The Two-Test Strategy in the Study of Inhibitory Conditioning

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It is commonly believed that both a summation test and a retardation test should be used to determine whether a stimulus becomes inhibitory in consequence of some specified treatment, because the 2 tests together rule out alternative interpretations. Depending, however, on the choice of control treatments, a single test may provide credible evidence of inhibition or both together may not. A comprehensive review of the 2-test literature shows that suitable controls have been used only rarely and that compelling evidence of inhibition is correspondingly rare. The only such evidence now available is provided by retardation tests in experiments with some variation of A+/AB− training as the putatively inhibitory treatment.

In an influential article on Pavlovian conditioned inhibition, Rescorla (1969b) recommended summation and retardation as the most direct tests of the acquired "ability of a stimulus to control a tendency opposite to excitation," suggesting that "when attentional accounts seem plausible, it may be valuable to have information from both" (pp. 84–85). A stimulus that has been subjected to some putatively inhibitory treatment may reduce response to an accompanying excitor (summation test) only because attention to the treated stimulus has been enhanced, Rescorla noted, and it may be slow to acquire excitatory strength when reinforced (retardation test) only because attention to it has been reduced. Other explanations must be found, however, when the treatment produces both effects. Attentional alternatives to inhibitory accounts either of summation alone or of retardation alone are not, of course, always plausible. Retarded excitatory conditioning of Stimulus B after successful differential conditioning with Stimulus A reinforced and the compound of A and B unreinforced is intuitively unlikely, for example, to be a product of reduced attention to B. Nevertheless, the view that both tests should be used to "securely identify a stimulus as a conditioned inhibitor" (Rescorla, 1971, p. 77) soon gained wide currency. "Most researchers, following Rescorla, either used both the summation and retardation tests or felt they should have," write Williams, Overmier, and LoLordo (1992, p. 275), in whose opinion the two tests, although perhaps not always "necessary," do together provide compelling evidence of inhibition because "they rule out rival hypotheses" (p. 287).

But do they? Any proper consideration of the matter must begin with the recognition that the question of whether a stimulus is a conditioned inhibitor represents a considerable oversimplification. What is really being asked in experiments on inhibitory conditioning is whether a stimulus becomes inhibitory in consequence of some specified treatment—a point on which Rescorla (1969a) was perfectly clear—and we try to answer by comparing response to a stimulus that is so treated with response to a control stimulus that is treated differently. On the assumption that the target treatment is inhibitory, one may look for slower conditioning of the target stimulus than of the control stimulus, or for less response to an excitor accompanied by the target stimulus than to one accompanied by the control stimulus. Even the realization of both expectations may not, however, be sufficient to establish that the target treatment is inhibitory, because the control procedure may be insufficient to rule out alternative interpretations, which too often is the case. Reasonably adequate controls are indeed so uncommon as to suggest that there is still relatively little dependable information about inhibitory conditioning. Our purpose in this review of the two-test literature (comprising 37 reports of experiments in which both summation and retardation tests were used to look for evidence of conditioned inhibition) is to emphasize the importance of the control problem.

Classification of Control Procedures

In all, control procedures of three different kinds have been used, one of which is to compare a stimulus that has been subjected to some putatively inhibitory treatment with a stimulus not previously encountered and assumed therefore to be neutral: the *novel-stimulus control*. In the between-groups design,

Group 1: Treatment 1 of Stimulus B (e.g., A+/B−), Test B[1],

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[1] In descriptions of experimental designs, A denotes a discrete stimulus trained as an excitor; B, a putative inhibitor; C, an excitor used in summation testing; D, a novel stimulus or in some within-subjects designs, a control stimulus; E, another control stimulus;

and

Group 2: Treatment 1 of Stimulus D (e.g., A+/D−), Test B.

Note that the putatively inhibitory treatment (differential conditioning) is the same for both groups, but the training stimuli are different and the test stimulus (the same for both groups) is novel for Group 2. In the within-groups design, the same animals are tested with B and D (the novel stimulus) after some treatment of B (e.g., A+/B−).

A second procedure is to compare the effects of a putatively inhibitory treatment with those of a different treatment that is assumed to be less inhibitory or not inhibitory at all: the *contrasting-treatment control*. In the between-groups design,

Group 1: Treatment 1 of Stimulus B (e.g., A+/AB−), Test B,

and

Group 2: Treatment 2 of Stimulus B (e.g., A+/B−), Test B.

Here the same stimuli are treated and tested in both groups, with only the treatments different. In the within-groups design, the same animals are tested with B and D after different treatments of the two stimuli (e.g., A+/AB−/D−).

A third procedure—solely a between-groups procedure—is a *hybrid* of the first two. It involves both a difference in treatment and a novel stimulus in the test:

Group 1: Treatment 1 of Stimulus B (e.g., A+/AB−), Test B,

and

Group 2: Treatment 2 without Stimulus B (e.g., A+/A−), Test B.

Treatment 2 may be nothing more than exposure to the training context.

The three control procedures provide a useful basis for classifying the diverse array of two-test experiments, but the classification is not exact. Although the two-test logic obviously requires that the training before both tests be identical, it is not uncommon to find experiments, which can be called *pseudo-two-test experiments*, in which the control procedures for the two tests are different. These experiments are considered where it seems most convenient to do so, and their deviant characteristics are duly noted. Other classifications of the experiments surely are possible, as, for example, on the basis of the putative inhibitory treatments under study or the alternative interpretations to which the results are susceptible. None, however, proves to be more manageable than a classification based on the control procedures, to which we are proposing

much more careful consideration should be given in the analysis of inhibitory conditioning.

Novel-Stimulus Experiments

In a conditioned suppression experiment by Miller, Hallam, Hong, and Dufore (1991), the target treatment was differential conditioning. Two groups of rats were given reinforced trials with C; then one group was trained with A+/B− and the other with A+/D−, after which there was a summation test in which C was presented with B (putatively inhibitory for the first group and novel for the second). The CB compound produced less suppression in the first group than in the second, which would be expected on the assumption that B was more inhibitory, but which might mean only that B was less excitatory; it seems reasonable to assume that excitation generalizing from C and A to B and D was reduced differentially by the nonreinforced experience with B (reduced generalized excitation). It is conceivable, too, that suppression of the instrumental baseline was enhanced in the second group by the novelty of B (Pavlovian external inhibition), as it would tend to be wherever excitation is measured in terms of the disruption of an instrumental baseline (Henderson, 1973).

In a model two-test experiment, two additional groups would have been trained exactly as were the first two and then given reinforced trials with B, although retarded acquisition in the A+/B− group as compared with the A+/D− group would have provided no unambiguous evidence of inhibition; the same outcome might as well have been attributed to reduced generalized excitation. Instead, Miller and colleagues (1991) used a different control procedure (a hybrid procedure) in which Group 1 had A+/B− training followed by B+ training, and Group 2 had C+ training followed by B+ training. There was less suppression by B in the first group than in the second, which can be explained in terms of reduced generalized excitation in the first group, external inhibition of the instrumental baseline in the second group, or both.

One would expect the stimuli to be counterbalanced in these experiments, but they almost never are. Consider again the design of the retardation test in the experiment by Miller et al. (1991) with light as A, tone as B, and click as C. Quite apart from the fact that generalized excitation to B was reduced by nonreinforcement in the training of Group 1, there probably was less generalization of excitation in Group 1 (tone from light) than in Group 2 (tone from click) to begin with. The danger inherent in failing to counterbalance at least the critical stimuli in such experiments is evident in the results of an autoshaping experiment by Reed-Elder and LoLordo (1985), who found more suppression of response to an excitatory keylight by a nonreinforced houselight than by a nonreinforced tone.

Differential conditioning was also the target treatment in three within-groups novel-stimulus experiments: a taste aversion experiment with rats by Lambert et al. (1989); an autoshaping experiment with pigeons by Wessells (1973); and an appetitive instrumental experiment with rats by Leeming, Larson, and Riddell (1984). In each case, a single

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+, reinforcement; −, nonreinforcement; and ±, partial reinforcement. The simultaneous presentation of two discrete stimuli, say, A and B, is denoted by AB; their sequential presentation, by A→B. For example, A+/AB−/D− means that A is reinforced on some training trials, the simultaneous AB compound is presented without reinforcement on other trials, and D is presented without reinforcement on yet other trials. Contextual stimuli are denoted by the letters X, Y, and Z. Group 1 is always the group that receives the putatively inhibitory treatment, and the others are control groups.

group of animals trained with A+/B− responded less to B than to D, the novel stimulus, when both stimuli were reinforced by turns in a subsequent retardation test. The difference is understandable on the assumption that the nonreinforcement of B reduced the generalized excitation from A, which in two cases may well have been less for B than for D to begin with. In the Wessells experiment, A was a green disk, B was a white vertical line, and D was a white disk; D may have been more similar to A than B was to A and more salient than B as well. In the experiment by Leeming et al., the stimuli were three white key lights in a row, A the right, B the left, and D the center; it seems likely that there was more generalization of excitation from right to center than from right to left. In the Lambert et al. experiment, where the stimuli were not counterbalanced, there was evidence of a strong unconditioned preference for B.

The accompanying summation tests contribute very little. In the Lambert et al. (1989) experiment, there was a contrasting-treatment control (A±/B−/+) that involved partial reinforcement of the excitor and some unsignaled presentations of the unconditioned stimulus (US). A summation test with A versus AB showed a smaller difference in the control group than in the differential conditioning group, which is not surprising in view of the fact that the excitor of the control group was only partially reinforced. In the Wessells (1973) experiment two groups were used for the summation test. One group was trained with A+/B− and the second with A+ alone, after which both groups were trained with C+ and tested with CB (a hybrid control procedure). There was less response to the compound in the first group, an outcome attributable to reduced generalized excitation. In the Leeming et al. (1984) experiment, the target treatment antedating the summation test was different (A+/AB− instead of A+/B−) and the stimuli used (again unbalanced) were different as well. After the A+/AB− training of a single group of animals, response to C, a separately established excitor, was found to be reduced by compounding it with B, an outcome understandable either in terms of competition for attention (as Rescorla, 1969b, originally suggested) or in terms of generalization decrement, that is, change in the sensory properties of C under the influence of B, a process that Hull (1945) called "afferent neural interaction" (p. 216). It should be noted that there was not only no novel-stimulus control in this summation test but no control at all—no comparison of the putative inhibitor either with a novel stimulus or with a stimulus treated differently. Unhelpful summation tests such as this are to be found elsewhere in the literature, both in within-groups (Gokey & Collins, 1980; Mis, Norman, Hurley, Lohr, & Moore, 1974) and in between-groups designs (Miller & Schachtman, 1985, pp. 56–60).

In two rather similar conditioned suppression experiments from the same laboratory by Schachtman, Brown, Gordon, Catterson, and Miller (1987) and by Matzel, Gladstein, and Miller (1988), the target treatment was negative contingency training (lower probability of reinforcement in the presence of the target stimulus than in its absence). The summation procedure in both cases was to train two groups of rats (Groups 1 and 2) with B, the target stimulus, and Group 3 with D, after which there was conventional C+ training for all groups. Then there were summation tests with the CB compound for Groups 1 and 3 (B was novel for Group 3) and a test with C alone for Group 2. The critical finding was that there was less suppression in Group 1 than in Group 3, which might only reflect greater attention to B on the plausible assumption that the salience of a stimulus is enhanced by a predictive relation to reinforcement (e.g., Mackintosh, 1975); that is, the competition with C for attention may have been greater in Group 1 than in Group 3.

The companion retardation tests—with different (hybrid) controls—are of no help. In the Schachtman et al. (1987) experiment, Group 1 had negative contingency training with B and Group 2 was trained with shock alone, after which both groups had excitatory training, first with C and then with B. The training with C, required for the summation test but not for the retardation test, was given in accordance with the strict two-test logic that the experience of the animals before each test should be the same, although the logic was disregarded in the choice of a different control procedure. For reasons that we need not consider, Group 1 had both its negative contingency training and its B+ training in context X, whereas Group 2 had its US-only training in context Y and its B+ training in context X. The result was retarded conditioning of B in Group 1 relative to Group 2, which can be understood in terms of contextual blocking in Group 1, external inhibition in Group 2, or both. The same result might have been obtained even if B had been absent in the original training of Group 1. The Matzel et al. (1988) retardation test was similar to the Schachtman test but included a third ("truly random") group treated like the first except that the probability of the shock was the same in the presence and absence of B. That the added group was less retarded than Group 1 is not surprising in view of the fact that it had twice as many shocks in the presence of B. There is now a good deal of evidence that a conditioned stimulus (CS) may become excitatory in the course of truly random training (Papini & Bitterman, 1990).

In an autoshaping experiment by Gokey and Collins (1980), the target treatment was A+/AB− training. A single group of pigeons for which the AB compound was simultaneous showed very little discrimination in training (perhaps because the two stimuli were presented on different keys), and in subsequent reinforced trials with B and D (the novel stimulus) there was no evidence of retardation. A second group of pigeons, trained with A+/B→A− (i.e., with a serial AB compound, A following B) did show both good discrimination and poorer subsequent conditioning of B than of D. The critical stimuli, B and D, were not balanced, although even if they had been the results could be understood without reference to inhibition. Discrimination between A and A-after-B could be understood in terms of change in A by interaction with the trace of B (afferent neural interaction), and the poorer conditioning of B could be understood in terms of reduced generalized excitation.

Two other groups of pigeons were trained in the same way as the first two (one with the simultaneous compound of A and B and one with the serial), but now there was reinforced training with C followed by summation tests with neither a novel-stimulus control nor any control at all. The simulta-

neous group discriminated poorly between A and AB as before and failed to respond differentially to C and CB in the test. The serial group again discriminated well between A alone and A-after-B and responded less to C-after-B than to C alone in the test, which can be accounted for in terms of change in C by afferent interaction, by enhanced attention to B, or both.

The only novel-stimulus experiment in which the summation and retardation tests were made after identical training—that is, the only proper two-test experiment—was a conditioned suppression experiment by Hallam, Matzel, Sloat, and Miller (1990) with a variation of A+/AB− training as the target treatment. The treatment differed from conventional A+/AB− training in that the simultaneous AB compound was not consistently negative but instead was reinforced on 25% of its occurrences. In the summation part of the experiment, three groups of rats were trained, Groups 1 and 2 with B (the target stimulus) and Group 3 with D. Then all had reinforced training with C, after which Groups 1 and 3 were tested with the CB compound (B was novel for Group 3) and Group 2 was tested with C alone. As in the experiments by Schachtman et al. (1987) and Matzel et al. (1988), the critical finding is that there was less suppression in Group 1 than in Group 3, which might mean only that attention to B was enhanced by the training.

In the retardation part of the experiment, two groups had the same putatively inhibitory training as before, one with B (the target stimulus) and the other with D, after which, as required by two-test logic, both groups had the same C+ training that preceded the summation test even though it was not necessary for the subsequent retardation test (with B+). The retardation test showed poorer acquisition in the first group than in the second, an outcome that cannot be understood in terms of enhanced attention and seems, therefore, to validate the two-test strategy. It might be argued, however, that the summation results already described are not needed to rule out an attentional interpretation, because it would be difficult to believe that attention to B was reduced by the training, especially if discrimination between A and the compound could be demonstrated. (Unfortunately, the technique used provides no data on the course of acquisition, only a single measure of suppression at the end of the experiment.) Although the fact that the compound was reinforced occasionally might seem to rule out an interpretation in terms of reduced generalized excitation, it is not entirely out of the question that the more frequent nonreinforcement resulted in a net loss of excitation, leaving B less excitatory in Group 1 than in Group 2; without a quantitative model, it is difficult to say. In any case, external inhibition would have tended to increase suppression of the baseline in Group 2, for which B was a novel stimulus at the time of testing.

The experiments reviewed in this section on novel-stimulus controls provide no convincing evidence of inhibition, failing to rule out what seem to be perfectly reasonable alternative interpretations of their results in terms of change in attention, reduced generalized excitation, and external inhibition of instrumental baselines. Nor is it clear how any experiment involving only a novel-stimulus control could possibly succeed.

Hybrid Experiments

In the pseudo–two-test experiments reviewed in the preceding section, a novel-stimulus control was sometimes used in the measurement of summation and a hybrid control was used in the measurement of retardation (as in Miller et al., 1991), or the reverse (as in Wessells, 1973). In the experiments now to be described, hybrid controls were used throughout—often in conjunction with contrasting-treatment controls, but always themselves playing a critical role in the interpretation of the results.

Consider a conditioned suppression experiment by Rescorla (1979, pp. 105–106) designed to test the hypothesis that a neutral stimulus added during the extinction of an excitor becomes inhibitory (a variant of A+/AB− training): Group 1 was trained first with C+, next with A+, and finally with AB−. Group 2 (hybrid) was trained first with C+, next with A+, and finally with A− alone (there was no experience with B). Group 3 (contrasting treatment) was trained with C+ and next with AB− (there was no intervening reinforcement of A). For each group there was then a summation test with C versus CB that showed less suppression in Group 1 than in the others, followed by training with B+ that showed retarded acquisition in Group 1 relative to the others. An explanation of the summation effect on the assumption that attention to B was enhanced by the A+/AB− training is ruled out by the retardation effect. Slower acquisition in Group 1 than in Group 2 might be due to reduced generalized excitation, external inhibition, or both, but another explanation would have to be found for the slower acquisition in Group 1 than in Group 3. The difference between Groups 1 and 3 could be due to US habituation or contextual blocking, but those possibilities are ruled out by the difference between Groups 1 and 2. As there is no reason to suspect that attention to B was differentially reduced by the target training, the retardation results for the three groups together seem to warrant an inhibitory interpretation. The summation test, it should be noted, makes no contribution at all, because its results can be understood in terms of attentional enhancement; the argument for inhibition rests on the results of the retardation test alone.

In a conditioned suppression experiment by Witcher and Ayres (1980), the target treatment (for Group 1) was explicitly unpaired training with B and shock. Group 2 had no shock in either the presence or the absence of B (contrasting treatment), and Group 3 had neither B nor shock (hybrid). In subsequent B+ training, acquisition was retarded in the first group relative to the others. Three additional groups were trained exactly as the first three and then trained with C+, after which there was a test with C versus CB in which suppression was least in the explicitly unpaired group. The summation results can be explained on the assumption of enhanced attention to B in Group 1, which is counteracted in the retardation test by US habituation and contextual blocking. The same pattern of results, open again to interpretation in terms of enhanced attention and contextual blocking, was obtained in a rabbit eyelid conditioning experiment by Hinson and Siegel (1980) with

trace conditioning as the target treatment and truly random training as the contrasting treatment.

Hybrid and contrasting-treatment controls were used also in a later experiment by Hinson and Siegel (1986) on pentobarbital-induced hypothermia with differential conditioning as the target treatment. Group 1 was trained with A+/B−, Group 2 was trained with A−/B− (contrasting treatment), and two hybrid groups were trained either with the drug alone (Group 3) or with nothing (Group 4). Then there was B+ training for all groups, the first trial of which was treated as a summation test (putative inhibitor plus drug). Tolerance was less throughout in Group 1 than in the others, which did not differ. A credible alternative to the inhibitory interpretation is that there were subthreshold CS- and US-preexposure effects in Groups 2 and 3, respectively, which summated in Group 1. Matzel, Schachtman, and Miller (1988) were unable to reject such an interpretation of learned irrelevance in a conditioned suppression experiment of analogous design with truly random training rather than differential conditioning for Group 1 and A− rather than A−/B− training for Group 2.

In a conditioned suppression experiment with A+/AB− training as the target treatment and only a hybrid control, Nieto (1984) looked for the transfer of conditioned inhibition across aversive USs (shock and horn). After C+ training with shock, Group 1 had A+/AB− training with horn and Group 2 had A+ training with horn. Then there was a summation test with C versus CB, followed by B+ training with shock. Both groups showed less suppression to CB than to C, which can be understood in terms of afferent interaction, and there was less suppression in Group 1 than in Group 2, which can be accounted for in terms of reduced generalized excitation. Poorer acquisition in Group 1 than in Group 2 also can be explained in terms of reduced generalized excitation.

A conditioned suppression experiment by Kremer (1978) was designed to test the deduction from the theory of Rescorla and Wagner (1972) that inhibition may be generated by the overprediction of reinforcement. Two groups were trained with A+ and C+, after which Group 1 was trained with A+, C+, and ACB+ and Group 2 was trained only with AC+ (receiving considerably fewer shocks). Then for both groups there was B+ training, the first trial of which was treated as a summation test—B plus the (excitatory) context. There was less suppression throughout in Group 1, which was taken as evidence of inhibition but can also be understood in terms of US habituation, contextual blocking, or both. Contrary results were obtained in a subsequent experiment by Schachtman, Kasprow, Chee, and Miller (1985) with a contrasting-treatment control that equated US frequency. After training with A+ and C+, Group 1 was trained as in the Kremer experiment with A+, C+, and ACB+, but Group 2 was trained with A+, C+, AC+, and B−. A summation test with C versus CB gave the same results for both groups, and a retardation test showed more suppression in Group 1 (which had been trained with ACB+) than in Group 2 (which had been trained with B−).

Hybrid control groups have also been used in experiments on latent inhibition. The typical procedure is to train Group 1 with B− and Group 2 with no stimulation, after

which both groups have B+ training. Retarded acquisition in Group 1 leads immediately to a summation test designed to determine whether the B− training makes B inhibitory or simply reduces attention to it. In a conditioned suppression experiment by Rescorla (1971), the training of the two groups was followed first by C+ training and then by a test with C versus CB. Group 2 responded somewhat less to CB than to C, suggesting afferent interaction, but response to C and CB was much the same in Group 1, suggesting reduced attention to B. In a somewhat similar experiment with more B− trials in the first stage (80 rather than 24), Kremer (1972) found less suppression of response to CB in Group 1 than in Group 2, which he interpreted in terms of conditioned inhibition, although the possibility of external inhibition was not ruled out. In an experiment on avoidance conditioning in honeybees, Abramson and Bitterman (1986) found less response to CB in subjects with previous nonreinforced exposure to B than in a control group without such exposure, which might be due, they suggested, to competing appetitive properties conditioned to B during exposure in a feeding situation. Reiss and Wagner (1972) used a contrasting-treatment control in an eyelid conditioning experiment with rabbits that is noteworthy for its rigorous design: The tests were parallel rather than sequential, C+ training preceded both tests although C played no role in the retardation test, and the critical stimuli were counterbalanced. The results favored an attentional interpretation.

Of the experiments reviewed in this section on hybrid procedures, only one—the experiment by Rescorla (1979) in which the conditioning of a neutral stimulus that had earlier been present during the extinction of an excitor was found to be retarded—provided persuasive evidence of inhibition. The results of the other experiments are open to a variety of alternative interpretations, such as change in attention, US habituation, contextual blocking, afferent interaction, reduced generalized excitation, and external inhibition of instrumental baselines. It is interesting to note that Rescorla's design involved a contrasting-treatment control as well as a hybrid control and that both were required to rule out alternative accounts.

Contrasting-Treatment Experiments

The most extreme of the contrasting-treatment controls is to omit the US entirely, as in a conditioned taste aversion experiment by Taukulis and Revusky (1975), who compared groups with A+/AB− training and A−/AB− training. Retarded acquisition in the first group relative to the second can be explained in terms of US habituation and contextual blocking, which may also have impaired conditioning of the excitor used in the summation test. In the summation test, fluid intake was greater in the first group than in the second, perhaps because of enhanced attention to B by differential reinforcement in the first group or because of reduced afferent interaction stemming from loss of attention to B. The summation results of a conditioned suppression experiment by Rescorla (1969a) with explicitly unpaired training as the target treatment and a CS-only control may be understood in

the same way. Rescorla's summation test also showed decreasing suppression in groups trained with increasing frequencies of the US in the absence of the CS (Groups 0–1, 0–4, and 0–8). These differences may reflect no more than increasing attention to the CS. A parallel retardation test showed poorer acquisition after 0–4 training than after 0–1 training, a difference that is not understandable in terms of enhanced attention alone. It is possible, however, that the facilitating influence of attention was overridden by US habituation, contextual blocking, or both. Acquisition of response to B in Group 0–4 was poorer also than in a control group trained with a different stimulus, which can be accounted for in terms of external inhibition of baseline responding in the control group.

Yet another control used in the retardation segment of Rescorla's (1969a) pseudo–two-test experiment was truly random training. Acquisition in the 0–4 group was slower than in a 4–4 group, which can be understood on the assumption that excitation produced by occasional CS–US pairings compensated for contextual blocking. Truly random controls were also used in two other experiments in which explicitly unpaired training was the target treatment: a conditioned suppression experiment by Baker (1977) and a heart rate conditioning experiment by Cunningham, Fitzgerald, and Francisco (1977). US frequency was equated, but the retardation found in both cases can still be explained on the assumption that the CS may become excitatory in truly random training. In the Baker experiment, summation was found only in the unpaired group, a reasonable explanation of which is that afferent interaction evident in the unpaired group was masked in the control group by excitation acquired in the truly random training. The Cunningham et al. experiment gave no evidence of summation.

In an experiment on nictitating membrane conditioning in rabbits by Marchant, Mis, and Moore (1972), the target treatment (for Group 1) was A+/AB– training and the control treatment (for Group 2) was partial reinforcement both of A and AB (A±/AB±). The summation test showed less response to the compound of B with an excitor than to the excitor alone in Group 1 but showed no difference in Group 2, which can be explained on the assumption that afferent interaction evident in Group 1 was counteracted in Group 2 by excitation acquired during partial reinforcement. The retardation test showed poorer acquisition in Group 1, which again may be attributed to the partial reinforcement of B in Group 2. The results of a similar experiment by Moore, Marchant, Norman, and Kwaterski (1973) were much the same and can be explained in the same way.

Differential conditioning (A+/B–) is widely used as a control where A+/AB– training is the target treatment. Experiments by Mahoney, Kwaterski, and Moore (1975) on nictitating membrane conditioning in rabbits, by Hoffman and Fitzgerald (1982) on heart rate conditioning in rats, and by Delamater, Kruse, Marlin, and LoLordo (1986) on conditioned taste aversion in rats gave no evidence of summation, but even if they had, an interpretation in terms of enhanced attention to B in the target group would have been tenable. The Mahoney et al. experiment gave no evidence of retardation, nor did the Delamater et al. experiment, in which the

A+/B– treatment was omitted and the only control was A–/AB– training with some additional unsignaled USs. In the Hoffman and Fitzgerald experiment, however, the conditioning of B relative to the differential group was retarded both in the A+/AB– group and in another group trained with the AB compound and shock explicitly unpaired. Retardation in the explicitly unpaired group can be accounted for in terms of contextual blocking, but retardation in the A+/AB– group seems to require an inhibitory interpretation for several reasons: (a) attention to B would not be expected to be reduced more by A+/AB– training (if reduced at all) than by A+/B– training; (b) owing to afferent interaction, generalized excitation from A to B should be reduced more by nonreinforcement in the A+/B– group than in the A+/AB– group, which would produce slower conditioning in the A+/B– group; and (c) exposure to B and exposure to the US were the same in both groups, ruling out explanations in terms of external inhibition, US habituation, and contextual blocking.

The same can be said about the retardation that was found in a conditioned suppression experiment by Holland (1984), who compared A+/AB– training with A+/B– training. The summation test was irrelevant in this case because (for reasons that need not be considered here) it followed the retardation test, which meant that both elements of the compound were excitatory. A variant of A+/AB– training was studied in a conditioned suppression experiment by Cunningham (1979), who gave A+ and C+ training to two groups and then extinguished them: Group 1 with AB– on some trials and D– on others and Group 2 with AD– on some trials and B– on others. A subsequent summation test with CB versus CD gave negative results, but in the final stage of the experiment conditioning of B was found to be retarded in Group 1 relative to Group 2. Here again—on the basis of the same reasoning that applies to the Hoffman and Fitzgerald (1982) and Holland experiments—the best alternative is an inhibitory interpretation. It may be useful to emphasize that in each of the three cases the evidence for inhibition is provided by the retardation test alone.

Opposite results were obtained by Williams, Travis, and Overmier (1986), who compared A+/AB– training with A+/B– training in a conditioned suppression experiment of interesting design. After trials with A+ and C+, two groups were trained with A+/AB–/D–, with B as the Pavlovian stimulus and D as the differential stimulus. (There was also a third [hybrid] group with no experience of B or D that adds nothing to the argument.) Here the differential stimulus produced less suppression than the Pavlovian stimulus in a subsequent summation test, and it conditioned more slowly than the Pavlovian stimulus in a terminal retardation test. Williams et al. suggested that both stimuli might be inhibitory, accounting for the differential response to them on the assumption that the inhibitory properties of the Pavlovian stimulus were masked by excitation acquired through within-compound association with A on AB trials. If, in fact, the Pavlovian stimulus does become excitatory in consequence of its pairing with A, the summation and retardation results can be accounted for on the assumption that the differential stimulus is not more inhibitory, but less excitatory. In the

summation test, suppression is reduced by afferent interaction in both cases, but suppression is greater in the Pavlovian case because of the greater excitation. However, within-compound association does not account for the retardation results of the Hoffman and Fitzgerald (1982), Holland (1984), and Cunningham (1979) experiments already reviewed, in which Pavlovian (A+/AB−) treatments were found to be inhibitory relative to differential conditioning controls (A+/B−).

A conditioned suppression experiment by Bouton and Swartzentruber (1986) was aimed at determining whether contextual stimuli can acquire inhibitory properties, but its design is easier to describe in terms of discrete CSs. Group 1 was trained with AC+/AB−/C− and Group 2 was trained with AC±B−, after which there was a retardation test with B+. For two other groups trained as were Groups 1 and 2, there was further training with D+ and a summation test with DB. (In the actual experiment, B and C were contexts and A and D were discrete stimuli.) The critical feature of the design is that A+/AB− training was compared with A±/B− rather than with A+/B− training (as in the experiments previously considered to provide good evidence of inhibition); that is, A was partially reinforced in both groups. An even better design would be to compare A+/AB− with A±DB−, because B would then be compounded with another stimulus in both groups. In none of these cases would a summation test provide clear evidence of inhibition because of the possibility that attention to B is enhanced by the target treatment, but for the reasons already enumerated evidence of retardation would be convincing. Unfortunately, the results of the Bouton and Swartzentruber experiment were uniformly negative.

In an appetitive conditioning experiment with rats, Pearce and Kaye (1985) found both summation and retardation with a variation of A+/AB− training in which A was a second-order excitor, but again it is only their evidence of retardation that seems to require an inhibitory interpretation. Group 1 was trained with A→C+ on some trials and AB− on others. Group 2 was trained with A−/C+/AB−. Then half the animals in each group were trained with B+ and the rest with C+/CB−. The summation test showed less response to CB in Group 1 than in Group 2, which can be accounted for in terms of enhanced attention to B. In the retardation test, there was less response to B in Group 1 than in Group 2, which is not readily accounted for in other than inhibitory terms.

A variation of A+/AB− training that is interesting because the putative inhibitor is always reinforced was used in a conditioned suppression experiment by Cotton, Goodall, and Mackintosh (1982). Group 1 was trained with A++/AB+ (++ denotes a higher intensity of shock than +), Group 2 was trained with A++/B+, and Group 3 (hybrid) was trained with A++/A+. In a subsequent retardation test with B+, response to B in Group 2 was asymptotic at the outset, which is not surprising because B alone had been reinforced in training, whereas response to B in Group 1 (trained with the compound) was less at the outset, presumably because of afferent interaction. Three other groups were trained as were Groups 1, 2, and 3, after which there was C+ training followed by a summation test with C versus CB. The response to C was the same in all groups, and CB produced less sup-

pression than C only in Group 1. These results can be accounted for on the assumption that attention to B was enhanced more by the training of Group 1 than of Group 2, an interpretation difficult to dismiss despite the good discrimination shown by both groups because the two problems were unequal in difficulty.

In two conditioned suppression experiments by Kleiman and Fowler (1984), the target treatments were backward conditioning and trace conditioning. Several control treatments were used, of which the most relevant is a variant of explicitly unpaired training (widely separated presentations of CS and US in strict alternation). Although the results obtained and their statistical treatment do not permit a clear conclusion about the actual outcomes of the summation and retardation tests, the experiments are interesting in principle. If the target treatments could not be assumed to reduce attention to the CS, retardation could be taken as evidence that the treatments are inhibitory (as Kleiman and Fowler believe they are); by the conventional two-test logic, summation and retardation together would rule out an attentional interpretation.

It should be clear from this analysis of contrasting-treatment experiments that summation and retardation tests together may not be sufficient to establish a target treatment as inhibitory and that both together are usually unnecessary. Only in one of the experiments reviewed (Kleiman & Fowler, 1984)—where there was no a priori basis on which to decide whether the target treatments (backward and trace conditioning) would enhance or reduce attention—did an inhibitory interpretation rest on the results of the two tests. In each of several other cases, inhibition could reasonably be inferred from the results of a single test, which as it happened was always a retardation test following some variation of A+/AB− training. It may be interesting in this connection to consider also the results of a somewhat unusual conditioned suppression experiment by Rescorla (1976) in which only a retardation test was made: Groups 1 and 2 had A+/AB− training and Groups 3 and 4 had A+/B− training, after which Groups 1 and 3 were trained with D→B− and Groups 2 and 4 had unpaired experience with D− and B−. In subsequent reinforced trials with D, retarded acquisition in Group 1 relative to the other three groups could be taken as evidence of second-order conditioned inhibition.

It would be a mistake to attribute the sufficiency of the retardation test in these experiments to the influence of what might be thought of as a summation test built into the A+/AB− treatment. Less responding to AB than to A does not demonstrate that B is inhibitory, but suggests only the hypothesis that B is inhibitory, which must be evaluated independently of the training. What accounts for the sufficiency of the retardation test in these experiments is only that attention to B cannot plausibly be assumed to be less after A+/AB− training than after A+/B− training. It is easy to think that retardation alone might be sufficient as well to show the effectiveness of putatively inhibitory treatments that do not involve anything resembling summation (such as A+/B− training in the course of which there is no less response to B than to the training context). Consider an experiment in which Group 1 has A+/B− training (as the target

treatment) in context X and exposure without other stimu-
lation to context Y, and Group 2 has A+ trials in context X
and B– trials in context Y, after which, for both groups, B is
reinforced in context Z. Or consider an experiment in which
Group 1 has explicitly unpaired training with B in context X
and exposure without other stimulation to context Y, whereas
Group 2 has B– trials in context X and unsignaled rein-
forcements in context Y, after which, for both groups, B is
reinforced in context Z. (At the very least, of course, contexts
X and Y would have to be balanced to equate generalized
excitation to Z.) In either experiment, poorer conditioning of
B in Group 1 than in Group 2 would warrant an inhibitory
interpretation, because it is unreasonable to assume less at-
tention to B in Group 1 than in Group 2 at the end of the
training. Both experiments seem worth doing.

Further Considerations

Williams et al. (1992) also have proposed that a single test
may be sufficient to demonstrate inhibition, and it may be
well to distinguish between their conclusion and ours. Our
own view is that inhibition, whether pure inhibition or only
net inhibition (in the sense that it is greater than any coex-
isting excitation), can with proper controls be demonstrated
by a single test, although a stimulus that is inhibitory should
(as inhibition is defined) pass both tests. Williams et al. have
suggested—contrary to the import of the results reviewed
here—that the retardation test may be inadequate in principle
to demonstrate inhibition. If a CS can have both excitatory
and inhibitory properties, and if "the expression of inhibition
carried by a mixed CS depends on concurrent excitation be-
ing provided by another stimulus," their argument runs, "a
mixed CS could pass the summation test but fail the retar-
dation test" (p. 284). They have also suggested that there may
be "forms of associatively learned inhibition that are not at
all antagonistic to excitation but that endow a stimulus with
the ability to suppress the output of some other response-
controlling process" (p. 285), that is, to function as what has
come to be called an "occasion setter" (Moore, Newman, &
Glasgow, 1969; Ross & Holland, 1981). In our view, neither
suggestion is convincing.

Can Excitation and Inhibition Coexist?

Pavlov's (1927) idea that a stimulus can have excitatory
and inhibitory properties at the same time was based on phe-
nomena such as spontaneous recovery and disinhibition, for
which plausible alternative explanations have since been pro-
posed (Mackintosh, 1974); contemporary experiments pre-
sumed to support the idea are not entirely convincing, usually
because inhibition has not been satisfactorily demonstrated.
In a second-order appetitive conditioning experiment by Hol-
land and Rescorla (1975), a group with A+/B→A– training
responded less to AB than to A alone in a summation test,
which did not in itself, of course, constitute good evidence
of inhibition. A control group trained with A±/B– showed
less responding than the first group to B in the training, but

responded more to AB than to A in the test, a puzzling result
that made between-groups comparisons "difficult" (p. 464).
Mackintosh and Cotton (1985, pp. 103–105) trained two
groups of animals with A+++/AB++ (+++ representing
20% sucrose and ++ representing 8% sucrose)—another
variant of A+/AB– training. One of the groups also had trials
with C+++ and the other with C+ (2% sucrose). In a sub-
sequent summation test, response to CB was less than to C
alone in the first group and greater than to C alone in the
second, which can be understood as hedonic averaging on the
assumption (entertained by Mackintosh and Cotton) that the
different concentrations were in some sense represented by
the stimuli paired with them. It is possible, too, that response
to the compound (very much the same in the two groups) was
determined primarily by B, attention to which was enhanced
by the target training. The same interpretation applies to the
like results of some appetitive conditioning experiments by
Nelson (1987), in which probability rather than magnitude of
reward was varied.

In an experiment by Tait and Saladin (1986), a stimulus
was assumed to be inhibitory after backward pairing with
shock because its subsequent forward conditioning was re-
tarded relative to CS-only, US-only, and unstimulated con-
trol groups, but the difference can be accounted for also—
like the results of Hinson and Siegel (1986) already
considered—in terms of summation in the backward group
of subthreshold CS- and US-preexposure effects. The
claim that the backward stimulus was excitatory as well
was based on the observation that it could be used to pun-
ish licking, which would not support the Pavlovian inter-
pretation even if the evidence of inhibition were incontro-
vertible because, as Tait and Saladin noted, the opposite
associative outcomes were found for different response
systems. The demonstration of inhibition in a conditioned
suppression experiment by Matzel et al. (1988) has already
been questioned on the ground that alternative interpreta-
tions in terms of attentional enhancement, contextual
blocking, and external inhibition were not ruled out.

In a conditioned suppression experiment by Williams and
Overmier (1988), C+ training was followed for one group
by the concurrent trace conditioning of two stimuli (B and
D), for another group by the concurrent backward condi-
tioning of those stimuli, and for a control group by training
with the US alone, after which for all groups there were
repeated unreinforced exposures to D and then summation
tests with CB and CD. In the tests with CB, the trace group
showed less suppression than the control group, which can
be accounted for either in terms of reduced generalized ex-
citation from C in the trace group or external inhibition of the
baseline in the control group; the trace and backward groups
did not differ from each other. In the tests with CD, the trace
and backward groups, but not the control group, showed less
suppression than in the tests with CB, which Williams and
Overmier took to mean that B and D acquired both inhibitory
properties and masking excitatory properties in the course of
trace and backward conditioning, the excitatory properties of
D being reduced by the interpolated D– training. Another
possibility (despite the contextual extinction that preceded

the D– training) is that the inhibitory strength of D was increased by the D– training. In any case, this promising line of investigation should be pursued further. On the assumption that enhanced attention may have played some role, it would be interesting to look for retardation in experiments of similar design.

Is Negative Occasion Setting a Special Case?

As to whether there may be a form of inhibition that yields summation but not retardation, the only evidence comes from a conditioned suppression experiment by Holland (1984) to which reference has already been made. In addition to a simultaneous feature-negative procedure, Holland used a serial feature-negative procedure, giving A+/B→A– training to a target group (Group 1) and A+/B– training to a control group (Group 2). In subsequent reinforced trials with B, performance was significantly better in Group 1 than in Group 2, a result that Holland attributed either to attentional decrement (latent inhibition) in Group 2 or to second-order conditioning in Group 1. It also seems reasonable to attribute the better performance to enhanced attention to B in Group 1. A subsequent summation test with A versus AB showed somewhat less suppression to AB than to A in Group 1, but the reported variability in the data suggests that the difference is unlikely to have been significant (no statistical evidence was provided). It is conceivable in any case that the summation results for Group 1 reflect the competing influences of enhanced attention and summation of excitation.

The question has been raised as to whether the reduced responding observed in serial feature-negative training actually requires an inhibitory interpretation. Jenkins (1985) has suggested that both feature-negative and feature-positive training can be understood as configural conditioning. Consider a within-groups experiment (e.g., Holland, 1989; Rescorla, 1985, pp. 318–321) in which animals are trained with A+/B→A–/C+/D→C–/E– and then tested with B→C (to look for transfer of occasion setting) and E→C (to distinguish between occasion setting and simple inhibition): The results are that response to C is suppressed by B but not by E. (Holland, 1989, found transfer of occasion setting even when different appetitive USs were paired with A and C.) Configural conditioning can account for transfer of occasion setting, as from D to B, on the assumption of stimulus generalization, but not (in an experiment with properly counterbalanced stimuli) for the lack of transfer to E. Perhaps the traces of B and D do function as simple inhibitors, in which case retardation would be expected in training with B→A+ as compared with E→A+; in this view, the failure of Holland (1984) to find retardation after A+/B→A– training was due to the fact that he tested with B+. In Rescorla's (1985) experiment, B continued to suppress response to A on B→A– trials even after B alone had been reinforced and had become excitatory, which suggests that a stimulus can be excitatory and its trace inhibitory. It has been known since Pavlov (1927) that animals can discriminate between stimuli and their traces.

Conclusion

It may be surprising that this review of the two-test literature has turned up so much evidence of inhibition that is unconvincing in the sense that alternative interpretations readily suggest themselves. The alternative interpretations may often seem somewhat less straightforward, but concepts such as generalization, US habituation, contextual conditioning, attentional modification, afferent interaction, and external inhibition have value in relation to a host of other data. The issue in experiments purporting to demonstrate inhibition is, after all, whether an inhibitory interpretation is required. For the purist, in fact, even the reasonably convincing experiments—in all of which the target treatment was some variation of A+/AB– training and in all but one of which (Rescorla, 1979) the control treatment was some variation of A+/B– training—leave something to be desired. One might ask, for example, about the stimulus specificity of the results (since the stimuli serving as A and B were counterbalanced in none of them) and about the role played by the inconsistent reinforcement of A in A+/AB– training. Such troublesome questions are unlikely to arise where the common language implies that the summation and retardation tests in themselves serve somehow to provide conclusive evidence of inhibition. Progress in the understanding of inhibitory conditioning will be slow until that misleading notion is dispelled and a more satisfactory consensus on the problem of control is achieved.

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