The Temporal Dynamics of a Visual Discrimination: The Role of Stimulus Comparison and Opponent Processes

R. C. Honey
University of Wales, Cardiff

The influence of trial spacing on simple conditioning is well established: When successive reinforced conditioned stimulus, CS+, trials are separated by a short interval (massed training), conditioned responding emerges less rapidly than when such trials are separated by longer intervals (spaced training). This study examined the influence of trial spacing on the acquisition of an appetitive visual discrimination in rats. Experiments 1 and 2 established that massed training facilitates the acquisition of such discriminations. The results of subsequent experiments demonstrated that this trial-spacing effect reflects the proximity of nonreinforced, CS−, trials to preceding (Experiment 3) and signaled (Experiment 4) presentations of the reinforcer. Experiment 5 showed that the facilitation of discrimination learning with massed training reflected an effect on learning rather than performance.

Of the many variables that influence the acquisition of Pavlovian conditioned responses (CRs) one of the most thoroughly investigated is that of trial spacing. It is well established that lengthening the interval between pairings of a conditioned stimulus (CS) and an unconditioned stimulus (US) facilitates the acquisition of CRs in a variety of conditioning procedures (e.g., Domjan, 1980; Gibbon, Baldock, Locurto, Gold, & Terrace, 1977; Gormezano & Moore, 1969; Kaplan, 1984; Prokasy, Grant, & Meyers, 1958; Salafia, Mis, Terry, Bartosiak, & Daston, 1973; Spence & Norris, 1950; Terrace, Gibbon, Farrell, & Baldock, 1975; Yeo, 1976; see also Durlach, 1989). The impression left by this body of evidence is that a general principle of learning has been established—namely, that learning proceeds more readily when training trials are spaced than when they are massed. There are, however, at least two good reasons to question the verity of this impression. First, little systematic study in nonhuman animals has been devoted to the role of trial spacing in situations other than simple Pavlovian conditioning (but see, Grant, 1975; Holland, 1995; Roberts & Kraemer, 1982). Second, theoretical grounds exist for anticipating that the effects of trial spacing might differ depending on the nature of the task that subjects are given.

Successive discrimination training differs in only one respect from a simple conditioning procedure—the introduction of nonreinforced presentations of a second stimulus, the CS−. One can, no doubt, imagine a variety of reasons for anticipating that discrimination training, like simple conditioning procedures, might be less effective when the interval between reinforced, CS+, and nonreinforced, CS−, trials is reduced. For example, if a memory trace of a stimulus remains active for some time after its presentation, then massed discrimination training might increase the probability that a trace of the CS− will be active on CS+ trials. Nevertheless, the possibility that the acquisition of a discrimination might actually proceed more rapidly when training trials are massed follows from two distinct theoretical perspectives.

Gibson (1969) suggested that discrimination training results not only in changes in the tendency of stimuli to elicit responses, but also in changes in the representations of the CS+ and CS−; that is, the acquisition of a discrimination involves a process of perceptual learning. Moreover, she suggested that one condition that is likely to be particularly effective in allowing the process of perceptual learning to operate is when stimuli are presented close together in time—and stimulus comparison will allow the abstraction of stimulus differences (Gibson, 1969, p. 145; see also Honey, Bateson, & Horn, 1994; Saldanha & Bitterman, 1951). One clear implication of Gibson's analysis is that discrimination learning will proceed more readily when CS+ and CS− trials occur close together in time because subjects will detect and learn about those aspects of the stimuli that differentiate them. However, this analysis might also, in principle, have implications for simple conditioning. Thus even when subjects are given a series of presentations of what is nominally the same stimulus, there might be differences in the subjects' reception of that stimulus across trials (see, e.g., Estes, 1950). If these differences are most readily detected when short intervals separate trials (Gibbon, 1969), then conditioning will occur less readily because what is learned on one trial will generalize only incompletely to the next.

The prediction that massed training might hinder the acquisition of simple conditioning while facilitating the acquisition of a discrimination can be derived from a quite different perspective. It has been argued that the presenta-
tion of reinforcement activates not only processes that support the development of excitatory learning but also opponent processes that support inhibitory learning (see, e.g., Wagner, 1981; Wagner & Larew, 1985). If it is assumed that these opponent processes outlast those that support excitatory learning, then presenting a stimulus soon after a CS+ trial should allow it to acquire inhibitory properties. According to this analysis, massed training will result in poor acquisition of the CR during simple conditioning because the CS+ will acquire inhibitory properties (see Ewing, Larew, & Wagner, 1985; but see also Janssen, Farley, & Hearst, 1995). However, during a discrimination the fact that massed training might allow the CS− to acquire inhibitory properties could facilitate discrimination learning because this inhibition will counteract generalized excitation from the CS+. More generally, to the extent that a given US activates dynamic and opposing processes, discrimination learning might be expected to proceed more readily when trials are massed rather than spaced. Experiments 3, 4, and 5 are investigations of the basis of this trial-spacing effect.

Experiments 1 and 2

In Experiments 1 and 2 I used appetitive conditioning procedures to examine the influence of trial spacing on visual discrimination learning in rats. Experiment 1 used a between-subjects design. Group Short received reinforced presentations of one stimulus, S+, and nonreinforced presentations of another stimulus, S−, that were separated by a short, 1-min interval. Group Long also received reinforced presentations of one stimulus, L+, and nonreinforced presentations of another, L−, but for Group Long the intertrial interval was longer, 2 min. Experiment 2 used a within-subjects design in which nonreinforced S− trials and nonreinforced L− trials were separated from adjacent C+ trials by 1 min and 2 min, respectively. Samples of the trial sequences used in Experiment 2 can be found in Figure 1. One advantage of this within-subjects design is that any generalized responding that the nonreinforced stimuli elicit has its origin in a single source, C+. A second advantage is that the critical nonreinforced trials are presented in an experimental context that has an identical training history.

Method

Subjects. The subjects were male hooded Lister rats supplied by Harlan Olac Ltd. (Bicester, U.K.). The rats were maintained at 80% of their ad-lib weights (Experiment 1: N = 24, M = 353 g, range = 326–382 g; Experiment 2: N = 16, M = 344 g, range = 331–361 g). The colony room in which the rats were housed was illuminated between the hours of 8:00 a.m. and 8:00 p.m. Training and testing began at 9:00 a.m. All rats had previously participated in studies of appetitive conditioning in which auditory stimuli signaled the delivery of food. Assignment of rats to conditions was counterbalanced with respect to the prior experimental treatments rats received.

Apparatus. Four operant boxes (Campden Instruments, Manchester, U.K.) were used. Each box had three aluminum walls and a Perspex door that served as the fourth wall. The ceiling was constructed from aluminum and the floor from stainless steel rods. Each box contained a recessed food tray to which 45-mg food pellets could be delivered. The opening to this food tray (6 cm high and 5 cm wide) was in the aluminum wall to the left of the Perspex door. Access to the food tray was gained by pushing a transparent flap that was attached by a hinge to the top of the opening. Pushing this flap from its vertical resting position actuated a microswitch, and each closure of the switch was recorded as a single response. As rats moved out of the food tray, the flap automatically returned to its resting position. Each box had four 3-W panel lights that were operated at 24 V. One of these lights was in a central position on the ceiling and provided background illumination in each of the experiments. The remaining three lights served as stimuli and were mounted on the wall that incorporated the recessed food tray. One light was mounted above the center of the entrance to the food tray and 15 cm above the floor. The remaining lights were mounted 7 cm to either side of the center of the food well and 10 cm above the floor. Each box was housed in a light- and sound-attenuating shell incorporating a ventilation fan that produced a background noise level of 68 dB (A weighting).

Procedure. On the first day of Experiments 1 and 2, rats received magazine training in which 20 food pellets were delivered on a variable-time 60-s (VT60) schedule. Subsequently, rats in Experiment 1 received a single discrimination training session on each of the next 10 days, and rats in Experiment 2 received two training sessions on each of the following 3 days.

In Experiment 1, all rats received 20-s presentations of the panel lights mounted to the left and right of the food tray. Presentation of one light was followed immediately by the delivery of two food pellets, and presentation of the second light was followed by no food; responding during the trials had no programmed consequences. The identity of the stimulus (left or right) that served as the reinforced or the nonreinforced stimulus was counterbalanced. There were 5 reinforced and 5 nonreinforced trials in each session.
The first trial was presented 4 min after the rats had been placed in the boxes. For rats in Group Short, the order in which reinforced S+ trials and nonreinforced S− trials were presented was pseudorandom, the constraint being that no more than two trials of the same type could occur in succession. For rats in Group Long, the same pseudorandom sequence was used to present reinforced L+ trials and nonreinforced L− trials. The interval between the offset of one trial and the onset of the next was 1 min in Group Short and 2 min in Group Long. Subjects in Group Short remained in the apparatus until those in Group Long had received their 10 trials, which thus equated overall exposure to the experimental apparatus.

In each session of Experiment 2, rats received 20-s presentations of the three panel lights that were mounted on the wall containing the food tray. Presentations of the center panel light were immediately followed by the delivery of two food pellets (C+ trials), and those of the left or right panel lights were nonreinforced. One-min intervals separated the onset of one nonreinforced light, S−, from the offset of the preceding C+ trial and the offset of the S− from the onset of the next C+ trial. Two-min intervals separated the onset and offset of the remaining nonreinforced light, L−, from adjacent C+ trials. The identity of the light (left or right) presented on S− and L− trials was counterbalanced. There were 10 trials in each session: 6 C+, 2 S−, and 2 L−. The C+ trials were presented in a fixed position in the sessions, and the position of the two types of nonreinforced trials within the sequence of C+ trials was counterbalanced. Thus in each training session, 4 subjects received one of the following sequences: Sequence 1 = C+, C+, S−, C+, L−, C+, C+, S−, C+, L−; Sequence 2 = C+, C+, L−, C+, S−, C+, C+, L−, C+, S−; Sequence 3 = C+, C+, S−, C+, L−, C+, S−, C+, L−; Sequence 4 = C+, C+, L−, C+, S−, C+, C+, L−, C+, S−. Within each session, half of the C+ trials were preceded by a 1-min stimulus-free period, and on the remainder, this period was 2 min; this arrangement meant that, pooling across the three trial types, the stimulus-free period preceding the presentation of a trial was, on average, 1.5 min.

The response measure used, referred to as net responses per minute (rpm), was the rate at which subjects responded during the 20-s presentations of each trial type minus the rate at which they responded during the immediately preceding 20-s periods (pooled across the different trial types within each session). The rejection level adopted for statistical analyses was \( p < .05 \).

**Results**

Experiment 1 used a between-subjects procedure to investigate the influence of trial spacing on discrimination learning. The results of Experiment 1, presented in two-session blocks, are shown in the upper panel of Figure 2. Inspection of this panel reveals that initially stimulus presentations tended to result in little magazine-tray activity or even to suppress this activity—a tendency that is more or less apparent in each of the experiments described in this article. This was to be anticipated given that rats had received magazine training on the previous day and that novel localized visual stimuli elicit a response, orienting, that tends to interfere with the target CR, magazine activity. Over the course of training, however, responding during reinforced trials increased and became more marked than responding on nonreinforced trials. More important, whereas there was no consistent difference in the rate of responding on reinforced trials between the two groups, rats in the short condition responded less vigorously on nonreinforced trials than those in the long condition. An analysis of variance (ANOVA) conducted on reinforced trials confirmed that there was an effect of block, \( F(4, 88) = 17.66 \), but no effect of condition and no interaction between these factors, \( F_s < 1 \). An ANOVA conducted on the nonreinforced trials revealed an effect of condition, \( F(1, 22) = 4.99 \), an effect of block, \( F(4, 88) = 4.18 \), and no interaction between these factors, \( F < 1 \). The rates of responding during stimulus-free periods in the two groups, with means of 3.63 rpm in Group Short and 3.25 rpm in Group Long, did not differ significantly, \( F < 1 \).

In Experiment 2 rats received intermixed presentations of nonreinforced S− trials separated from adjacent reinforced C+ trials by 1 min and nonreinforced L− trials separated from C+ trials by 2 min. The results of Experiment 2, again presented in two-session blocks, are depicted in the lower panel of Figure 2. Inspection of this panel reveals a pattern similar to that observed in Experiment 1. Thus, initial presentations of the panel lights tended to suppress magazine activity, but as training progressed rats responded at a higher rate during the stimuli than in their absence. It is also clear that rats responded at a higher rate both on C+ trials and nonreinforced L− trials than on S− trials. This description of the results is supported by an ANOVA revealing effects of trial type, \( F(2, 30) = 11.29 \), and block, \( F(2, 30) = 10.34 \), but no interaction between these two factors, \( F < 1 \). Tukey’s honestly significant difference (HSD) test indicated that subjects responded more vigorously both on C+ and L− trials than on S− trials. The rate of responding during stimulus-free periods was 4.29 rpm.

**Discussion**

The results of Experiments 1 and 2 demonstrate that massed training enhances the acquisition of a visual discrimination. These results are consistent with the suggestion that when a short interval intervenes between reinforced and nonreinforced trials, subjects learn something that reduces the extent to which what is acquired on reinforced trials generalizes to nonreinforced trials.1 There are at least two ways in which such a reduction in generalization might occur. First, presenting two stimuli close together in time might result in a bias toward subjects’ learning about aspects of the stimuli that differentiate them (see, e.g., Gibson, 1969, p. 145; see also Honey et al., 1994; Saldanha & Bitterman, 1951). Second, a nonreinforced stimulus might be especially likely to acquire inhibitory properties when presented shortly after a reinforced trial (e.g., Wagner, 1981). The acquisition of these inhibitory properties by a nonreinforced stimulus would counteract excitatory proper-

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1 In principle, the facilitation of discrimination learning observed in Experiments 1 and 2 might reflect rats’ becoming, for example, less satiated and therefore more likely to respond as the interval following the presentation of food is extended. The absence of group differences on C+ trials in Experiment 1 reduces the plausibility of accounts of this sort. More important, the results of Experiments 4 and 5 demonstrate the inadequacy of such accounts of the trial-spacing effects observed in Experiments 1–3.
ties that generalize to it from the reinforced stimulus. In Experiment 3 I investigated the two forms of explanation outlined above.

Experiment 3

A single group of subjects received presentations of three stimuli. One stimulus, the center panel light, was reinforced, C+. The remaining two stimuli, the left and right panel lights, were nonreinforced. These nonreinforced trials were presented in the intervals separating pairs of adjacent C+ trials. For one nonreinforced stimulus, designated SL−, a short interval (1 min) separated its onset from the preceding C+ trial, and a long interval (3 min) separated its offset from the next C+ trial. For the second nonreinforced stimulus, designated LS−, a long interval separated its onset from the preceding C+ trial, and a short interval separated its offset from the next C+ trial. Figure 3 depicts samples of the trial sequences used in Experiment 3. Inspection of Figure 3 shows that both types of nonreinforced trials, SL− and LS−, were presented equally closely to the C+. Accordingly, if massed training facilitates discrimination learning because it affords subjects the opportunity to “compare” the stimuli (Gibson, 1969), then the discrimination between the C+ trials and SL− and LS− should proceed equally readily. If, however, trial spacing modifies the acquisition of inhibitory properties on nonreinforced trials (Wagner, 1981), then responding on SL− trials should be less vigorous than on LS− trials—only SL− trials are presented shortly after reinforced C+ trials.

Method

Subjects and apparatus. The subjects were 16 naive male hooded Lister rats with a mean ad-lib weight of 372 g (range = 350–395 g). The rats were maintained at 80% of their free-feeding weights. The apparatus was that used in Experiment 1.

Procedure. On the first 2 days rats received magazine training in which 40 food pellets were delivered on a VT60 schedule. On the first day of magazine training, the flap covering the opening to the food tray was fixed in a raised position, and on the second day it was lowered and rats were required to move it to retrieve the food pellets. On the next 4 days rats received discrimination training with the three wall-mounted panel lights. Presentations of the center panel light were reinforced, C+ trials, whereas those of the left and right panel lights were nonreinforced. The nonreinforced stimuli were presented in the intervals between pairs of adjacent C+ trials. The onset of one nonreinforced stimulus, designated SL−, was 1 min after the offset of the first of a given pair of C+ trials, and the offset of SL− was 3 min prior to the next C+ trial. The onset of the second nonreinforced stimulus, designated LS−, occurred 3 min after the first of a pair of C+ trials, and the offset of LS− was 1 min prior to the onset of the next C+ trial.

The identity of the light (left or right) that served as the SL− or LS− was counterbalanced. There were 12 trials in each session: 8 C+, 2 SL−, and 2 LS−. The C+ trials were presented in a fixed position in the session, and the positions of SL− and LS− trials within the sequence of C+ trials were counterbalanced. Thus in each session of training, 8 rats received one of the following sequences and the remainder received the other sequence: Sequence 1 = C+, C+, SL−, C+, SL−, C+, SL−, C+, C+. C+, C+; Sequence 2 = C+, C+, LS−, C+, SL−, C+, C+. LS−, C+, SL−, C+, C+. Within each session, the stimulus-free period preceding presentation of a C+ trial was 1 min on half of the trials and 3 min on the remainder; this arrangement meant that, pooling across the three trial types, the stimulus-free period preceding the presentation of trial was, on average, 2 min.

Other details of Experiment 3 that have not been specified were identical to those of Experiment 2.
Results and Discussion

Inspection of Figure 4, which illustrates the results of Experiment 3, indicates that during the four blocks of training, rats came to respond at a higher rate in the presence of the stimuli than in their absence. More important, responding was more vigorous both on C+ trials and on LS- trials than on SL- trials. This description of the results is supported by an ANOVA that revealed main effects of trial type, $F(2, 30) = 24.98$, and block, $F(3, 45) = 11.01$, and an interaction between these factors, $F(6, 90) = 2.66$. Simple main effects indicated differences on Block 2, $F(3, 45) = 9.60$, Block 3, $F(3, 45) = 6.49$, and Block 4, $F(3, 45) = 21.28$. Tukey’s HSD test revealed that rats responded more vigorously on C+ trials than on SL- trials (Block 3) and that rats responded more vigorously on C+ and LS- trials than on SL- trials (Block 4). The rate of responding during stimulus-free periods was 5.14 rpm.

The results of Experiments 1 and 2 demonstrate that massed training enhances the acquisition of a visual discrimination. The results of Experiment 3 show that this effect relies on nonreinforced trials occurring shortly after reinforced, C+ trials. This finding is inconsistent with the suggestion that massed training facilitates discrimination learning because it gives subjects the opportunity to compare the target stimuli and thereby allows the process of perceptual learning to operate more successfully (Gibson, 1969). Rather, the results of Experiment 3 favor the suggestion that the recent presentation of a reinforced trial can, for a limited time period, produce conditions that allow the development of inhibition to a nonreinforced stimulus. In Experiment 4 I examined what aspect of a reinforced trial is responsible for this effect.

Experiment 4

There were two groups of rats in Experiment 4. All rats received two sessions of training on each day in which they received the same schedule of food presentations. These food presentations were signaled by a center light in one session, C+ trials, and were unsignaled in the other session.

Figure 4. Group mean response rates (net responses per minute, or rpm) in Experiment 3. Nonreinforced SL- and LS- trials were presented in the intervals between pairs of reinforced C+ trials. SL- trials occurred 1 min after the first of a given pair of C+ trials and 3 min prior to the second C+ trial, whereas LS- trials were presented 3 min following the first C+ trial and 1 min prior to the next C+ trial.
Rats also received nonreinforced presentations of two other stimuli, a left light and a right light. Presentations of one light were separated from those of food by a short interval (S− trials), and presentations of the remaining light were separated from food by a long interval (L− trials). For Group Signaled, S− and L− trials were presented in the session in which food presentations were signaled, and for Group Unsignaled these nonreinforced trials were presented in the session in which presentations of food were un signaled. If the trial-spacing effects observed in Experiments 1–3 reflect the relative recency of US presentations, then in both groups, responding on S− trials should be less vigorous than on L− trials. If, however, the difference in responding on S− and L− trials is brought about by differences in the relative recency of an effectively signaled reinforcer, then a difference between these two trial types should be apparent only in Group Signaled. The suggestion that the acquisition of inhibitory properties by a stimulus might be modulated not only by the recency of a reinforcer but also by whether or not that reinforcer is signaled has been discussed by Wagner (1981) and is an issue that is taken up in the General Discussion.

Method

Subjects and apparatus. The subjects, 32 naive male hooded Lister rats with a mean ad-lib weight of 380 g (range = 325–420 g), were maintained at 80% of their free-feeding weights. The apparatus was that used in Experiment 1.

Procedure. Rats were magazine trained in the manner described in Experiment 3 and then received two sessions of training on each of the next 6 days. During one of the sessions on each day rats received presentations of food that were signaled by the center panel light, C. In the remaining session unsignaled food was presented according to the same schedule. All rats also received nonreinforced presentations of the left and right panel lights. For rats in Group Signaled, these nonreinforced trials occurred in the session in which food was signaled by C. As in Experiment 2, for Group Signaled, presentation of one of the nonreinforced lights was separated from adjacent C+ trials by 1 min (S− trials) and presentation of the other light was separated from adjacent C+ trials by 2 min (L− trials). For rats in Group Unsignaled, nonreinforced S− and L− trials had the same temporal relationship to food as they did for rats in Group Signaled. However, for rats in Group Unsignaled, nonreinforced trials were presented in the session in which food was not preceded by C. Whether subjects received signaled food presentations in the first or second session in each day was counterbalanced. One of the rats in Group Signaled died during the experiment, and this rat’s scores together with those of the rat from the identical part of the counterbalancing in Group Unsignaled were omitted from the analysis of the experiment. Other details of Experiment 4 that have not been specified were identical to those of Experiment 2.

Results

The results of Experiment 4 are shown in Figure 5. The left-hand panel shows the behavior of rats in Group Signaled, and inspection reveals a pattern similar to that of Experiment 2. In particular, over the course of training rats came to respond at a higher rate on L− trials than on S− trials. The right-hand panel of Figure 5 shows the behavior of rats in Group Unsignaled. In this panel indicates that, unlike rats in Group Signaled, those in Group Unsignaled responded at similar rates during the two types of nonreinforced trials, S− and L−. This description of the results is supported by an ANOVA with group, block, and trial type as factors. This analysis revealed no effect of group, F(1, 28) = 2.42, an effect of block, F(2, 56) = 16.09, no interaction between group and block, F < 1, an effect of trial type, F(2, 56) = 4.10, no interaction between trial type and group, F < 1, an interaction between trial type and block, F(4, 112) = 3.07, and a three-way interaction, F(4, 112) = 2.45. I assessed the source of this interaction by conducting separate ANOVAs for each group. Analysis of the scores for Group Signaled revealed no effect of stimulus, F(2, 28) = 2.07, an effect of block, F(2, 28) = 8.58, and an interaction between these factors, F(4, 56) = 4.80. Analysis of simple main effects revealed a difference between the trial types on Blocks 2, F(2, 28) = 4.46, and 3, F(2, 28) = 3.98. Tukey’s HSD test indicated that the scores on L− trials differed from those on the S− trials on Block 2. A parallel analysis of the scores for rats in Group Unsignaled revealed no effect of stimulus, F(2, 28) = 2.18, an effect of block, F(2, 28) = 7.61, and no interaction between these factors, F < 1.

Figure 5 gives the impression that responding on C+ trials was somewhat lower in Group Unsignaled than in Group Signaled. It is therefore possible that the failure to find differences on S− and L− trials in Group Unsignaled reflected the fact that C+ had, for some reason, acquired less capacity to elicit responding. There are two reasons that reduce the tenability of this possibility. First, the impression that responding on C+ trials differed in the two groups is not supported by statistical analysis (see below). Second, on blocks of training where responding on C+ trials was essentially equivalent in Groups Signaled (Block 2) and Unsignaled (Block 3), there was a marked and significant difference only on the critical trial types (S− and L−) in Group Signaled. Supplementary ANOVAs were conducted that compared responding in Groups Signaled and Unsignaled on each of the trial types (C+, S−, , and L−). Analysis of C+ trials revealed that there was an effect of block, F(2, 56) = 8.31, but no effect of group, F(1, 28) = 1.40, and no interaction between these factors, F < 1. Analysis of S− trials revealed no effect of block, F(2, 56) = 2.07, no effect of group, and no interaction between these factors, F < 1. Finally, analysis of L− trials revealed an effect of block, F(2, 56) = 18.89, no effect of group, F(1, 28) = 1.31, and an interaction between group and block, F(2, 56) = 3.80. Analysis of simple main effects revealed that the groups differed on the second block of training, F(1, 73) = 4.85. The overall rates of responding during stimulus-free periods in the two groups, with means of 4.97 rpm for Group Signaled and 3.90 rpm for Group Unsignaled, did not differ significantly, F(1, 28) = 2.90.
**Discussion**

Experiment 4 examined the contribution of different aspects of the C+ trial, C and the reinforcer, to the effects of massed and spaced discrimination training. For all rats, presentations of one nonreinforced stimulus, S−, were separated from adjacent reinforcers by a short interval, whereas those of a second nonreinforced stimulus, L−, were separated from adjacent reinforcers by a long interval. For one group of rats, Group Signaled, the reinforcers presented in the critical sessions were signaled by the presentation of a center light, and in a second group, Group Unsignaled, these reinforcers were unsignaled. Rats in Group Signaled responded more vigorously on L− trials than on S− trials, whereas those in Group Unsignaled responded at an equivalent (and low) rate on the two types of nonreinforced trial. The results of Group Unsignaled suggest that a difference in the proximity of the delivery of food to S− and L− trials is not sufficient to produce differences in responding on these trials. The finding that a difference between massed and spaced training depends on the presence of an explicit signal for food is consistent with an account of associative learning incorporating the suggestions that (a) the presentation of a US can provoke opposing processes, and (b) the time course of these opponent processes differs and can be modulated by the presence of an effective signal (Wagner, 1981). I present a more detailed application of this account to the results of Experiment 4 and other experiments after reporting the results of a final experiment, Experiment 5.

**Experiment 5**

The results of Experiments 3 and 4 suggest that the beneficial effect of massed discrimination training (see Experiments 1 and 2) depends on the presentation of a nonreinforced trial shortly after a reinforced trial. One interpretation of these results follows from Wagner's (1981) theorizing, which assumes that a reinforced C+ trial activates an opponent form of the US representation that can, for a limited time period, support the acquisition of inhibitory properties by a stimulus. This interpretation attributes the beneficial effect of massed training to enhanced inhibitory conditioning—that is, to an effect on learning rather than performance. The results of Experiment 4 provide indirect support for this interpretation. In Experiment 5 I sought to provide more direct evidence regarding whether the trial-spacing effects observed in Experiments 1–4 reflect an effect on learning or performance.

There were two groups of rats in Experiment 5. Rats in Group Consistent received the same form of training as was given to rats in Experiment 2. Each rat received presentations of three panel lights. The center panel light was followed by the delivery of food (C+ trials), and the two
remaining lights were nonreinforced. One of the nonreinforced lights was separated from adjacent C+ trials by 1 min (S− trials), and the other light was separated from C+ trials by 2 min (L− trials). For subjects in the second group, Group Inconsistent, presentations of the center light were also reinforced (C+ trials). However, on nonreinforced trials the relationship between the identity of the visual stimulus (left or right) that was presented and the separation of that stimulus from C+ trials (1 min or 2 min) was inconsistent. Thus on half of the S− and L− trials the left panel light was presented, and on the remaining S− and L− trials the right panel light was presented. If the difference in responding between S− and L− trials in Experiment 2 reflects a simple performance effect, then rats in both groups should respond less vigorously on S− than on L− trials. If, however, the difference in responding on S− and L− trials is a consequence of a difference in what is acquired by a given stimulus on the different sorts of trials, then a difference in responding on these nonreinforced trials should be evident only in Group Consistent.

Method

Subjects and apparatus. The subjects were 32 male hooded Lister rats, maintained at 80% of their ad-lib weights; the mean ad-lib weight was 352 g (range = 315–383 g). All rats had previously participated in a study of appetitive conditioning in which auditory stimuli signaled the delivery of food. Assignment of rats to conditions was counterbalanced with respect to their prior experimental treatments.

Procedure. On the first day of Experiment 5, rats were magazine trained in the way described in Experiment 2. On each of the next 3 days all rats received two discrimination training sessions. Rats in Group Consistent received the same form of training as those in Experiment 2. Thus presentations of the center panel light were followed by the delivery of food (C+ trials), whereas presentations of the left and right lights were nonreinforced. One of the nonreinforced lights was separated from adjacent C+ trials by short, 1-min intervals (S− trials), whereas the second nonreinforced light was separated from adjacent C+ trials by long, 2-min intervals (L− trials). Rats in the second group, Group Inconsistent, received the same training procedure as those in Group Consistent with the exception that the identity of the stimulus (left or right light) presented on S− and L− trials was inconsistent across the two sessions within a day. The stimulus presented on S− trials during the first session of the day was presented on L− trials in the second session, and the stimulus presented on the L− trials in the first session was presented on S− trials in the second session. For all subjects there were 10 trials in each session: 6 C+, 2 S−, and 2 L−. In each training session, 8 subjects received one of the two sequences: Sequence 1 = C+, C+, S−, C+, L−, C+, C+, S−, C+, L−; Sequence 2 = C+, C+, L−, C+, S−, C+, C+, L−, C+, S−. Details of the procedure that have not been mentioned were the same as in Experiment 2.

Results

The results of Experiment 5 are illustrated in Figure 6. The left-hand panel shows the behavior of rats in Group Consistent, and inspection reveals a pattern similar to that observed in Experiment 2: After the first block of training, rats responded at a higher rate on C+ trials and on L− trials than on S− trials. The right-hand panel of Figure 6 shows the behavior of rats in Group Inconsistent. The differences in responding between the three types of trial were less marked in Group Inconsistent than in Group Consistent. By the final block of training, rats responded at a higher rate during C+ trials than during the nonreinforced trials and there was little difference between the two types of nonreinforced trials, S− and L−. Indeed, on this final block, responding on nonreinforced trials in Group Inconsistent was at a level that was intermediate in relation to the responding shown by Group Consistent on S− and L− trials. This description of the results was supported by an ANOVA with group and trial type as factors conducted on the final two blocks of training. This analysis revealed an effect of trial type, F(2, 60) = 28.15, and an interaction between trial type and group, F(2, 60) = 3.26, but no other significant effects or interactions, largest F(2, 60) = 1.44. Tukey’s HSD test revealed that rats in Group Consistent responded more vigorously on C+ trials than on L− trials and more vigorously on L− trials than on S− trials. It also revealed that rats in Group Inconsistent responded more vigorously on C+ trials than on either type of nonreinforced trial and that there was no difference between the two types of nonreinforced trial. The impression gained by inspecting Figure 6 that rats in Group Consistent responded more vigorously on C+ trials than in Group Inconsistent was not supported by a separate statistical analysis conducted on Blocks 2 and 3, largest F(1, 30) = 1.97. The rates of responding during stimulus-free periods in the two groups, with means of 4.66 rpm for rats in Group Consistent and 3.58 for those in Group Inconsistent, did not differ significantly, F(1, 30) = 2.26.

Discussion

The pattern of results observed in Group Consistent of Experiment 5 is similar to that found in rats given equivalent training in Experiment 2. Thus rats responded less vigorously during presentations of a stimulus separated from C+ trials by 1-min intervals (S−) than during presentations of a second stimulus separated from C+ trials by 2-min intervals (L−). A second group of rats, those in Group Inconsistent, also received nonreinforced trials separated from C+ trials by 1 min and 2 min. However, in Group Inconsistent the identity of the stimulus presented on S− and L− trials varied from one session to the next. In this group there was no difference between the rates of responding on S− and L− trials. This pattern of results suggests that the influence of trial spacing on discrimination learning does not reflect a simple performance effect—if it had, then a similar pattern of results should have been apparent in both groups of rats. Instead, the results of Experiment 5 suggest that what is learned about a given stimulus varies as a function of whether that stimulus is consistently separated from C+ trials by a short or long interval.
Figure 6. Group mean response rates (net responses per minute, or rpm) in Experiment 5. For all rats the presentation of reinforcement (+) was signaled by one visual stimulus, a center light, C. One-min intervals separated nonreinforced S− trials from adjacent C+ trials, and 2-min intervals separated nonreinforced L− trials from C+ trials. In Group Consistent (left panel) one stimulus (e.g., left light) was presented on S− trials and another (right light) was presented on L− trials. In Group Inconsistent (right panel) the identity of the stimulus (left or right light) presented on S− and L− trials varied from one session to the next.

General Discussion

This study investigating the influence of trial spacing on discrimination learning warrants a number of conclusions. First, within the range of temporal intervals used, massed discrimination training is a more effective means for establishing differential responding to two stimuli than is spaced training (Experiments 1–5). It should be noted, however, that a more extensive investigation including a wider range of intervals will be required in order to determine the generality of this conclusion. Second, this advantage does not rely on the general proximity of reinforced and nonreinforced stimuli (cf. Gibson, 1969), but rather reflects the fact that during massed training nonreinforced trials are presented shortly after reinforced trials (Experiment 3). Third, the difference between massed and spaced training does not represent, in any simple fashion, a performance effect, but instead reflects a difference in what is learned during a nonreinforced trial that follows the presentation of a signaled reinforcer (Experiments 4 and 5). Fourth, the results are consistent with an account of associative learning in which associatively generated opponent processes play a central role (Wagner, 1981; Wagner & Larew, 1985). Application of this account to the results summarized above is relatively simple.

According to Wagner (1981), an unsignaled US will provoke a primary state of activation (A1) in its central representation, whereas a US that is signaled will enter what can be regarded as an opponent state (referred to as the A2 state). It is assumed that when the occurrence of a stimulus is coincident with the A1 state, that stimulus can acquire the capacity to provoke A2 activity in the US representation, whereas when a stimulus is coincident with the A2 state it can acquire the capacity to suppress associatively provoked (A2) activity in the US representation. Given that the A2 state, once entered, is relatively short-lived, then it is to be expected that inhibitory properties will be more likely to accrue to a stimulus presented on S− trials than to one presented on L− trials. Consequently, future presentations of the S− should elicit less conditioned responding because these inhibitory properties will counteract excitation that generalizes from C+. Wagner’s model thereby provides a ready explanation for the behavior of subjects in, for example, Group Signaled (Experiment 4) and for the differences between Groups Consistent and Inconsistent (Experiment 5). The failure to observe differences in responding on the two types of nonreinforced trials in rats for whom food was not explicitly signaled (Group Unsignaled, Experiment 4) is also explicable within the theoretical framework presented by Wagner (1981). Thus, when food is unsignaled there are a variety of reasons to suppose that there might be a more
extended (or less well differentiated) period during which a stimulus could acquire inhibitory properties. For example, according to Wagner a poorly signaled US will first enter a primary state of activation, A1, that is of limited capacity and then enter the A2 state if displaced by un signaled stimuli. Clearly, under these conditions the window of opportunity for a stimulus to acquire inhibitory properties as a result of a recent US might be quite different from when the US is signaled. Alternatively, the inhibition acquired on S− and L− trials in Group Unsignaled might be based on the context’s capacity to provoke the A2 state in the US representation. Given that this capacity might be relatively high and invariant across temporal intervals during a session in which the US is not explicitly signaled, then responding on S− and L− trials might be expected to be equivalent in Group Unsignaled. The results of Experiments 1–5 are then consistent with Wagner’s theorizing. In the absence of the traditional (retardation and summation) assays of inhibition, however, this conclusion should be tempered with some caution.

My analysis of the results of this study emphasizes the benefits of adopting the approach to conditioning phenomena developed by Wagner (1981) and his colleagues. It is clearly possible, however, to extend more traditional analyses of simple conditioning (e.g., Rescorla & Wagner, 1972; see also Mackintosh, 1975; Pearce & Hall, 1980) to account for the influence of trial spacing on discrimination learning. For example, if the context’s associative strength declined during an interval following initial reinforced training trials, then a nonreinforced stimulus presented in the early portion of such an interval (S−) could acquire more inhibitory properties than one presented later in the interval (L−). This difference in the inhibitory properties of the two stimuli, acquired during initial training, would then be capable of counteracting generalized excitation from the reinforced stimulus in later training sessions when the context’s associative strength had become uniformly low.2

Before closing the discussion of this study, I refer the reader to the results of a recent study of pigeon autoshaping that appear inconsistent with those presented here. Janssen et al. (1995) reported that the presentation of a keylight is more likely to elicit withdrawal if it is separated from food by long as opposed to short intervals. In Experiment 4, increasing the separation of nonreinforced stimuli from food either had little effect (Group Unsignaled) or actually increased the tendency for subjects to show the CR of approach (Group Signaled; see also Experiments 1, 2, and 5). There are many differences between my experiments and those reported by Janssen et al. (1995), and it is difficult to be certain which of the differences, if any, contributed to the studies’ differing outcomes. However, it seems possible that a single explanatory framework might be developed to accommodate both sets of findings. For example, at the shorter of the intervals used by Janssen et al. (1995) the keylight may have acquired both excitatory and inhibitory properties. If, as the interval separating the keylight from adjacent food presentations was lengthened, the probability of excitatory learning declined, then this would allow the inhibitory properties of the keylight to be revealed.

The results of the present study have a number of general implications. First, at an empirical level, trial spacing can have different effects depending on the task that is studied, simple conditioning or discrimination learning. Second, the choice of intertrial interval in a discrimination training procedure might well have a profound influence on the basis of differential responding in that procedure. Finally, the differing effects of trial spacing on simple conditioning and discrimination learning can be accommodated within a single explanatory framework (Wagner, 1981).

2 It is much less clear that other analyses of simple conditioning (e.g., Gibbon & Balsam, 1981; see also Miller & Schachtman, 1985) could be similarly extended to account for the effects of trial spacing on discrimination learning. In particular, these analyses provide no grounds for anticipating differences in performance to two nonreinforced stimuli (presented in a common experimental context) as a function of their positions relative to prior reinforced trials (but see Barnet, Grahame, & Miller, 1993).

References


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