THE MEASUREMENT OF RESPONSE FORCE DURING A LEVER-PRESS SHOCK-ESCAPE PROCEDURE IN RATS¹

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Three albino rats were given extensive exposure to an escape procedure in which shocks were scheduled to occur 30 sec apart. The amount of downward force exerted on the lever was continuously recorded and compared with traditional discrete measurement in which only responses above an arbitrary force threshold were recorded. Subjects typically remained in contact with the lever throughout the shock-free intertrial interval. Shock onset reliably occasioned a brief lurch from and return to the lever, which resulted in a lever-press escape response being recorded. Lever contact, which occupied an average of 90% of session time, showed great stability in force after a brief (*e.g.*, 5-sec) period of instability after each shock terminated. In general, continuous measurement revealed considerably different results than discrete measurements of on-lever behavior. For example, continuous lever contact fluctuating near response threshold was often recorded as discrete responding, and sustained lever contact occurring below response threshold was omitted from discrete measurement.

The present experiment investigated the amount of force subjects exerted while in contact with a lever throughout extensive exposure to a lever-press shock-escape procedure.

Despite the fact that escape conditioning represents perhaps the simplest aversive-control procedure, the behavior it produces is far from understood. For instance, escape conditioning characteristically produces "extra" responses that bear no scheduled relationship to shock termination. The most common of these are discrete responses and lever holding, which occur throughout the shock-free intertrial interval (Dinsmoor and Hughes, 1956; Migler, 1963).

The most systematic analysis of response force was undertaken by Notterman and Mintz (1965), who examined the amount of force exerted on a lever by rats exposed to a

variety of schedules of positive reinforcement and nondiscriminated avoidance. Their general findings documented the fact that response force is a sensitive measure of the effects of traditional operant variables and, in some cases, their findings extended what is known about schedule effects from response-rate data (*e.g.*, Mintz, 1962). To date, however, there does not appear to be an instance of response-force measurement during a shock-escape procedure.

Escape conditioning, like most operant research, has usually involved dichotomous measurement, *i.e.*, a preselected response-force criterion that includes all responding above this level and excludes all below it. It is therefore possible that under dichotomous measurement, some recordings of contact with the lever might be lost or misinterpreted. By substituting continuous measurement of lever contact for dichotomy-bound discrete measurement, the present procedure may provide a method for obtaining additional data on escape behavior and point to some possible errors occurring under discrete measurement.

METHOD

Subjects

Three experimentally naive male Wistar rats, approximately 120 days old at the start

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of the experiment, were individually housed with food and water freely available in their home cages. The subjects weighed 416, 405, and 432 g at the start of the experiment.

Apparatus

The subjects were tested in a Lehigh Valley grid-shock chamber 30.5 cm long by 20.3 cm wide by 19.0 cm high. The floor consisted of 15 stainless-steel grids 0.64 cm in diameter spaced 1.9 cm apart. A constant-current shock generator and scrambler (Campden Inst. Co.) delivered a 0.4-mA shock to the grid floor, cage walls, and lever of the chamber. A 1.3 cm by 5.1 cm response lever protruded 2.2 cm from the front cage wall, 5.1 cm above the grid floor. The lever was mounted to allow a 1.5 mm downward excursion under maximum load.

The relative immobility of the lever might suggest some degree of caution in generalizing the results of the present procedure. Despite the fact that conventional levers typically allow excursions greater than 1.5 mm, comparisons made in our laboratory between such manipulanda and the present lever have revealed no differences in the essential properties of escape behavior (*e.g.*, latency, number of responses, amount of sustained lever contact, response topography). That the escape response is rapidly and consistently acquired in the present apparatus suggests that whatever physical differences may exist between the levers or the degree of response feedback they provide, any differences in their effects on the major characteristics of escape behavior are negligible.

Figure 1 illustrates the apparatus for recording response force. The amount of downward force the subject exerted on the lever was expressed as a pen deflection on a Beckman physiograph (Type RS). The force exerted on the lever was transferred through a 10-cm metal rod to a strain-gauge transducer (West Coast Research, Model 33) mounted beneath the lever. The transducer, which converted force to voltage change, was powered by a highly regulated 5-V power supply (Acopian 5 × 10). This output was amplified by a factor of 100 (Analog 40-J op-amp) and then run through an ac-dc coupler to serve as adequate input to the physiograph. The sensitivity of the transducer ranged from 0.1 mV to 100 mV, with 0.1 mV equivalent to 0 g downward force

on the lever, and 100 mV equated to 135 g (1.32N) force. Sensitivity within this range was linear. In order to prevent shock delivered to the lever from causing interference to the force transducer, a small insulating ceramic sleeve was placed between the lever and the load cell of the transducer.

A Schmitt trigger allowed three different response force criteria: 15 g (0.147N), 30 g (0.294N), or 45 g (0.441N). The settings on the Schmitt trigger were recalibrated before each experimental session. The force criterion in the present experiment was identical to its usual application; *i.e.*, all lever contacts equal to or greater than a minimum force value were treated as "responses" and they activated scheduling and recording equipment; all lever contacts less than criterion force failed to activate scheduling and recording equipment. In the present experiment, however, the force of all contact with the lever, regardless of which criterion response force was in effect, was recorded on the physiograph.

Procedure

Pretraining. Before the first session, subjects were trained to press the lever to escape (terminate) shock. Shocks (0.4 mA) occurred 30 sec apart from offset to onset. Shock duration was initially controlled by the experimenter, who terminated shock with a manual switch as the subject made successive approximations to the lever press. In subsequent sessions, shock remained in effect until a response was made. Shaping was discontinued when a subject made 10 consecutive low latency (1 sec or less) escape responses. Responses in the absence of shock had no scheduled consequence.

Escape behavior. As originally conceived, the procedure was to involve a three-phase, within-subject design in which each subject would ultimately be exposed to each of three criterion response force requirements. Each experimental phase lasted a minimum of 18 daily sessions of 50 trials per session. Shock trials were separated by a 30-sec intertrial interval. Thus, in Phase I, Rats 1, 2, and 3 were exposed to criterion response force values of 15 g, 30 g, and 45 g, respectively. After approximately 18 sessions, Phase II values of 45, 15, and 30 g were to be assigned to Rats 1, 2, and 3, respectively.

Of necessity, the experimental design was altered after the thirtieth session with Rats 2

Fig. 1. Block diagram of apparatus used to record the force of lever contact during shock-escape procedure.

and 3 already changed to Phase II criterion values. (Rat 1 was 15 days behind the other subjects and was therefore still under its Phase I criterion response-force value). It was apparent that the criterion response-force manipulation was having no effect on behavior and all subjects were henceforth maintained at their existing criterion values (Rat 1 at 15 g, Rat 2 at 15 g, Rat 3 at 30 g) for the remainder of the experiment. All subjects were tested for a total of 51 sessions. Rats 2 and 3 were exposed to Phase I criterion response-force values for the first 18 sessions, and Phase II values for the remaining 33 sessions. Rat 1 was maintained at its original Phase I value throughout the experiment.

RESULTS

Properties of the escape response. All subjects learned to escape consistently as escape latencies averaged 0.32, 0.35, and 0.28 sec over all sessions for Rats 1, 2, and 3 respectively.

The physiograph recording in Figure 2 illustrates the major force characteristics of lever contact during the initial portion of the intertrial interval. Each escape trial began with the delivery of shock. Because the subject was usually in contact with the lever at this moment, shock delivery resulted in the subject's

lurching from the lever. This movement produced an "equal but opposite" effect, *i.e.*, a brief and forceful depression of the lever, with peak magnitude ranging between 45 and 150 g and averaging 112, 110, and 105 g, for Rats 1, 2, and 3, respectively. It was followed immediately by a drop to the zero point on the record as lever contact was broken, and returned rapidly to a value ranging between 40 and 70 g when the subject again touched the lever, usually in less than 0.5 sec. Once the subject returned to the lever, the force of contact usually remained erratic for a brief (*e.g.*, 5-sec) interval before it stabilized at some value typically ranging between 30 and 50 g, which remained in effect throughout the balance of the intertrial interval. This entire sequence appeared on 98%, 93%, and 92% of the records obtained for Rats 1, 2, and 3, respectively.

As indicated in Figure 2, on most trials shock was actually terminated only after lever contact had been re-established. Shock terminated at the moment that the rapidly increasing force passed through the criterion value. Thus, had the animal's contact with the lever before shock been at a force value below the criterion, the lurch from the lever, rather than the lever contact that followed it, would have resulted in shock termination. There was no

Fig. 2. Composite illustration of major features of response-force records obtained during initial portion of 30-sec intertrial interval. Subject was in contact with lever exerting approximately 48 g force at the moment of shock onset (Point A). As subject lurched from the lever (Point B) a peak force reading was momentarily reached, followed immediately by a return to 0 g (Point C). When lever contact was re-established, shock offset occurred at the moment the force of lever contact passed through the criterion response value, in this case 45 g (Point D). The force of lever contact usually remained erratic for a brief period thereafter, during which time discrete "responses" were recorded whenever the response force passed through the criterion value. (Point E).

indication, however, that such experience with rapid shock termination, when it did occur, had any effect in modifying the characteristics of subsequent intertrial contacts with the lever.

Properties of intertrial lever contact. Total session time in contact with the lever averaged 95%, 82%, and 92% for Rats 1, 2, and 3, respectively. These data, which included all lever contact regardless of force, were higher than values recorded in the experiment under dichotomous measurement. Moreover, the disparity between these measures was larger when higher criterion response-force values were used. For example, Rat 2's lever contact, which averaged 82% of session time when recorded irrespective of response force, appeared at 76% under discrete measurement with a 15-g cri-

terion, but fell to 43% during exposure to a 30-g response criterion.

The force of lever contact showed a relatively high degree of stability: moment-to-moment fluctuations in force did not generally exceed 5 g, and in some cases were less than 2 g over periods in excess of 25 sec. In addition to its stability, no pattern, either of increasing or decreasing force, described the majority of intertrial lever contacts. Although there were isolated occasions when stable response force did increase or decrease monotonically within the intertrial interval, these cases were in a minority and during no session exceeded 20% of the trials. Moreover, probability of such patterns of response force was not affected by differences in criterion response-force value, subject, or number of experimental sessions.

Discrete versus continuous measurement of lever contact. Discrete response measurement resulted in recordings of intertrial responding that were not consistent with recordings under continuous measurement. For instance, the brief period of erratic response force that occurred following shock termination often resulted in an inflated response count when dichotomous measurement was imposed. That is, when force fluctuations occurred near the criterion response-force value, each momentary drop in force below the criterion disengaged the mechanism so that the subsequent increase operated the counters. As many records indicated (see Figure 3) such recordings of "discrete" responding actually occurred at a time when the animal had not broken contact with the lever. There were many additional instances in which fluctuations in response force, far less pronounced than those in Figure 3, resulted in lever-press counts. Such deflections, in fact, often corresponded to metabolic ac-

tivity such as heart rate or respiration of an animal that was otherwise motionless while in contact with the lever (see Figure 4). Such metabolic activity operated counters simply because the force of lever contact happened to be centered at a value close to the criterion. On occasion, more than 1000 such "responses" were counted in a single session. The frequency of these recordings increased whenever the criterion response force approximated the average force of the subject's intertrial lever contact. For example, Rat 3, exposed to two response-force criteria (30 and 45 g) that overlapped the force range of its intertrial lever contact, averaged 510 and 506 responses per session respectively at these two values. Rat 2, also exposed to a 30-g force requirement, averaged 815 responses; however, this measure was reduced to 123 when the force criterion was lowered to 15 g. Similarly, Rat 1, exposed only to a 15-g criterion, averaged 71 intertrial responses per session.

Fig. 3. Physiograph recordings of lever contact indicating instances (e.g., at arrows) when momentary fluctuations in force around the 45-g criterion were recorded as discrete responses, despite the fact that the subject had not broken contact with the lever. Peak-force readings produced by lurches from the lever indicate the approximate start of each trial. The intertrial interval was 30-sec. Each heavy ruling along the vertical axis represents a 15-g increment in force.

Fig. 4. Response-force records of two subjects indicating the basis for intertrial response counts. Metabolic activity, such as respiration of the subject while "frozen" on lever, appears as the slight scallop shown on records. When this activity, however slight, was centered at the criterion value for response force (45 g in upper record, 30 g in lower record), discrete responses were counted throughout the intertrial interval despite the subject's sustained contact with the lever.

The occurrence of postshock response bursts also contributed to the number of "discrete" responses recorded. This behavior, which was consistently caused by attack directed at the lever following shock, also resulted in brief spikes of activity (see Figure 5) of sufficient magnitude to activate counting and recording mechanisms. The force of these contacts, however, did not exceed that of the lurch from the lever, and typically ranged between 50 and 75 g, with an average response force of 60 g (0.588N). The duration of such bouts of activity ranged between 0.5 and 4 sec, and averaged 1.8 sec. In contrast to response-force fluctuations that were recorded for all subjects, postshock response bursts were observed only for Rat 3. Examination of this subject's records reveals that postshock response bursts emerged gradually over sessions and eventually occurred on 70% of the trials by Session 24. Their frequency remained fairly constant over

the following 20 sessions and then began to decrease, reaching an average of approximately 15% of the trials by the final session. During these latter sessions, postshock response bursts were typically replaced by an absence of contact with the lever, during which time postshock "attack" may have been directed at another target.

DISCUSSION

In light of the present results, it is now reasonable to question the distinction between "lever holding" and "discrete responses" in escape behavior. Such terms, which imply both temporal and topographical differences, as well as possible differences in the motivation of the subject, appear to be unwarranted. The present analysis indicates that what occurs on the majority of trials is simply that the subject exhibits sustained contact with the lever.

Fig. 5. Pattern of response force produced by postshock response bursts (at arrows). In addition to response counts produced by such behavior, the lower record illustrates force pattern produced by respiration, which became more rapid as the 30-sec intertrial interval progressed. Twenty-two "responses" at a 45-g criterion were counted following postshock response burst on the lower record, despite subject's sustained contact with the lever.

Dichotomous measurement may alter this contact to provide a "discrete" lever-press count, but such measurement may misrepresent or fail to describe an important dimension of the data. For example, the recorded response that follows the lurch from the lever and terminates shock, or the sequence of "extras" that appear when lever contact fluctuates near force threshold, are both alternately understood in terms of sustained lever contact.

The present analysis also indicates that the recording of much on-lever behavior is lost simply because it occurs below the arbitrarily chosen force threshold. Although the loss of such data might not always prove critical, it may underlie a questionable interpretation. For example, Winograd (1965) reported that the frequency of lever holding was reduced to 2% by raising the criterion response force to 60 g. Had continuous measurement been employed in that situation, it is conceivable that the record of on-lever behavior would have remained basically unchanged even when the criterion response force was altered. Such an analysis is consistent with data from the present experiment that appear to replicate Winograd's finding, if one considers only threshold-bound discrete measurement, rather than the continuous record of lever contact.

Given the present view of on-lever behavior during escape, it is now possible to reflect upon several theoretical accounts of escape behavior. For instance, the concept of "preparation" has been employed to account for the persistent lever holding between shock onsets (*e.g.*, Dinsmoor, Matsuoka, and Winograd, 1958). Perhaps the clearest evidence for the preparatory argument was proposed by Campbell (1962), who demonstrated that trials in which the subject was on-lever at the moment of shock onset resulted in shorter escape latencies than those in which the subject was not in contact with the lever. Another view of escape behavior advanced by Bolles (1970; 1971) and Bolles and McGillis (1968) suggests that escape behavior may not be under operant control, but may rather depend largely upon innate and reflexive components. This argument assumes that rats learn to freeze, a species-specific defense reaction (SSDR), while on the lever because any other location prolongs shock. The subject is then thrown briefly from the lever by the next shock onset, and it is this movement that results in the lever-press response that terminates shock. Bolles and McGillis (1968) reported extremely low escape latencies (*e.g.*, 0.05 sec) which they argued could not be operant in nature.

The present data elaborate Campbell's (1962) findings because it appears that the "topographical advantage", as Campbell described it, is actually based upon subjects lurching from the lever in response to shock. In addition, the present study's consistent documentation of what Bolles and McGillis have termed the "reflexive lurch" supports the SSDR analysis of escape behavior.

A potentially more effective form of "preparation" is available to the subject, although the present data show no sign of its use. As previously noted, escape efficiency could be increased if on-lever behavior were of slightly less force than criterion, rather than in excess of it. Such intertrial behavior would then, of necessity, result in shock termination by the reflexive lurch itself, rather than by the lever contact that follows it by approximately 0.2 sec. The difference between these two types of intertrial behavior may be conceptualized in terms of *release-press* and *immediate-press*, which are similar to techniques previously examined during escape conditioning (see survey by Dinsmoor, 1968). What occurs when the subject holds the lever at a force in excess of the criterion is that it must release the lever (or lower the force to below criterion) before the next lever press can be recorded. Thus, despite the option of more rapid escape, subjects consistently exert above-criterion force on the lever and thereby impose a release-press condition.

Some aspects of the present data are incompatible with the "preparatory" analyses of lever holding. It is reasonable, for instance, that subjects "preparing" to execute a low-latency escape response might show a gradual change in the force of lever contact as the intertrial interval progressed. For instance, there might be a continuous decrease in force so that contact with the lever at shock onset was minimal and therefore conducive to a milder reflexive lurch and more rapid escape latency. Nevertheless, trials on which force systematically increased or decreased never occupied a substantial portion of the session, and did not change in probability either within or between sessions.

Aspects of the present experimental situa-

tion; e.g., sex, age, and strain of the subject, temporal properties of the intertrial interval, may be critical to the outcomes reported. For instance, a survey of more than 20 published experiments dealing with escape from shock revealed not a single instance in which albino rats were not used as subjects. That this is more than coincidence is borne out by the informal, yet common, knowledge among investigators that hooded rats are not good subjects for escape, since they do not freeze as much or hold as reliably. It is possible that the continuous recording of lever contact will enable investigators to translate this and related "folklore" into experimental data that relate to identifiable causal factors.

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