Physiol. Psychol. 47, 419 (1954)]. Such intermittency would produce substantial extinction in that situation, especially in comparison to their control animals which were pretrained to press the lever.

We take issue with Cantor’s assertion (his reference 7) that the use of a constant-current stimulator is no protection against the artifact that invalidated his results. His figure 1 shows the contact resistance of his plug rising to a peak value of about 100 kilohms. Any constant-current stimulator able to deliver up to 40 Volts would be able to overcome that resistance. Furthermore, the oxide or dirt film that is usually responsible for poor contact in these plugs can withstand only a few volts, so that as the stimulator voltage rises to overcome the higher resistance it breaks down the film and restores good contact. Our experience in monitoring current from a constant-current source is that unless the contact is completely broken, in which case the animal gets no stimulation under any circumstances, the current is held constant, with variation of only a few percent.

Cantor’s main criticism of our experiment is that because its results are out of line with those of several previous experiments, they must therefore be wrong. He notes that the highest rates we reported at a random interval (RI) 45-second schedule are much lower than the rate he obtained at a variable interval (VI) 2-minute schedule with the rat in his experiment, and speculates that we were thereby discouraged from testing leaner schedules. We have published data from just such a test (2). Eight rats were trained on progressively leaner RI schedules for response-contiguous BSR. All rats continued to respond up to or beyond RI 3-minute schedules, with one rat performing on a schedule as lean as RI 10 minutes. Representative cumulative response curves both during RI and extinction sessions are shown in Fig. 1. Absolute rates depend on individual characteristics of subjects and apparatus and cannot be compared from one experiment to another. However, the response rates are precisely determined by the reinforcement schedule, as is clearly the case in this experiment. Spontaneous recovery from extinction is shown from the first to the second session. These results confirm and extend those presented earlier (1). We were surprised at the difference between our results and those of others (4). The difference does not depend on a gradual transition from high to low rates of reinforcement; we obtained the same results when naive rats were trained for several days on continuous reinforcement and switched immediately to an RI 45-second schedule.

Environmental control was tighter in our experiment than in most earlier stud-
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