Quantitative Two-Process Analysis of Avoidance Conditioning in Goldfish

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The shuttlebox performance of goldfish was studied under standardized conditions in a variety of problems—with or without an avoidance contingency, a conditioned stimulus (CS)-termination contingency, and an escape contingency. The effects of CS-only, unconditioned stimulus (US)-only, and explicitly unpaired training were also examined. All the data could be simulated quantitatively with a version of O. H. Mowrer's (1947) 2-process theory expressed in 2 learning equations (1 classical, the other instrumental) and a performance equation. The good fit suggests that the theory is worth developing further with new experiments designed to challenge it.

Familiar objections to Mowrer's (1947) early two-process theory of avoidance conditioning were recently reviewed by Levis (1989), in whose opinion they reflect misunderstandings of the theory that are attributable at least in part to the loose language in which the theory has been expressed. Our purpose in this work is to explore the possibilities of a mathematical formulation of the theory designed to yield entirely unambiguous predictions of experimental outcomes. Efforts at quantitative simulation of real avoidance data on the basis of theories resembling Mowrer's have been made in the past (Atkinson, Bower, & Crothers, 1965; Bush & Mosteller, 1955; Hoffman, 1965; Theios, 1963) but were not carried very far.

What is required first in such a project is a large and readily expandable database, and for that reason we turned to shuttlebox experiments with fishes. Fishes are inexpensive to acquire and to maintain properly, and the shuttlebox technique developed for them (Horner, Longo, & Bitterman, 1961) is efficient, easily standardized, and well-suited to a variety of species (Klinman & Bitterman, 1963; Leschova & Zhuikov, 1989; Wodinsky, Behrend, & Bitterman, 1962). Another important advantage of the technique is that shuttling, at least in goldfish, is produced by purely classical as well as instrumental conditioning (Woodard & Bitterman, 1971, 1973). Although there is much to be gained from the study of avoidance responses different from, and even largely incompatible with, responses that are classically conditioned with the same aversive stimulus (Brogden, Lipman, & Culler, 1938; Hunter, 1935; Kamin, 1956), it may be more instructive at the outset, and certainly much simpler, to use a situation in which classical and instrumental influences are indexed by the same response (Gormezano, 1965; Logan, 1951).

A Quantitative Restatement of Two-Process Avoidance Theory

The first main premise of the theory is that pairing a neutral stimulus with shock (Pavlovian reinforcement) results in the formation of an association between them. In consequence of that association and to an extent proportional to its strength (\(c\)), scaled from 0 to 1, the conditioned stimulus (CS) has two properties: It is aversive (Mowrer's conditioned fear), and it tends to evoke shuttling. Change in \(c\) with reinforcement and nonreinforcement (presentation of the CS without shock) is described by the equation,

\[
\Delta c = \beta_c (\lambda_c - c),
\]

with \(\Delta c\) representing the change in \(c\), \(\beta_c\) the rate of change, and \(\lambda_c\) the asymptotic value of \(c\), which is determined by the functional intensity of shock (\(s\)). When \((\lambda_c - c) > 0\), \(c\) increases, and \(c\) decreases when \((\lambda_c - c) < 0\), with the possibility considered that the rate of increase (the incremental \(\beta_c\) or \(U\beta_c\)) and the rate of decrease (the decremental \(\beta_c\) or \(D\beta_c\)) are different. No inhibitory process is assumed.

The second main premise of the theory is that an association between the CS and the shuttling response develops when shuttling in the presence of the CS is followed by reduction in the discomfort generated by the CS (Hullian reinforcement). In consequence of that association, too, and again in proportion to its strength (\(i\)), scaled from 0 to 1, the CS tends to evoke shuttling. Change in \(i\) with reinforcement and nonreinforcement is described by the equation,

\[
\Delta i = \beta_i (\lambda_i - i),
\]

with \(\Delta i\) representing the change in \(i\), and \(\beta_i\) the rate of change, the incremental and decremental values of which (\(U\beta_i\) and \(D\beta_i\)) may differ from each other as well as from \(U\beta_c\) and \(D\beta_c\). When \((\lambda_i - i) > 0\), \(i\) increases, and it decreases when \((\lambda_i - i) < 0\). Scaled from 0 to 1, \(\lambda_i\) is the asymptotic value of \(i\), which is determined by the magnitude of reinforcement.
Magnitude of reinforcement is defined as the extent to which the aversiveness of the antedating situation is reduced. In avoidance experiments, in some of which the CS is turned off by the response and in others of which it is changed by the addition of a "safety signal" or by feedback from the response alone, \( \lambda_i = (c - g \times c); g \) (scaled from 0 to 1) is a measure of the similarity of the sensory conditions following the response (CS') to those preceding it (CS) and hence the extent to which c generalizes from CS to CS', which itself is never paired with shock (Bower, Starr, & Lazrovitz, 1965). Where g is large, the magnitude of reinforcement is small; where the response terminates the CS, g is taken as 0. It may be well to emphasize that no inhibition of fear is assumed (cf. Mackintosh, 1983), only reduced excitation. In classical conditioning (where shock occurs independently of shuttling), \( \lambda_i = 0 \) whatever the value of g, because CS and CS' are not differentially paired with shock.

In some experiments (e.g., Hunter, 1935), the programmed shock is brief and terminates independently of response, leaving i unchanged. In others (e.g., Warner, 1932), there is an escape contingency; that is, the shock, once turned on, remains on until the animal responds. Where shock is terminated by shuttling, \( \Delta t \) is computed with \( \lambda_i \) taken as the functional intensity of the shock (s). In the first of the present experiments, one group of animals had classical training in the sense that avoidance was impossible, but there was an escape contingency that was expected to permit the development of i.

The third main premise of the theory is that the probability of a shuttling response \( R \) in the presence of the CS is a joint function of three probabilities: one (C) associated with c, a second (I) with i, and a basal shuttling tendency \( U \). No effort is made at the outset to decompose \( U \), which may be in part unconditioned and in part a product of contextual conditioning. It is simply defined as the probability of responding in a period of time equal to the CS-US interval, the time between the onset of the CS and the onset of the unconditioned stimulus (US), which is sampled repeatedly in the intertrial intervals of each experimental session.

The probabilities, C, I, and U, are summed in the conventional manner (Feller, 1950) with the equation

\[
R = C + I + U - C \times I - C \times U - I \times U + C \times I \times U,
\]

which, of course, restricts values of \( R \) to the range of 0 to 1. Mowrer (1947) assumed that fear is required both for instrumental conditioning and for the activation of the instrumental response, or, in our terms, that \( i \) is potentiated by \( c \) (cf. Hoffman, 1965). There is some reason, however, to believe that although the development of \( i \) depends on \( c \), once developed, may contribute to \( R \) independently of \( c \) (Mackintosh, 1983), and the simplicity of the autonomy assumption recommends its consideration. For the reason of simplicity also, no parameters are introduced to shape the contributions of \( c \) and \( i \) to performance; as a first approximation to reality, C is taken as \( c \), and \( I \) as \( i \).

To compute \( R \), it is necessary to evaluate the six parameters \( (U \beta_c, D \beta_c, U \beta_i, D \beta_i, S, \text{and } g) \) that affect the growth and decline of \( c \) and \( i \), and it was to that end that we directed the present experiments. Our strategy was to collect some data on shuttlebox performance in a wide range of problems in the hope that a fitting process would permit reasonable estimates of the parameter values. Those estimates would permit rigorous quantitative predictions from the theory that we could then test in further experiments. We also had to consider the possibility that no reasonably good fit to the data would be found with any set of parameter values, which would show the theory to be deficient in one or more respects and raise the question of how it might be improved.

We should note that new experiments were required because the data in the literature are fragmentary and sometimes inconsistent, probably because they were obtained under different circumstances. To appreciate the importance of a standardized training environment in which quantitative rather than merely ordinal prediction is to be attempted, it is necessary to consider only how performance may be expected to vary, for example, with the size of the shuttlebox compartments, with the difficulty of response, and with the way in which shock is delivered. The four experiments reported here provide a large block of data obtained under the same, precisely described conditions.

**Experiment 1**

The purpose of this experiment was to sample the behavior of subjects in a wide variety of problems in our standardized training environment. We used both classical and avoidance procedures, with and without an escape contingency, and in the avoidance case, with and without a CS-termination contingency. Probability of reinforcement was varied in the classical case, and repeated conditioning and extinction were studied in both cases.

**Method**

**Subjects.** The subjects were 24 10-cm goldfish (Carassius auratus), all experimentally naive. They were maintained in individual enclosures made by partitioning large tanks, the water of which was continuously aerated, filtered, and recirculated with partial replacement. A 24-hr feeding schedule was used. Note that it is especially important in such experiments to minimize variation in the size of the subjects. Given the fixed level of water over the hurdle, both the effortfulness of response and the salience of the feedback from response may increase with size. The effectiveness of shock, which depends on the voltage drop across the animal, also increases with size.

**Apparatus.** The animals were trained in a set of four identical shuttleboxes of the same general design as those described by Horner et al. (1961), although substantially larger in size (Figure 1). Each box was constructed entirely of black Plexiglas except for the walls of milk-Plexiglas between the animal's compartment and the light-boxes at either end. The light-boxes contained colored 7.5-W Christmas tree lamps that served as CSs. The electrodes used for shock were stainless steel rods, 3 mm in diameter, set against the long walls. As in the earlier model of the apparatus, there were photodetectors on both sides of the hurdle, which made it possible to define response as a complete crossing from one end of the
shuttlebox to the other; a response was registered only when the subject had passed through both photobeams and not by mere approach to the hurdle. Continuously circulating through each chamber was water coming from and returning to the same system that supplied the living tanks. A single desktop computer programmed the stimuli and monitored behavior in all four shuttleboxes. (All experiments were fully automated.)

Procedure. Two groups of 12 animals, each group divided into 3 subsets of 4 animals, were given three daily 40-min periods of adjustment to the apparatus. This pretraining was followed by 114 daily training sessions; in each session there were 20 trials with a mean intertrial interval of 90 s. Of the 20 trials, 10 were widely separated blank trials (each providing a 10-s sample of activity) and 10 were CS trials (scheduled in balanced quasirandom orders). The CS was general illumination provided by red lamps turned on simultaneously at both ends of the shuttlebox. The mean interval between CS presentations was 180 s, with a range of 90 to 290 s.

The training of one group was classical in that the US was turned on 10 s after the onset of the CS regardless of whether a shuttling response occurred in that interval, but to begin with there was an escape contingency as well (classical-escape or C/E training). The US was a train of .25-s pulses of ac shock (.33 v/cm) delivered at intervals of 2.5 s across the long walls of the shuttlebox; the CS remained on until it was terminated along with the train of shock pulses by the first shuttling response following the 10-s CS-US interval, or after 30 s. After 10 sessions (see Figure 2 for details), the animals were shifted to purely classical (C) training for 15 sessions, that is, the escape contingency was removed; each 10-s CS terminated with a single .25-s pulse of shock. In the subsequent 21 sessions, the percentage of reinforcement was reduced progressively to 60% for 2 sessions, to 40% for 2 sessions, and to 30% for the rest (classical-partial or C/P training); with 30% reinforcement, the frequency of shock was almost as low as in an avoidance group that was trained concurrently. A series of 18 extinction sessions followed, after which there were 5 series of 5 reacquisition sessions (with 100% reinforcement) alternating with 5 series of 5 extinction sessions.

The second group had avoidance training. In the first 10 sessions, the CR both terminated the CS and avoided the US, and on trials on which the CR did not occur, the escape contingency was in force (avoidance-escape or A/E training). In the next 5 sessions (see Figure 2), the escape contingency was eliminated (pure avoidance or A training) and then, for 31 sessions, the CS-termination contingency was eliminated as well, that is, the CR avoided shock but did not terminate the CS, which stayed on during the scheduled 10-s CS interval (A/N training). As with the classical group, a series of 18 extinction sessions followed in which there still was no CS-termination contingency (making the extinction conditions exactly the same for both groups), and then there were 5 series of 5 reacquisition (A/N) sessions alternating with 5 series of 5 extinction sessions.

The probability of response for the two groups under the various conditions of training in Experiment 1 is shown in Figure 2. A/E = avoidance training with CS-termination and escape; C/E = classical training with escape; A = avoidance training with CS-termination; C = classical training; A/N = avoidance training without a CS-termination contingency; C/P = classical training with partial reinforcement; EXT = extinction; ACQ = acquisition.
Results

In Figure 2, the performance of the two groups is plotted in terms of the mean probability of response to the CS in each 10-trial session (the mean number of responses divided by the number of trials). The two groups conditioned rapidly, and in the first 25 sessions their performance did not differ significantly (p < 0.05, which is the confidence level adopted throughout). An analysis of variance yielded a significant sessions effect, F(24, 528) = 50.80, but did not yield either a significant groups effect (F < 1) or a significant Groups x Sessions interaction, F(24, 528) = 1.12. When, in the next 21 sessions, the probability of reinforcement was progressively reduced for the classical group, its performance fell to a level significantly below that of the avoidance group, F(1, 22) = 4.93; the sessions effect was significant, F(20, 240) = 2.51, as was the Groups x Sessions interaction, F(20, 440) = 1.66. The better performance of the avoidance animals, which had even fewer CS-US pairings than did the classical animals, is understandable on the assumption that lower c was compensated for by the development of i.

In the subsequent 43 extinction sessions, the avoidance group responded significantly more than the classical group, F(1, 22) = 6.72; the sessions effect was significant, F(42, 924) = 2.99, but the Groups x Sessions interaction was not, F(42, 924) = 1.23. Although performance in the first series of 18 sessions without reinforcement may suggest that extinction of response to the CS was not carried very far even in the classical group, that impression is incorrect, because the observed probability of response in the absence of the CS (U) was about .25 (see Figure 8). The considerably lower level of response to the CS by both groups in the first conditioning session reflects a general suppression of activity accompanying the introduction of shock (see also Woodard & Bitterman, 1971, 1973) from which there was rapid recovery. In reacquisition as in extinction, there was significantly more responding to the CS in the avoidance group than in the classical group, F(1, 22) = 5.77; the sessions effect was significant, F(24, 528) = 1.76, but the Groups x Sessions interaction was not, F(24, 528) = 1.23.

Experiment 2

This experiment was designed to expand the database subsequently to be used in the estimation of parameter values. Classical and avoidance training again were compared in two groups of animals but now without the escape contingency for either group and with no CS-termination contingency for the avoidance group. The training was continued long enough to provide reasonable approximations of asymptotic performance, after which the classical group was shifted to partial reinforcement, and then there were extinction and reacquisition sessions for both groups.

Method

Subjects. The subjects were 24 10-cm goldfish, all experimentally naive. They were drawn from the same pool of subjects and maintained in the same way as those of Experiment 1.
tive to that of the avoidance group, $F(1, 22) = 1.38$. Reduction to 30% did, however, produce a significant difference between the two groups, $F(1, 22) = 5.46$, suggesting again that the lower c consequent to fewer CS-US pairings is compensated for by $i$ in the avoidance group; the sessions effect was not significant, $F(5, 110) = 1.89$, nor was the Groups X Sessions interaction, $F(5, 110) = 1.01$.

In extinction, too, the avoidance group responded significantly more than the classical, $F(1, 22) = 13.30$, whose performance fell close to the intertrial level of responding ($U$) of about .25; the sessions effect also was significant, $F(7, 154) = 4.05$, but the Groups X Sessions interaction was not ($F < 1$). As in Experiment 1, intertrial responding was sharply suppressed with the introduction of shock in the first training session, but recovered for the most part by the third session. In reacquisition, with the classical animals again consistently reinforced, responding in both groups increased rapidly.

Experiment 3

One purpose of this experiment was to test the hypothesis that the escape contingency was responsible for the fact that acquisition at the outset of training was better in Experiment 1 than in Experiment 2. Our strategy was to train two groups of classical animals concurrently in yoked pairs, with response of the master animal of each pair terminating the shock for both; that is, the escape contingency was in effect for the master animals but not for the yoked animals, with exposure to shock the same for both. Another and somewhat broader purpose was to assess the compatibility of the data of experiments separated in time, which would have to be assumed in pooling them for purposes of parameter estimation. We were interested, therefore, in how closely the performance of the master animals would resemble that produced by C/E training in Experiment 1. We were interested also in how closely the performance of the yoked controls would resemble that produced by C training in Experiment 2.

Method

Subjects. The subjects were 16 10-cm goldfish, all experimentally naive. They were drawn from the same pool of subjects and maintained in the same way as in the previous experiments.

Apparatus. The apparatus was the same as that used in Experiments 1 and 2.

Procedure. Two groups of 8 animals each were trained in subsets of 4 animals. Each subset comprised two pairs of animals, with 1 member of each pair the master (C/E) animal and the other its yoked (C/Y) control. There were three daily 40-min periods of adjustment to the apparatus, followed by 20 daily training sessions in each of which were 20 trials in quasi-random sequence with a mean intertrial interval of 90 s. Of the 20 trials, 10 were widely separated blank trials (each providing a 10-s sample of activity) and 10 were CS-trials. The CS was general illumination provided by red lamps turned on simultaneously at both ends of the shuttlebox, and it was followed after 10 s, independently of response, by the US. As in Experiment 1, the US was a train of .25-s pulses of shock (.33 V/cm) delivered at intervals of 2.5 s, and the CS remained on for both members of each yoked pair until it was terminated along with the train of shock pulses by the first response of the master animal following the CS-US interval, or after 30 s. The mean interval between CS-presentations was 180 s, with a range of 90 to 290 s.

Results

The performance of the two groups is plotted in Figure 4 in terms of the probability of response to the CS in each session. Both groups conditioned rapidly, with the escape group (whose prompt response to shock restricted the mean number of pulses to 1.5 per trial for both groups) reaching a higher level of response to the CS than the yoked group. An analysis of variance yielded a significant groups effect, $F(1, 14) = 5.94$, and a significant sessions effect, $F(19, 266) = 11.92$, with a negligible Groups X Sessions interaction ($F < 1$). These results clearly show enhancement of classical performance by the escape contingency, although reservations about the yoked-control procedure (Church, 1964) may suggest that the possibility of a purely Pavlovian explanation has not been ruled out. The fact should be considered in this connection that (as will appear later) all the results of these experiments can be simulated nicely with two processes but can not be simulated when the instrumental component of the theory is eliminated. With respect to the question of comparability across experiments, it should be noted that acquisition in the master group was very much like that in the classical-escape group of Experiment 1 (Figure 2), but the asymptotic performance of the control group was somewhat lower than in the classical group of Experiment 2 (Figure 3), although the frequency of shock was a bit higher in this experiment.

Parameter Estimation

The simulation method was a computational one (Couvillon & Bitterman, 1989), which is superior to the familiar

Figure 4. The session-by-session performance of the two groups in Experiment 3. C/E = classical training with an escape contingency; C/Y = yoked controls.
Monte Carlo method both because it is much faster and because it is free of the random error of simulation inherent in the Monte Carlo method. The Monte Carlo method is to deal with each of a set of stat-animals in turn, using a probability-generator set at $R$ to determine whether or not the animal responds on a given trial. If, in avoidance training, the animal does not respond on a given trial, $c$ is incremented. If the animal does respond $c$ is decremented, and $i$ either is incremented when $i < c$ (that is, $i < \lambda_i$) or decremented when $i > c$, as might be the case, for example, where $c$ has been separately extinguished following avoidance training (e.g., Wilson, 1973). Then $R$ is calculated for the next trial, the probability-generator is consulted again, and so forth. The simulated performance is the average performance of a large number of stat-animals; the larger the number, the smaller the random error of simulation. Our own method is to calculate mean associative strengths on the assumption that the proportion of animals responding on each trial is $R$. The change in $c$ on an avoidance trial is the sum of a decrement equal to $R \times DB_c \times (0 - c)$ and an increment equal to $(1 - R) \times UB_c \times (c - \lambda_c)$. When $i < c$, there is an increment in $i$ equal to $R \times UB_i \times (\lambda_i - i)$; when $i > c$, there is decrement equal to $R \times DB_i \times (\lambda_i - i)$. It should be obvious that in the classical case, where the CS and US are paired (or not) independently of response, the Monte Carlo procedure would be pointless.

Efforts were made to simulate the results of Experiments 1 and 2 together. (Experiment 3 was redundant for the purpose, because the training of the master group was like the initial training of the classical group in Experiment 1 and the training of the yoked group was much like the initial training of the classical group in Experiment 2.) In the first simulations, the six parameters of the theory (the four learning rates, the effective intensity of the shock, and the generalization constant) were varied factorially over a wide range. The variation in parameters was coarse at first and then was narrowed as the computer homed in on the best fits, defined in terms of minimal root-mean-square (RMS) deviation of the simulated session-by-session performance from the obtained performance of the two groups in each of the two experiments.

Shown in Table 1 are the parameter values that yielded the small cluster of best fits, 26 of which (.04% of 57,875 simulations) have RMS-deviations < .087. $UB_c$, which proved not to be very closely determined by the data, is much larger than the other learning rates. The small values of $g$ suggest that feedback from the shutting response was itself highly discriminable and that CS-termination contributed little to the growth of $i$, although there was not a great deal in the training procedure to constrain $g$. The values of $s$ suggest that the shock-intensity chosen supported the development only of intermediate levels of $c$. The small variations in parameter values shown in Table 1 actually made little difference. The set of values chosen for the purpose of illustration ($UB_c = .6, DB_c = .02, UB_i = .04, DB_i = .01, g = 0, and s = .5$, with RMS = .086) is the one that yielded the marginally very best fit to the avoidance data of Experiment 1, which proved to be the most constraining. The fits with these values to the classical and avoidance data of both experiments (involving 3,160 training trials) are shown in Figures 5 (Experiment 1) and 6 (Experiment 2).

It is evident that the main features of this large set of data, not only ordinal, but exact, are captured fairly well in the simulations, with only three discrepancies worth noting. One is that the performance at the very outset of training is consistently overestimated; the second is that the performance of the avoidance group of Experiment 1 is underestimated at several points, and the third is that the asymptotic performance of the classical group of Experiment 2 is underestimated. Such discrepancies may be due to either error in the theory, error in the data (a certain amount of which is, of course, to be expected in work with small groups), or both. The first discrepancy points to theoretical insufficiency, seeming to reflect a general suppression of activity concomitant with the introduction of shock on which the theory is silent; the suppression was studied in Experiment 4 (described next). The interpretation of the second discrepancy is in doubt; we are inclined now to attribute it to random error in the data, although it may be resolved with changes in the theory required by the results of new experiments designed to introduce further constraints. That the third discrepancy may be due to error in the data is suggested by the lower level of performance in the comparably trained control (C/Y) animals of Experiment 3.

A simulation of the results of Experiment 3 with the same parameters is plotted in Figure 7. The satisfactory fit (RMS = .106) might be taken as a successful quantitative prediction in the sense that the results of Experiment 3 were not used in the choice of parameters, although the achievement is perhaps not very dramatic because the training procedures of Experiment 3 essentially replicated some of those in the previous experiments. An interesting outcome is that the fit to the asymptotic performance of the control (C/Y) group of Experiment 3 is better than to that of the purely classical group of Experiment 2, because the level of performance was lower in the third experiment than in the second. If the data of Experiment 3 are taken as a better estimate of classical performance under these conditions than the data of Experiment 2, the third of the three discrepancies in the fit to the data of Experiments 1 and 2 disappears.

The way in which the model works is illustrated by Figure 8, which shows the hypothetical changes in $c$, $i$, and $R$ during the initial extinction of the avoidance group over Sessions 47–64 of Experiment 1. (The plotted values of $U$ are based, of course, on observed intertrial responding.) There is rapid decline in $c$, but $R$ declines less rapidly than it does in the classical group (see Figure 2) because of the

Table 1

<table>
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<th>Parameters</th>
<th>$UB_c$</th>
<th>$DB_c$</th>
<th>$UB_i$</th>
<th>$DB_i$</th>
<th>$g$</th>
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Note. $UB_c$ = incremental $\beta$ for $c$; $DB_c$ = decremental $\beta$ for $c$; $UB_i$ = incremental $\beta$ for $i$; $DB_i$ = decremental $\beta$ for $i$; $g$ = generalization constant; $s$ = effective intensity of shock.
Experimental contribution of \( i \). It is evident here that, despite the relatively small values of \( UB_i \) and \( DB_i \) required to fit the data of Experiments 1 and 2, the instrumental component of the theory cannot be dispensed with entirely. Simulations of the data of the two experiments with only the classical process yield a minimal RMS of .135 for \( UB_i = .5, DB_i = .02, \) and \( s = .6 \). The obtained and simulated results of Experiment 1 are compared in Figure 9, which shows, as might be expected, large and consistent underestimation of the performance of the avoidance group with the instrumental process excluded.

Experiment 4

This experiment was prompted by the principal discrepancy between the simulated and obtained results of the three experiments, which was the overprediction of response to the CS at the outset of conditioning. The discrepancy seemed to reflect a general suppression of activity produced by shock, and we thought further study of the circumstances under which suppression occurs was warranted. Our plan was to compare intertrial activity in four groups of animals, a group that was classically conditioned with a brief shock, a CS-only group, a group for which the CS and US were explicitly unpaired, and an unstimulated control group.

Method

Subjects. The subjects were 48 10-cm goldfish, all experimentally naive. They were drawn from the same pool of subjects and maintained in the same way as those of the previous experiments.

Apparatus. The apparatus was the same as that used in the previous experiments.

Procedure. The design called for four groups of 12 animals each to be trained in subsets of 4 animals, but 1 animal in each group except the CS-only group was eliminated because of bacterial infection developed in the course of the training. There were 40 daily training sessions of about 40 min in length, during each of which activity was sampled in 10 widely separated 10-s intervals (blank trials). In the first 8 sessions, all animals were unstimulated. In each of the next 17 sessions, the paired group had, in addition to the blank trials, 10 classical training trials as in Experiment 2 (10 trials on which a 10-s illumination of the red lamps was followed by a single unavoidable .25-s pulse of .33-V/cm shock). The CS-only group had, in addition to the blank trials, 10 unreinforced exposures of the
CS alone, the unpaired group had 10 exposures to the CS and 10 brief shocks in quasi-random sequence, and the activity control group (with 20 blank trials) was unstimulated as before. In the final 15 sessions, the training of all groups was classical. The mean interval between CS-presentations was 180 s, with a range of 90 to 240 s.

Results

In Figure 10, the intertrial activity of the four groups is plotted in terms of the probability of response on the 10 blank trials programmed in each of the 40 sessions. The probability of response both in the activity group and in the CS-only group increased at first and then declined gradually over sessions to a fairly stable level. With the introduction of shock in Session 26, the intertrial responding in both groups fell off sharply and then recovered in the next few sessions. An analysis of variance showed a significant sessions effect, $F(39, 819) = 5.12$, but did not show either a significant groups effect ($F < 1$) or a significant Groups $\times$ Sessions interaction, $F(39, 819) = 2.97$.

Performance in the classical training, which closely resembled the classical performance shown in Figure 3, was much the same in the four groups; there was no evidence either of latent inhibition (CS-only vs. activity, $F < 1$) or of retarded acquisition produced by the explicitly unpaired training (unpaired vs. activity, $F < 1$). These results give no indication of contextual conditioning, perhaps because the brief shocks were relatively weak and the shock-free periods relatively long. The observed suppression seems then to be a nonassociative effect of shock that soon habituates and whose only significance for the theory is that it leads to over-prediction of response to the CS for a few sessions. Before formalizing that assumption, however, we think it might be wise to study the effect under a wider range of conditions.

General Discussion

Apart from the usefulness of the results of these experiments in the development of a quantitative theory, they add substantially to the store of qualitative information on the shuttlebox performance of goldfish.

1. It is now much clearer than before (cf. Scobie & Fallon, 1974; Woodard & Bitterman, 1973) that the rates of acquisition in classical and avoidance training may be under certain circumstances very much the same, and the stage is set for an inquiry into the conditions under which the rates may be different.

2. Performance in classical conditioning is impaired by partial reinforcement even with frequencies of reinforcement no less than those experienced in avoidance conditioning, and resistance to extinction is reduced as well.

Figure 6. Comparison of the simulated and obtained results for each of the two groups of Experiment 2.

Figure 7. Comparison of the simulated and obtained results for each of the two groups of Experiment 3. C/E = classical training with escape; C/Y = yoked controls.
yoked controls and some indication of better performance who found better acquisition in avoidance groups than in circumstances in which classical and instrumental influences produced also by CS-US contiguity alone, that is, under conditions in which the response produced by CS-US pairing alone is different from the avoidance response, or even to some extent incompatible with it. Although our shuttlebox results for goldfish can be simulated fairly accurately on the assumption of a substantial contribution of \( c \) to \( R \), that may not be true of other animals or other situations. Consider, for example, the fact that the performance of rats in a conventional shuttlebox as distinct from a “one-way” apparatus is poorer with a higher intensity of shock than with a lower intensity (Anisman & Waller, 1972; Moyer & Korn, 1964; Theios, Lynch, & Lowe, 1966) or the fact that the two-way shuttlebox performance of dogs both in avoidance training and in extinction is nonmonotonically related to shock intensity (Brush, 1957): \( c \) may increase as shock intensity increases, and with it the aversiveness of the CS and the reinforcing effect of its termination (\( \lambda_i \)), but at the same time the contribution to \( R \) may decline, or even become negative, if the overt response classically conditioned to the CS at the higher intensity is less compatible with the avoidance response.

There has been little other study of avoidance under circumstances in which the avoidance behavior tends to be produced also by CS-US contiguity alone, that is, under circumstances in which classical and instrumental influences are indexed by the same response. General activity in goldfish was conditioned by Greenway and Bitterman (1972), who found better acquisition in avoidance groups than in yoked controls and some indication of better performance with a CS-termination contingency. Leg-flexion in dogs was conditioned by Wahlsten and Cole (1965), who found better performance in avoidance training than in classical training but no reliable effect of a CS-termination contingency. Experiments on human eyelid conditioning (Gormezano, 1965; Logan, 1951) have shown poorer acquisition but greater resistance to extinction in avoidance as compared with classical training, and experiments both on human eyelid conditioning and on nictitating-membrane conditioning in rabbits (Gormezano, 1965) have shown better performance in avoidance animals than in yoked controls. In recent work on cheliped-extension in crayfish, Hoshino (1988) found no differences in the performance of classical and avoidance groups trained with or without a CS-termination contingency; classical acquisition was as good after CS-only experience, US-only experience, and explicitly unpaired training as after mere exposure to the experimental situation. In general, these results seem to present no serious challenge to two-process theory as formulated here in the sense that most of them can readily be simulated with parameter values tailored to the different species and training conditions used.

Figure 8. Theoretical changes in \( c \) (the classical component), \( i \) (the instrumental component), and \( R \) (response to the CS), and observed changes in \( U \) (intertrial responding) during the initial extinction of the avoidance group in Experiment 1.

3. When blocks of conditioning and extinction sessions are alternated, performance both in classical and avoidance training changes appropriately, and the overall level of responding is higher in avoidance training even with consistent reinforcement in the classical training.

4. Shuttlebox performance is facilitated by an escape contingency; an indication of such an effect in avoidance training appeared some years ago (Behrend & Bitterman, 1964), and here it appears also in classical training.

5. The suppression of activity with the onset of conditioning, which itself has been observed before (Woodard & Bitterman, 1973), appears now to be a nonassociative effect of shock.

6. Classical conditioning is not retarded by frequent prior exposure to the CS alone, to the US alone, or to the CS and US explicitly unpaired, with no indication of the unusual suppressing effect of CS-preexposure on asymptotic performance found by Shishimi (1985); null results also have been reported for avoidance training (Scobie & Fallon, 1974), and both sets of results are intriguing in the light of the marked impairments commonly found in work with other vertebrates (Mackintosh, 1983).
search for a unified treatment of appetitive and aversive conditioning. In answer to the question, there are several points to be made: The first, bearing on our choice of subjects, is that the so-called "paradoxical reward effects" such as successive incentive contrast, which have been primarily responsible for loss of confidence in the principle because they suggest learning "about" reward, occur in birds and mammals but not in fishes or any of the older vertebrate lines (Bitterman, 1987). The second is that the paradoxical effects, even where they do occur, go only to the sufficiency and not to the necessity of the principle, for which in our opinion no satisfactory substitute has yet been proposed. Mowrer's (1960) alternative, it is interesting to note, was the dubious assumption that animals are constantly scanning their behavioral repertoires, sampling the proprioceptive feedback from each response in turn. The third and most important point is that Mowrer's earlier theory, which continues to be featured prominently in the textbooks as a yardstick against which alternatives are measured, does promise to lead to a rigorous account of avoidance conditioning, not only in goldfish, but in other animals as well.

Of sporadic earlier efforts to provide exact quantitative simulations of avoidance data, the best known perhaps are those of Bush and Mosteller (1955), who used a two-operator linear model to simulate the shuttlebox acquisition data reported by Solomon and Wynne (1953) and of Theios (1963), who used another two-component model to simulate some one-way data of his own. Both models are reminiscent of Mowrer's theory, although the interest that led to their development was descriptive rather than theoretical or "reductionist" (Theios, 1963, p. 414). As Atkinson et al. (1965) put it, the strategy was first to try to find "a satisfactory quantitative model" and then to try to "coordinate" it with a theory (p. 250). Our interest, like that which prompted an earlier effort by Hoffman (1965) to simulate some data reported by Hoffman and Fleshler (1962), is first of all in the theory. For us, the model is the theory, the expression of which in a few simple equations permits exact quantitative predictions of experimental data and the validity of which can be assessed unequivocally in terms of the accuracy of those predictions. The substantial block of data provided by the present experiments might of course be used to explore the possibilities of any theory of avoidance, as, for example, the neural-network model recently developed by Schmajuk (in press), who has thus far considered only its ordinal implications.

Figure 9. Comparison of the obtained results for each of the two groups of Experiment 1 with results simulated on the assumption of classical conditioning alone.
of further experiments, the continuing strategy will be to ask whether the model predicts each new set of data and, if not, how the model can be changed to fit the new data together with all the data already at hand (Couvillon & Bitterman, 1991).

References


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