TOWARDS AN EMPIRICAL CALCULUS OF REINFORCEMENT VALUE

THOM VERHAVE¹

AMES RESEARCH CENTER²

Only one of two keys reinforces the subject with food. This key can assume one of two colors, each associated with a different fixed-ratio schedule for obtaining reinforcement. The function of the second key is to permit the animal to switch from the long schedule to the short schedule. If the difference between the ratio schedules is large enough, a preference for the shorter schedule is demonstrable. A quantitative index of preference is obtained as follows: each time the animal switches to the shorter schedule, the number of pecks required to produce the next switch is increased. As the "ante" on the switching key increases, the effective difference between the two ratio schedules decreases. After each food reinforcement, when the bird is exposed to the choice-situation, it takes longer before the bird switches again. This is used to "titrate" the bird's preference. If it does not switch within x sec, the progressively increasing ratio schedule of the switching key is decreased. A specific value, in terms of a rather specific number of responses the bird settles at on the choice key, is obtained. This equilibrium is employed as a dependent variable. Several variables of which it is a function are explored.

In most of the animal research in which the experimenter observes only one operant, the choice between responding or not responding presents no conflict. If food is used as a reinforcer, a conflict situation can be produced by systematically making the food less palatable. This can be done, for example, by adding more and more of a bitter substance with each successive reinforcement. Eventually a rejection point is reached and the subject (S) stops working (Miller, 1957).

In a more complex situation, the S is not given a choice between obtaining a reinforcer or no reinforcement, but between two alternative routes to a reinforcer and no reinforcement. Brady and Thach (1960) trained rhesus monkeys to work on a multiple schedule. Each of the two components consisted of a two-link chained schedule. In one of these schedules the S s were trained to work in the presence of a distinct visual cue (stimulus 1) to produce another cue (stimulus 2). In the presence of stimulus 2 food could be obtained on a fixed-ratio schedule. The second chained schedule was programmed in an alternating fashion with the

above one. Here the monkeys were again required in the presence of a distinct cue (stimulus 3) to produce another stimulus (no. 4). During stimulus 4 a DRL schedule was in effect. The important aspect of this experiment was that the same schedule (FI 4.5) was in effect during both stimuli 1 and 3.

A preference for some of the fixed ratio (FR) schedules employed was inferred in terms of higher response rates during the fixed interval component (stimulus 1) preceding the FR schedule component (stimulus 2). Although the authors (Brady and Thach, 1960) do not explicitly suggest this, it seems clear that the ratio of the FI rates during the initial links of the two-chained schedules (stimuli 1 and 3) might be taken as a likely candidate for a quantitative "index of preference" for one conditioned reinforcer (stimulus 2) over another (stimulus 4).

A different approach towards the development of a quantitative index of preference is suggested by the work of Herrnstein and Morse (1955), Findley (1958), Sidman (1960), and Verhave (1959a, 1959b, 1962a and b). Herrnstein and Morse demonstrated that under certain conditions pigeons will peck one key to change the schedule of reinforcement in effect on another key.

Findley demonstrated that pigeons will work on the second key, which he referred to as the "switching key", to produce the more

¹Reprints may be obtained from the author, Ames Research Center, National Aeronautics and Space Administration, Moffett Field, California.

²The work reported here was performed at the Lilly Research Laboratories, Indianapolis, Indiana.

favorable (lower mean interval) of two VI schedules programmed on the main key.

Verhave (1959a, 1959b, 1962b) and Sidman (1960, 1962) demonstrated that responding could be maintained on a switching key which produced a stimulus correlated with a longer time out from an avoidance schedule than the brief time out (RS interval) produced by the other or main key.

In all of the studies cited the *S* is presented with two (actually three) alternatives. In the Herrnstein-Morse and Findley experiments the *S* was given a choice between different reinforcement schedules. In the Sidman and Verhave experiments the alternative conditions were different durations of safe periods from electric shock.

It is clear that if an animal can be made to produce one of two alternative conditions (schedules, reinforcers, etc.) via a switching or choice key, a preference is demonstrated for the condition produced by the choice key.

The experiments mentioned above allowed the experimenter to establish if a preference between two conditions exists. The next step is to ask to what degree does an organism prefer one condition over another?

The research to be described was started with rats and avoidance schedules (Verhave, 1959b). Once this work had progressed successfully, it was judged desirable to follow the work up with pigeons and the use of non-aversive schedules for two reasons: (1) to check on the generality of the findings with rats, and (2) because the amount of time required to obtain the desired information was correctly judged to be considerably less with pigeons using positive reinforcement. The research conducted with pigeons will be described first.

METHOD

The subjects for the first experiments to be described were white Carneaux pigeons. The general experimental conditions were as follows: a bird was given access to two plastic keys mounted 5 in. apart in the wall of the experimental chamber. During experimental sessions, which occurred daily except on weekends, a bird was permitted to obtain a total of 60 to 75 reinforcements of a commercially available seed mix presented by a mechanically-operated hopper. Access time to the food

per reinforcement was 4 sec unless stated otherwise. All birds were maintained at 80% of their *ad lib* feeding weight. After the last reinforcement was obtained, all key lights were extinguished and a house light was turned on.

In addition to the above, the following conditions were in effect; only the left key produced food reinforcement. It was therefore designated the main key. It could, during a session, assume one of two colors—red or green. When the red color was present, an *S* could produce reinforcement by pecking 100 times on the red-colored key. If, however, the main key was green, a reinforcement could be produced by 10 pecks. Normally the main key was red and FR 100 was in effect. Whenever a reinforcement was obtained in red or green (the green light and FR 10 could be produced by *S* in a manner to be described immediately below), the red FR 100 condition was reimposed and will therefore be designated as the “imposed condition”, in opposition to the other “alternative condition”. The right key served as a “choice” or switching key; it never produced food reinforcement directly but merely produced a switch from the imposed condition in effect on the main key. With respect to both choice and main keys the following discriminative cues were employed: when the main key was red, the choice key was lighted with a white translucent light. In this condition, pecking the choice key produced a switch to the alternative condition (green) on the main key and the light behind the choice key was immediately extinguished (S^{Δ}). This stopped any pecking on the choice key that might occur during the time the alternative FR schedule was in effect. The darkening of the choice key served as an additional cue to indicate the change of color on the main key. For a summary of conditions see Table 1.

When the choice key was functional the schedule in effect was a variation of an adjusting ratio schedule first described by Ferster and Skinner (1957). With each successive switch in main key conditions produced by the bird, the value of the FR schedule on the choice key was increased according to a simple arithmetic series. Thus with each success obtained on the choice key, the ante for the next switch was automatically increased. In this respect the schedule is similar to the “progres-

Table 1
Summary of Stimulus and Schedule Conditions of the Experiments with Pigeons

<i>Left Key: Main Key</i> <i>Color</i>	<i>Schedule</i>	<i>Right Key: Choice Key</i> <i>Color</i>	<i>Schedule</i>
Dark	Pre- and post-session time out	Dark	Pre- and post-session time out
Red	Imposed or Prevalent FR Schedule	White	Adjusting FR Schedule
Green	Alternative FR Schedule	Dark	Time out (S ^a)

sive" schedules described by Findley (1958, 1962) and Hodos (1961).

Specifically, the adjusting ratio schedule was of the following kind. The first choice-key reinforcement was obtained on FR 2. With each subsequent reinforcement obtained on the choice key, the ratio required on the choice key to produce the next change in the FR schedules on the main key was increased by two. If a given ratio on the choice key was not completed within 30 sec after the last return to the imposed condition (main key red, FR 100) the ratio schedule on the choice key was reduced. For each additional 30 sec that the choice-key ratio was not completed it was again reduced by the same amount. In other words, if the choice-key ratio after the n^{th} reinforcement (a switch in main-key cues) was 90, the schedule on the choice key would be driven back to FR 2 if the bird did not produce a change within 45 times 30 sec. This arbitrary time criterion parameter is called the allotted time criterion (ATC).

Under these conditions it would be possible for the bird to emit only a certain part of the total of a momentarily required choice-key ratio and then stop and pause (or work on the red main key). From that moment on, the choice-key ratio would be reduced by two points for every successive 30 sec during which no further responses occurred on the choice key. The value of the schedule might therefore be driven below the number of responses the bird had already emitted up to the moment that pausing started. If this occurred, a provision was added in the control circuit so that from that moment on only one more response on the choice key was required to produce a change in the schedules of the main key. After reinstatement of the choice conditions, the number of responses necessary

to obtain the next change in main key conditions was determined by the length of pausing during the previous run.

The relatively complex performance required of the birds in these experiments was developed in the following stages:

- 1) Feeder training (one brief session).
- 2) Key pecking, continuously reinforced on main key only. During this phase the key color changed from red to green with each successive reinforcement (one session).
- 3) A fixed ratio of five on one day and 10 on the next day was programmed in red. In green, the schedule was maintained on CRF (two sessions).
- 4) The switching key was introduced. During this phase the white light behind the choice key was turned on after every other reinforcement on FR 10 in red on the main key. At the same time the color on the main key remained extinguished. To procure food reinforcement at this time, the bird was thus required to emit one peck on the choice key. This produced the green light on the main key. In this way a simple two-link chain was established involving the choice and the main key (two sessions).
- 5) After this chain was well established, the red light was reintroduced and the white light in the choice key was turned on after each reinforcement whether in red or green. Thus, a choice situation was in effect from this point on (one session).
- 6) During the next stage, the FR schedule of the imposed condition (main key, red) was increased during the next sessions by steps of 10 or 15 until it reached a value of 100. Then the schedule of the alternative condition was raised to FR 10 (eight to 10 sessions).
- 7) After a bird had run under these final conditions for at least six sessions, the adjust-

ing fixed ratio schedule, described previously, was introduced.

Before discussing some of the data, it may be useful to summarize the adjusting procedure and point out the type of results expected.

By gradually increasing the ante on the choice key with each successively obtained switch in main-key conditions, I expected, on the basis of previous data (Verhave, 1959b), that straining on the choice key would develop as the choice-key ratio increased. If, however, the procrastination became such that a bird did not produce the next switch within the arbitrary time limit imposed by the adjusting schedule, the adjusting ratio was automatically decreased. I therefore expected that the adjusting schedule would increase up to a certain point and then settle or reach an equilibrium around a certain value. The manner in which the adjusting ratio schedule increases to the equilibrium point and especially the equilibrium value itself are therefore the major dependent variables of these experiments.

Procedural Refinements. Before proceeding very long with the employment of this equilibrium value as a dependent variable in further experiments it was found necessary to introduce several procedural refinements.

1) Under the conditions described so far it is possible for the bird to meet the FR requirement on the red main key up to the point where only one more peck would be necessary to produce reinforcement. At that point it might switch to the white choice key. If the bird would peck this key only once and then immediately switch back to the main key, it would immediately produce reinforcement. There exists, therefore, the possibility of a spurious source of reinforcement for responding on the switching key which could produce unwanted superstitious behavior (Skinner, 1948; Sidman, 1962). For this reason an "anti-superstition contingency" was added; if the FR requirement on the main key (red) was met up to the point where only one more peck would produce reinforcement, a response on the choice key would eliminate the possibility for reinforcement on the main key for 20 sec. Each further choice-key response reset the 20-sec anti-superstition clock.

The same possibility exists with respect to the reinforcer for responding on the white

choice key. Here also a superstitious chain could develop; the bird might come to make a few responses on the red key before responding on the choice key. This possibility was eliminated in identical fashion. A similar use of anti-superstition contingencies has been reported and studied by Sidman (1962).

2) A second change in the procedure consisted in the introduction of "forced trials". After every 10th food reinforcement, obtained by going through the alternative condition, only the red light on the main key came on. The choice key remained unilluminated. In this way the bird was periodically forced to go through the imposed condition.

3) The reason for the third change in the procedure is illustrated by the records of Fig. 1. During the first two sessions and again during session 5 there were large sudden decreases in the length of the adjusting schedules. Inspection of the cumulative records of the responding on the choice key revealed that during these pauses the bird was actually working on the main key (FR 100). The programming circuit, therefore, was arranged so that any food reinforcement obtained on the prevalent schedule (FR 100) would reset the timer that programmed ATC.

RESULTS

Figure 1 shows the records obtained during the first seven sessions of pigeon no. 1366 on the adjusting ratio schedule described.

The specific conditions under which this bird was run were as follows: P-1366 had an *ad lib* weight of 545 g and was maintained at 448 g, slightly less than 82% of the *ad lib* weight. The imposed condition was FR 100 (left key red), the alternative condition (left key green) was FR 10. The period of access to grain per food reinforcement was 4 sec. The allotted time criterion of the adjusting schedule was set at 30 sec (ATC = 30 sec).

The records shown in Fig. 1 were obtained as follows: the length or value of the adjusting schedule was programmed by a bi-directional stepping switch, and the up and down (actually rotary) movements of this switch were monitored by a recording potentiometer (Varian Model G-10) in combination with a voltage-dividing circuit or by a specially constructed recorder. The shaft of a bi-directional stepper was extended to permit the mounting

Fig. 1. The course of the adjusting ratio schedule on the choice key during seven successive sessions plotted against successive switches produced in the main-key schedules. The unit movement per step is arbitrary for both abscissa and ordinate. The arbitrary unit distance the pen of the recorder moved to the right with each reinforcement was increased after the first session for purposes of clarity.

of a pulley. The stepper is mounted on top of a paper drive (similar to the paper drive of the Varian Model G-10 recorder) laying flat. A pen is driven up and down the paper by a wire running over the pulley on the shaft of the stepper. With each successive reinforcement on the choice key (*i.e.*, a switch in conditions on the main key) the pen moved vertically an arbitrary unit distance and also an arbitrary unit distance horizontally to the right. Each time that a bird did not meet the allotted time criterion of the adjusting schedule, the pen was moved one step downward. Thus the ordinates of the graphs are labeled "length of FR schedule" and give at any point the value of the adjusting schedule. The abscissa records the successive switches or reinforcements obtained on the choice key. Because the adjusting ratio schedule was changed up or down in steps of two, there are five steps between successive decade values on the ordinates.

The equilibrium value was reached during the first session (December 1) on the adjusting schedule and had the same value (about 65) during the six succeeding sessions.

The stable equilibrium value obtained empirically from the behavior of an organism under certain specific experimental conditions is designated as EV (Equilibrium Value). In general terms EV might be defined as the number of responses an organism emits to produce a condition, alternative to another, imposed condition for a particular ATC value. In a half-serious vein it could be suggested that EV be considered an index of seducibility.

If ATC is so small that it is exceeded by the time necessary to emit one peck on the choice key, EV will stay at one (CRF). ATC can be increased however, to a point where further increases have no effect on EV. For the specific conditions of these experiments, the number of pecks a bird will emit (for a change in main-key conditions as reinforce-

ment) reaches a maximum (P) which itself is some function of the difference between the values of the imposed and alternate FR schedules. If ATC is made so long that the FR value required to produce such procrastination is larger than this maximum (P), any increase in ATC will not further influence EV. EV, if it still can be determined, will have approached P. EV then is a complex S-shaped function of ATC.

Figures 2 and 3 consist of records obtained with bird P-1366 under experimental conditions that included the procedural refinements described above. The specific values of the various schedules, *etc.*, were as follows: the prevalent schedule on the main key was FR 300, the alternative schedule was FR 60. The bird was forced through FR 300 after each 10th successive reinforcement obtained through FR 60. ATC was set at 40 sec. Feeder-time duration was set at 6 sec. The adjusting fixed-ratio schedule was increased according to a simple arithmetic series by steps of six. After the first switch in the main key schedules was obtained on CRF, the next change in main-key conditions was programmed on FR 6, FR 12, *etc.* (unless ATC was exceeded). Cumulative records of the responding on the two keys is presented in Fig. 2. Figure 3 shows the EV record obtained during the same session. The actual values of the adjusting schedule programmed for each choice-key reinforcement can be obtained by multiplying each value on the graph by three. In Fig. 2,

Fig. 2. Cumulative records obtained with one pigeon during a single session. The depression in the baseline below the FR 300 record indicates forced FR 300 runs.

Fig. 3. The course of the adjusting schedule obtained during the same session that the cumulative records of Fig. 2 were obtained.

the baseline under the record obtained from the main key under FR 300 shows the occurrence of the enforced FR 300 periods by a depression. At any other time (baseline pen up), the bird was presented with both the red light on the main key and the white light on the choice key.

The following points can be made on the basis of Fig. 2:

- 1) The post-reinforcement pauses on FR 60 are shorter than those for both other schedules.
- 2) At no time did the bird "voluntarily" go through FR 300. Figure 3 shows that EV oscillated between 22 and 26. If EV is tentatively assumed to be 24, then the actual average value of EV on June 5 was 3 times 24, or 72. Figure 3 also shows that EV stabilized at the beginning of a session if the adjusting schedule was started at some value very close to the EV value of previous sessions under otherwise identical conditions.

Further proof that the stability and reproducibility of EV from session to session is relatively independent of the initial value of the adjusting schedule at the beginning of a session is presented in Fig. 4.

Between May 22 and May 31, conditions for bird P-1366 were identical to those described for June 5 (Fig. 2 and 3). The only exception was that the adjusting schedule was started at different values (in Fig. 4 the actual values of the schedule are shown on the ordinate). It is clear from these data that there is no complete independence. There is a clear-cut readjustment towards stabilization at $EV = 88$, from May 22 through May 25. During these sessions the schedule was started at

Fig. 4. A series of successive adjusting ratio records obtained when the adjusting schedule was started at different values at the beginning of a session.

too high a value. A similar period of readjustment is evident from May 27 through May 31 when the schedule was started too low. The final EV levels on May 25 and 31, however, are almost the same.

The Nature of the EV, ATC Relationship. The specific value of EV obtained under a particular set of conditions depends on the specific value of the arbitrary allotted time criterion (ATC). EV is, within certain limits of ATC, an increasing function of ATC. An increase in ATC increases EV because the amount of straining produced by a ratio schedule depends on the length of the ratio schedule employed. Therefore, if ATC is increased, the adjusting schedule increases up to the point where it again produces enough procrastination to equal and exceed the new ATC value. It remains to present some data obtained with a particular bird. Bird P-5557 was run under the following conditions: red = FR 200, green = FR 60, feeder duration: 4 sec. The adjusting schedule was always started at FR 2 at the beginning of each session and the schedule increased four points with each reinforcement (switch in main-key conditions). All other conditions were identical to those described for P-1366 for Fig. 2, 3, and 4.

ATC was varied in the following order: 40, 60, 20, 90, 10, and 40 sec.

The bird was run at each particular value until during three successive sessions, no change in EV occurred ± 2 recorder units (each recorder unit represented four points in terms of the actual adjusting FR schedule). The data obtained are shown in Fig. 5. Notice

that EV reaches a maximum of 100 for ATC at 90 sec.

The Effect of Satiation on EV. Since the post-reinforcement pause produced by a FR schedule is influenced by satiation (Sidman and Stebbins, 1954) it might be expected that EV, which also depends on a post-reinforcement pause, would, under the present circumstances, also be affected by satiation. Although I have not made any systematic observations on this matter, some evidence indicates that it is not. Figures 6, 7, and 8 show data obtained with bird P-5557 on September 16, 1961. ATC was 40 sec, red FR = 200, green FR = 60. All other conditions were similar to those used to determine the function of Fig. 5.

Unfortunately, during the previous session the programming circuit had not functioned properly so that the EV data on September 16 are initially out of line with those shown in Fig. 5. This is, however, irrelevant to the main point. On September 16 the bird was run to satiation through September 17. Figure 6 shows the differential effect of satiation on two ratio schedules of different length. Periods of no-responding were eliminated from the record of the FR 200 behavior at the arrows in the figure. The durations of these periods are indicated. Figure 7 shows the cumulative record of the choice-key responding and Fig. 8 the corresponding EV record. During the middle of the session the adjusting schedule only briefly reached a value (between 50 and 60) in line with the usual EV for ATC at 40 sec. The following feature is of more interest.

In Fig. 8 the adjusting schedule drops abruptly at A and B. The corresponding points are indicated in Fig. 7. Figure 7 re-

Fig. 5. EV, the equilibrium value of the adjusting ratio schedule on the choice key, as a function of ATC, the straining criterion.

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MAIN KEY - GREEN - FR 60

Fig. 6. Cumulative records obtained on the main key during a continuous two-day session.

veals that these decreases are due to what they should be due to—long periods of no responding on the choice key. Following the first abrupt decrease, however, and also following subsequent abrupt decreases in the adjusting FR schedule, the adjusting schedule increases again up to the value maintained before the first sudden decrease (at A). During the same general period there are long (over 1 hr) pauses on the main key during the forced red periods. It appears that as long as the bird is active on both keys, EV is relatively stable. There is no evidence of a slow general decrease in EV as the number of reinforcements obtained in the session increases.

A plausible explanation of this can be given. If it is accepted that EV is a matter of relative preference for, in this case, one

FR schedule over another, then EV should be a function of the difference between the schedules (as indeed it is) but not of the bird's general level of deprivation. As long as food functions as a positive reinforcer, the preference for one way or the other to get to the food should remain the same. If the bird works at all, it will prefer to work on the lower main-key schedule.

I will present sufficient data to show that EV can be obtained with rats in a situation which in many aspects differs radically from those previously described for the pigeon experiments (Verhave, 1959b).

Rats were first trained to press a modified Switchcraft lever (Verhave, 1958) to avoid electric shock (Sidman, 1953); SS was 3 sec and RS was 30 sec. The shock was provided

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CHOICE KEY - FR ADJUSTING

Fig. 7. Cumulative record obtained on the choice key during a continuous two-day session.

by a constant current generator passing half-wave 60-cycle current at 1.5 ma and 400 v. After avoidance responding was well established, a second lever was made available to the animal. Each press on this lever produced a 10-min time-out (TO) from the avoidance schedule. The TO was indicated by a 433-cps tone. All animals simultaneously (1) came to produce the TO, and (2) learned to discriminate between tone and no-tone conditions as

indicated by the absence of responding on either lever during TO (Verhave, 1962b). No separate phase of discrimination training between TO and avoidance periods was given before the introduction of the TO lever. A detailed description of the acquisition of the TO producing behavior, *etc.*, is published elsewhere in detail (Verhave, 1962b).

In terms of the terminology introduced to describe the pigeon preference experiments,

Fig. 8. Record of the course of the adjusting schedule during a continuous two-day session.

the TO lever is the switching or choice key. The imposed condition is the regular free-operant avoidance schedule (during which, if it is not in TO, the animal has to press the avoidance lever—the main key—to postpone shock). The alternative condition is the 10-min TO period.

The next step in the experiment was to put the responding on the TO lever (the switching key) on the same kind of adjusting ratio schedule described previously for the pigeon experiments.

Specifically, after each TO, the fixed ratio required to produce the next TO was increased one step at a time. However, if 5 min had passed since the termination of the previous TO and the rat had not yet produced a new TO, the ratio requirement of the TO lever was reduced again, one step at a time for each successive 5 min during which no new TO was produced; ATC was 5 min. Other features were similar to those described for the pigeons. The procedural refinements described there were not used, however, with the rats. As in the case of the birds, the main datum recorded was the length of the adjusting ratio schedule maintained by the animal throughout a session. The rats were run every other day. Figure 9 shows the first series of EV records obtained with the first rat for which the TO behavior was put on an adjusting ratio schedule, under the conditions described above. The top two panels show that from April 27 through May 12, 1959, the adjusting schedule stabilized around 34 (EV = 34).

Notice that from May 10 on, the adjusting FR schedule was no longer started at CRF.

Fig. 9. Course of an adjusting ratio schedule (for a time-out from avoidance as reinforcement) maintained on the time-out or choice lever during successive sessions of about 10 hr each. The first record shown (obtained on April 21) was the first session on the adjusting schedule for rat 12.

The data show, that with rats on avoidance schedules, a stable EV can be obtained.

In subsequent experiments with rats, EV was used as the dependent variable in a study to determine the changes in EV due to variations in the duration of the TO as a measure of the strength of the TO-producing behavior (Verhave, 1962a).

DISCUSSION

The empirical definition of a positive reinforcer defines it as any event which, when its presentation is made contingent upon a bit of behavior, increases the probability of recurrence of that behavior. The quantitative implications of this definition have been poorly developed. The notion of "amount of reinforcement" is an explicit recognition that the effect of a reinforcement on a certain bit of behavior is a graded one. It is well substantiated that some reinforcers are more effective than others. However, quantitative experimental techniques to compare the relative effectiveness of reinforcers have barely been developed.

The previous experiments outline a basic paradigm for determining the relative strength of reinforcers. It is possible to use the experimental situation as a psychological Wheatstone bridge to determine the value of unknown reinforcers relative to any set of arbitrary standard conditions, as is done in calorimetry.

I have shown above that if the imposed and alternative conditions on the main key consist of two different ratio schedules, a definite stable value (EV) of an adjusting schedule can be found on the choice key for a particular value of ATC. Some other imposed condition can, however, be substituted for the one originally used. One can then empirically determine the specific value at which the new imposed condition produces the same EV as the previous one under otherwise identical circumstances (except for the increased age and additional experimental history of the organism).

Specifically, if (as in the case of bird P-5557) FR 200 versus FR 60 on the main key produces an EV of 100 for ATC at 90 sec, I can determine at what specific value of an FI schedule EV will also be 100.

Similarly, in another experiment, FR 600 could be substituted for FR 200 and EV redetermined. If this time EV would change to 200 would it be permissible to conclude that compared to FR 60, FR 600 is twice as "bad" as FR 200? Whether such a conclusion can be justified depends on whether certain other conditions are met. It has to be demonstrated that changes in certain arbitrary parameters inherent in the general procedure do not force a change in conclusions.

Let me clarify: for any set of imposed and alternative conditions, the particular EV value obtained depends on ATC. In general terms, the question can be put as follows. Assume that for imposed condition IC_1 and alternative condition AC_1 , EV_1 is P when ATC is X, and for another imposed condition IC_2 and another alternative condition AC_2 , EV_2 is N when ATC is X. Does the following relationship hold?

$$\frac{P}{N} = K$$

where K is a constant. Suppose ATC is changed from X to Y, EV_1 and EV_2 are re-determined and the new values obtained are $EV'_1 = L$ and $EV'_2 = M$. Is it true that

$$\frac{P}{N} = \frac{L}{M}?$$

If the above, so far hypothetical relationships obtain, then it would be true that for any two sets of imposed and alternative conditions the ratio of their EVs (which may be defined as an index of preference) is constant and independent of ATC and other arbitrary parameters such as the distance between the keys, feeder duration, etc. It should be kept in mind that EV is determinable only within a limited range of ATC values.

If the ratio of two EVs is indeed independent of ATC and other such arbitrary parameters, then a ratio scale of measurement can be constructed. If no such independence exists, at least an interval scale can be arrived at (Stevens, 1951).

Theoretical Implications of EV as a Dependent Variable.

1) In addition to the use of EV as a way to define a quantitative index of preference, it is clear that EV can be used to generate indifference functions and what P.T. Young has called "isohedonic" contours (1960).

2) Since, as is clear from the data obtained so far, each animal produces his own unique EV value for any specific set of conditions, the constants of the EV, ATC function, and especially the constants of the equations which describe empirically obtained isohedonic contours might well be interesting quantitative indexes of individual differences between organisms.

There are three other interesting uses of EV and the experimental procedure that produces this measure.

3) The technique allows the study of the minimum differences between schedules of reinforcement and other reinforcement parameters (duration, amount, etc.) that produce a difference in behavior as measured by EV. This will permit the development of a psychophysics of schedules and other reinforcement parameters.

4) It appears that EV may also be employed as a unique quantitative measure of short-term memory. The rationale for this statement is based on the following considerations. The fact that EV is a stable equilibrium value implies that the organism changes its behavior (specifically post-reinforcement pause, etc.) repeatedly with each additional new exposure to the continuously changing values of the adjusting schedule of the choice key.

The length of the adjusting schedule at any point determines the degree of procrastination that occurs during the next exposure to the choice-key adjusting schedule. The degree of this control can be assessed by programming black-out periods of increasing duration before the bird is again presented with the choice situation. Although I have not done any systematic research on this issue, I do have evidence that the stability of EV breaks down when such imposed black-out periods reach a certain duration.

5) The equilibrium value EV presents a new dimension as a dependent variable. Although it is obtained in what is basically an operant conditioning type situation, in which rate of responding is traditionally the basic dependent variable, it bears no direct relationship to rate of responding. It is a new datum or measure in its own right.

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