The Influence of Predictive Accuracy on Serial Autoshaping:
Evidence of Orienting Responses

Jacky A. Swan and John M. Pearce
University College, Cardiff, Great Britain

In four experiments we examined the influence of the predictive accuracy of the first element of a serial compound on the rate of autoshaped keypecking. In Experiment 1 a single group of pigeons received trials on two keys. On one key, Stimulus A was followed by either a 5-s conditioned stimulus (CS) or a different CS of 20-s duration. On the other key, Stimulus B was also followed by different stimuli, but both were randomly either 5- or 20-s duration. All trials ended with the delivery of food. It was found that responding was faster during A than B. Experiment 2 replicated this finding by using a between-groups design. In Experiments 3 and 4 response rates were faster to A, which was followed on some trials by a 10-s duration CS and on others by a 30-s duration CS, than to B, which was always followed by a 10-s duration CS. These results can be most readily explained by the proposal that autoshaped keypecking consists of two kinds of response—a conditioned response and an orienting response—and the strength of the latter is inversely related to the accuracy with which the immediate consequences of the CS can be predicted.

In this article we examine the proposal by Collins and Pearce (1985) that autoshaped keypecking in pigeons is composed of two classes of response: a conditioned response (CR) and an orienting response (OR). In keeping with the majority of contemporary views of autoshaping, Collins and Pearce (1985) suggested that the repeated pairing of an illuminated response key with food results in the growth of an association between internal representations of these events. The vigor of the CR is then held to be directly related to the strength of this association. The novel feature of their account is that superimposed upon this conditioned responding are ORs, also directed towards the illuminated key, which are held to be influenced by the "predictive accuracy" of the conditioned stimulus (CS). This term may be defined as the accuracy with which the value of the reinforcer that will immediately follow the CS can be predicted during that CS. When the keylight can serve as an accurate predictor of this value, then it is expected to elicit only a weak OR, but when training is such that this value is not reliably predicted, a substantially stronger OR is expected to occur.

Collins and Pearce (1985) presented a detailed theoretical account of these claims; here it is sufficient to note that they stem from two sources: first, from the Pearce and Hall (1980) theory which asserts that the predictive accuracy of a CS during conditioning determines the amount of attention it receives and, second, from the supposition that the strength of the OR directed toward a stimulus is directly related to the amount of attention subjects are paying to it (cf. Kaye & Pearce, 1984).

An experiment by Collins and Pearce (1985) provides some support for their claims. In this experiment two groups of subjects received serial conditioning trials in which the first element of the serial compound (A) could be followed by either of two different stimuli (B or C) that were subsequently followed by food or by nothing. In Group AB+0AC+/0 both of the second elements (B and C) were paired with food on half of their occurrences. These different stimuli should therefore possess equivalent associative strength and be of equal value as Pavlovian reinforcers. In this group, then, once conditioning has reached asymptote, subjects should be able to predict accurately the conditioned reinforcement that follows A, and as a result a weak OR should be directed toward this CS. In Group AB+0AC0, on the other hand, B was always paired with food but C was never paired with food so that B and C acquired entirely different associative strengths. In these circumstances subjects can never reliably predict during A which of two events with very different reinforcing values will follow, and A should therefore elicit a strong OR. The outcome of this design was a much faster rate of keypecking to A in Group AB+0AC0 than in Group AB+/0AC+/0. Because the strength of the CR toward A was expected to be the same for both groups, because A had the same relation with food, this difference was attributed to differences in the strength of the OR. It is also worthwhile to note that in both groups the eventual occurrence of food is poorly predicted by A. Although this might be expected to result in a strong OR to A in both groups, Collins and Pearce (1985) maintain that it is the accuracy with which the immediate consequences of a CS can be predicted that largely determines the strength of the OR it elicits.

This account of autoshaping is a recent one and, as such, has received only limited attention. To evaluate it further, in the experiments reported below, a novel procedure for manipulating the predictive accuracy of a serial compound was employed. Serial conditioning was used because it provides an opportunity to vary the predictive accuracy of a CS without modifying its relation with the unconditioned stimulus (US). In the first experiment a single group of pigeons received conditioning trials...
with four serial compounds. Two compounds, AX⁴ and AY²⁰, began with A and were presented on one key while the other compounds, BX⁵/₂⁰ and BY⁵/₂⁰ began with B and were presented on a different key. All trials terminated with the delivery of food, and the duration of A and B was always 10 s. Presentations of A were followed by either X⁴, which was consistently of 5-s duration, or Y²⁰, which was consistently of 20-s duration. Stimulus B was also followed by either of two stimuli, X⁵/₂⁰ or Y⁵/₂⁰, but the duration of each was randomly either 5 s or 20 s. The temporal relation between the first elements, A and B, and food is the same, and thus, as far as the CR is concerned, subjects might be expected to respond at similar rates during these stimuli. On the other hand, it is very likely that the conditioned properties of X⁴ and Y²⁰ will differ after several sessions of training, because X signals the arrival of food in 5 s, and Y, its arrival in 20 s. Consequently, during A, subjects will never be able to predict reliably which of two stimuli with different values as reinforcers will follow, and this should result in A's eliciting a relatively strong OR. The stimuli that follow B, however, share the same temporal relation with food so their conditioned properties should be similar. Subjects will thus be able to predict accurately the magnitude of the reinforcer that follows B, and a weak OR should be directed toward this CS during conditioning. Hence, if the Collins and Pearce (1985) account of autoshaping is correct, responding during A will ultimately be faster than responding during B. Because this prediction was confirmed, the remaining experiments that are reported examine the generality of this outcome and evaluate a number of different explanations for it.

Experiment 1

Method

Subjects

The subjects were 16 experimentally naive male pigeons with a mean free-feeding weight of 350 g (range: 291–460 g). Before training they were gradually reduced to 80% of their free-feeding weights by food deprivation and were maintained at this level by being given a restricted amount of food after each experimental session.

Apparatus

The apparatus consisted of four pigeon test chambers, each containing a three-key pigeon panel (Campden Instruments Ltd.). The keys, each 2.8 cm in diameter, were located 24 cm above the floor with a distance of 11 cm between their centers. Food was delivered by a grain feeder (Campden Instruments Ltd.), which was illuminated every time food was presented. The chambers were permanently illuminated by a 2.8-W bulb operated at 24 V and located 4 cm above the center of the central response key. The walls of the chambers provided some degree of sound proofing. Background noise was provided by the continuous operation of an extractor fan. A Cube microprocessor in an adjoining room used an Onlibasic program to control stimuli and record responses.

Procedure

Feeder training. On the first session, lasting 15 min, all subjects were placed in the chambers with the grain feeders permanently operated. For the next four sessions, each lasting 40 min, food was presented on a fixed time (FT) 60-s schedule. The feeder presented grain on successive sessions for 20, 10, 5, and 3 s. If, on any session, subjects failed to eat, they received additional training before progressing to the conditions scheduled for the next session.

Pretraining. All subjects received eight sessions of autoshaping during which two differently colored stimuli (red or green) were presented on each of two keys (center or right-hand side). The offset of these stimuli was followed immediately by operation of the feeder for 3 s. Sessions consisted of 40 trials, which occurred with an intertrial interval (ITI) of 65 s. Thirty trials were presented on one key. On half of these the key was illuminated with one color (red for the first 8 subjects and green for the second 8) for 5 s (X⁴), and on remaining trials it was illuminated with the other color for 20 s (Y²⁰). The 20 remaining trials were presented on the other key. Ten of these consisted of illumination of this key with one color (red for the first 8 subjects and green for the second 8) for either 5 s on half of its presentations or 20 s on the other half (Y⁵/₂⁰). Similarly, on remaining trials the key was illuminated with the other color for 5 s on half of its presentations and 20 s on the other half (X⁵/₂⁰). Side of stimulus presentation was counterbalanced across subjects, and the sequence of trials was random with the constraint that no more than three trials of the same type could occur in succession.

Prior to testing all subjects received two exposure sessions consisting of eight nonreinforced presentations of each response key, illuminated white for 10 s, randomly intermixed among 24 conditioning trials of the type presented in previous sessions. Trials occurred with an ITI of 65 s. The purpose of these sessions was to minimize the rate of keypecking to the stimuli to be employed as the first elements of the serial compounds prior to the test stage.

Testing. Subjects received 16 sessions of serial conditioning during which the stimuli that were used during pretraining, and with the same temporal parameters (X⁴, Y²⁰, X⁵/₂⁰, Y⁵/₂⁰), now served as the second elements of the serial compounds. Presentations of X and presentations of Y⁰ on one key were always preceded by white illumination of this key for 10 s (A). On the other key, presentations of X⁵/₂⁰ and Y⁵/₂⁰ were always preceded by white illumination of that key for 10 s (B). Thus each session consisted of 40 trials—10 each of the type AX⁴ and AY²⁰ on one key and 10 each of the type BX⁵/₂⁰ and BY⁵/₂⁰ on the other key. Trials occurred with an ITI of 65 s and terminated with food delivery. The sequence of trials was random, with the constraint that no more than three trials of the same type could occur in succession.

Results

Figure 1 shows the results for the final two sessions of pretraining in which A and B were occasionally presented alone and the results for the 16 sessions of testing. The left-hand panel displays the mean rate of responding during the first elements of the serial compounds, A and B. The effect of exposure to A and B was to reduce response rates to them. Analysis of variance revealed a significant effect of sessions, F(1, 15) = 7.72, p < 0.05. There was also a tendency to respond faster to B than to A though this was not statistically significant, F(1, 15) = 3.65, p > 0.05.

On the first day of testing, response rates were marginally faster to A than to B, and this difference increased as serial conditioning continued so that by the end of testing, subjects responded substantially faster to A. Analysis of variance for the 16 sessions confirmed that responding to these two stimuli differed over sessions by revealing a Stimulus × Session interaction, F(15, 225) = 2.30, p < .01, as well as an effect of stimulus, F(1, 15) = 6.96, p < .05. The effect of sessions was not significant, F(15, 225) = 1.30, p > .20. An analysis of simple main effects (Keppel, 1973, p. 430) showed that responding to A and B differed on Sessions 9–16, F(1, 15) = 5.55, p < .05, but not on the remaining sessions.
The right-hand panel of Figure 1 shows mean rates of responding to the second elements of the serial compounds. The means shown are for the initial 5 s of these stimuli. Thus, on trials when a 20-s stimulus appeared (all presentations of \( Y^{20} \) and half the presentations of \( X^{5/20} \) and \( Y^{5/20} \)) responding only during the initial 5 s is shown. Responding increased slightly to all stimuli over the final two sessions of pretraining and was faster to \( X^5 \) than to any other stimulus. Analysis of variance revealed a significant effect of stimulus, \( F(3, 45) = 7.02, p < .001 \), and of sessions, \( F(1, 15) = 6.60, p < .05 \), but no interaction between these factors (\( F < 1 \)). Subsequent multiple comparisons based upon the Newman-Keuls procedure for the two sessions combined showed that the difference between responding to \( X^5 \) and each of \( Y^{20}, X^{5/20}, \) and \( Y^{5/20} \) was significant but that these three did not differ (\( p \) set at .05).

Throughout testing, subjects responded substantially faster to \( X^5 \) than to \( Y^{20} \) and at similar, intermediate rates to \( X^{5/20} \) and \( Y^{5/20} \). Analysis of variance revealed a significant effect of stimulus, \( F(3, 45) = 12.43, p < .001 \), and of sessions, \( F(15, 255) = 2.50, p < .01 \). The Stimulus \( \times \) Session interaction was not significant, \( F(45, 675) = 1.11, p > .05 \). Multiple comparisons based upon the Newman-Keuls procedure for the 16 sessions combined showed that there was no difference in response rates to \( X^{5/20} \) and \( Y^{5/20} \) but that all other comparisons between stimuli were different (\( p \) set at .05).

**Discussion**

When an element of a serial compound was followed by stimuli that had different temporal relations with food, it elicited a higher response rate than when it was followed by stimuli that shared the same temporal relation with food. An interpretation of this finding in terms of the OR is straightforward. It rests on the assumption that the onsets of \( X^5 \) and \( Y^{20}, \) which appear in the compounds \( AX^5 \) and \( AY^{20}, \) are events of very different values to the animal, as indicated by the different rates of autoshaped keypecking they support. Thus, \( A \) is followed either by an event of high appetitive value (\( X^5 \)) or by an event of poor appetitive value (\( Y^{20} \)), and in this respect \( A \) can be regarded as an inaccurate predictor of its immediate consequences. As such, according to Collins and Pearce (1985), \( A \) should elicit a strong OR, which, combined with a CR will contribute to a high overall rate of keypecking.

In contrast, \( X^{5/20} \) and \( Y^{5/20}, \) which appear in the compounds \( BX^{5/20} \) and \( BY^{5/20}, \) should have the same appetitive value to the animal, as indicated by the similarity in response rates to them both. Eventually, therefore, subjects will be able to anticipate correctly the reinforcing value of the events that follow \( B, \) and this will result in a weak OR's being directed toward this CS.

**Experiment 2**

One aim of the next experiment was to discover whether the effect reported above can be obtained with a between-subjects design. Two groups of pigeons each received conditioning with two different serial compounds both of which commenced with \( A, \) which was followed by \( X \) in one compound and by \( Y \) in the other and then was followed by food. For Group \( X^5Y^{20}, \) \( X \) was consistently of 5-s duration and \( Y \) of 20-s duration, whereas the duration of these stimuli for Group \( X^{5/20}Y^{5/20} \) was randomly
either 5 s or 20 s. The reinforcing value of X and Y should eventually be similar for Group X\(^{3/20}Y^{5/20}\) and quite different for Group X\(^Y^{20}\). Consequently, if the findings from Experiment 1 are reliable, then responding during A should ultimately be faster for Group X\(^Y^{20}\) than for Group X\(^{20}Y^{5/20}\).

It was assumed in the previous experiment that because the first elements of the serial compounds had the same relation with food, their conditioned properties should not differ. A second aim of this experiment was to test this assumption. After receiving the serial conditioning described above, both groups received a number of sessions in which each of the original compounds was preceded by a new stimulus, B. If the associative strength of A is similar for the two groups, then, according to most accounts of Pavlovian conditioning (e.g., Rescorla, 1980), this CS should support equivalent rates of higher order conditioned responding during B.

**Method**

**Subjects**

The subjects were 16 experimentally naive male pigeons with a mean free-feeding weight of 344 g (range: 291–386 g). At the beginning of the experiment, subjects were randomly assigned in equal numbers to two groups. The deprivation conditions were the same as for Experiment 1. The apparatus was the same as for Experiment 1, except that all the response keys were used.

**Procedure**

**Pretraining.** Both groups received feeder training as described in Experiment 1. They were then given eight sessions of autoshaping. In each session there were 40 trials, which occurred with an ITI of 65 s. On half the trials a keylight (X) was presented on one side key, and on remaining trials a differently colored keylight (Y) was presented on the other side key. All trials terminated with food delivery. Stimuli X and Y were counterbalanced across groups for both color (red or green) and side of presentation. In Group X\(^Y^{20}\), X was always illuminated for 5 s, and Y was always illuminated for 20 s. In Group X\(^{20}Y^{5/20}\), X was illuminated for 5 s on half of its presentations and for 20 s on the other half. Similarly, Y was illuminated for 5 s on half of its presentations and for 20 s on the other half.

Prior to testing, both groups received two exposure sessions consisting of eight nonreinforced presentations of the center key illuminated white for 10 s, randomly intermixed among 16 conditioning trials with each of X and Y with the same durations as in previous sessions.

**Testing.** The first stage of testing continued for 16 sessions. Group X\(^Y^{20}\) received 40 trials in which the center key was illuminated white (A) for 10 s. For 20 of these trials, the offset of A was followed immediately by illumination of X for 5 s followed by food. The offset of the remaining 20 A presentations led immediately to illumination of Y for 20 s followed by food. Group X\(^{20}Y^{5/20}\) also received forty 10-s presentations of A. Of these presentations, the offset of 10 led immediately to illumination of X for 5 s, 10 led immediately to 20-s illumination of X, 10 led to 5-s illumination of Y, and 10 to 20-s illumination of Y. All trials terminated with food delivery, and the ITI was 65 s.

A second stage of serial conditioning was then given to both groups in which an additional element was added to the serial compounds. Prior to this stage of testing, all subjects received four sessions in each of which there were eight nonreinforced presentations of the center key illuminated yellow (B) for 10 s, randomly intermixed among 32 serial conditioning trials of the sort given in the first stage of serial conditioning. These trials occurred with an ITI of 65 s, and their purpose was to reduce the rate of responding to B.

Subjects then received six sessions of serial conditioning in which the trials were the same as those for the first stage except that A was always preceded by 10-s presentations of B. Thus each serial conditioning trial consisted of a series of three elements: B followed by A followed by X or Y, and finished with food delivery. There were 40 trials in each session which occurred with an ITI of 65 s.

Procedural details, where omitted, were the same as for Experiment 1.

**Results**

One subject had to be discarded from Group X\(^Y^{20}\) because it failed to acquire any autoshaped keypecking. Because the groups contained an unequal number of subjects, the data were analyzed by using nonparametric statistical tests.

The results of the final two sessions of pretraining, in which A was occasionally presented alone, and for the 16 sessions of the first stage of testing are shown in Figure 2. The left-hand panel displays the median rate of responding during A for the two groups. The effect of exposure to A was to reduce considerably the rate of responding to it. Further, response rates to A in Group X\(^{20}Y^{5/20}\) appeared to be higher than in Group X\(^Y^{20}\). Analysis of individual mean response rates for these two sessions combined confirmed that this difference was significant, Mann-Whitney $U = 10.5$, $p < .05$. This finding is unique to this experiment, and we can offer no explanation for it. The first day of serial conditioning did not result in a change in this relation, but from Session 2 onward it was reversed. Responding to A in Group X\(^Y^{20}\) was substantially higher than in Group X\(^{20}Y^{5/20}\), which responded at a very low rate. These observations were supported by statistical analysis of individual mean response rates over the 16 sessions combined, $U = 11$, $p < .03$, one-tailed.

The right-hand panel shows the median response rates to X and Y during the initial 5 s of each CS. Over the final two sessions of pretraining there was no difference in responding to X and Y in Group X\(^{20}Y^{5/20}\), Wilcoxon $T = 14.5$, $p > .10$. In Group X\(^Y^{20}\), on the other hand, the rate of responding to X was much faster than to Y, $T = 1.5$, $p < .05$. This pattern of responding was maintained throughout the first stage of testing. Analysis of individual mean response rates combined over the 16 sessions revealed no difference in response rates to X and Y in Group X\(^{20}Y^{5/20}\), $T = 7.5$, $p > .05$, but substantially faster responding to X than to Y in Group X\(^Y^{20}\), $T = 1$, $p < .05$. It appears from Figure 2 that on most testing sessions there was less responding to X in Group X\(^Y^{20}\) than to either X or Y in Group X\(^{20}Y^{5/20}\). However, analysis of individual mean response rates for the 16 sessions combined showed that there was no difference between responding to X in Group X\(^Y^{20}\) and to X in Group X\(^{20}Y^{5/20}\), $U = 20$, $p > .30$. There was also no difference between responding to X in Group X\(^Y^{20}\) and to Y in Group X\(^{20}Y^{5/20}\), $U = 20$, $p > .30$.

Figure 3 shows results from the second stage of testing, during which subjects received four sessions of B alone intermixed with serial conditioning trials, and six sessions of serial conditioning in which B immediately preceded A on every trial. The left-hand panel displays median response rates to B (open symbols) and to A (closed symbols). The effect of exposure to B was to reduce response rates to it. Analysis of individual mean response rates for the four sessions combined revealed no difference in responses to B between the two groups, $U = 18.5$, $p > .30$. The response rates for the eight serial conditioning sessions were compared using nonparametric statistical tests, and the results are displayed in the right-hand panel. The difference between responding to X in Group X\(^Y^{20}\) and to Y in Group X\(^{20}Y^{5/20}\) was statistically significant, $U = 11$, $p < .03$, one-tailed.
During subsequent serial conditioning with B, response rates to this stimulus remained at a low level in both groups. Analysis of individual mean response rates for these six sessions combined revealed that there was no difference between groups, $U = 23.5, p > .40$. Response rates to A, on the other hand, were quite different between the two groups. Animals in Group $X'SY^{20}$ responded to A at a higher rate than in Group $X'SY^{20} Y^{5/20}$. This difference did not quite reach significance over the four sessions of intermixed exposure to B, $U = 14, p = .06$, one-tailed. Over the six sessions of serial conditioning, however, analysis of individual mean response rates did show that this difference was significant, $U = 12.5, p < .05$, one-tailed.

The right-hand panel of Figure 3 shows median response rates to X and Y during the second stage of testing. As in the previous stage, responses only during the initial 5 s of these stimuli are shown. The pattern of response rates to these stimuli was the same as that shown during the first stage of testing. Subjects in Group $X'SY^{20}$ responded at a much higher rate to X than to Y both during the four sessions of exposure, $T = 0, p < .05$, and during the six sessions of serial conditioning with B, $T = 0, p < .05$. Response rates to X and Y in Group $X'SY^{5/20} Y^{5/20}$, however, were no different during the exposure, $T = 7.5, p > .05$, or during the serial conditioning components of this stage, $T = 7.5, p > .05$.

**Discussion**

The results replicate the findings of Experiment 1. Subjects responded faster to A in Group $X'SY^{20}$, where A was followed by events of different value, than in Group $X'SY^{5/20} Y^{5/20}$, where the events that followed this CS had the same value. Although the pattern of response rates to the second elements of the serial compounds in this experiment was slightly different from those of Experiment 1, the crucial relations were the same across experiments. In Group $X'SY^{20}$ response rates were substantially faster to X than to Y, thus confirming that these events had different appetitive values. In Group $X'SY^{5/20} Y^{5/20}$, on the other hand, response rates to X and Y were not statistically different, indicating that in this group these events had similar values. The predictive accuracy of A, then, was poor for Group $X'SY^{20}$ so that, in accordance with the claims made by Collins and Pearce (1985), this stimulus should have elicited a stronger OR and a faster response rate in this group than in Group $X'SY^{5/20} Y^{5/20}$ for which A served as an accurate predictor of its consequences.

As an alternative to this account, it is possible that the higher response rates to A in Group $X'SY^{20}$ than in Group $X'SY^{5/20} Y^{5/20}$ reflect differences in the vigor of the CR to this stimulus that, for some reason, arose from the different training schedules. The results from the stage in which a new stimulus, B, was added to the serial compounds do not support this suggestion. If A had acquired greater associative strength in Group $X'SY^{20}$ than in Group $X'SY^{5/20} Y^{5/20}$, then it should have supported a higher level of conditioned responding during B. This did not occur, suggesting that the conditioned properties of A were the same in both groups.

On the other hand, the results obtained with B are entirely consistent with the account offered by Collins and Pearce.
Because this stimulus was always followed by A, it should have served as an accurate predictor of its immediate consequences and elicited a weak OR in both groups. In addition, this account stipulates that, because the relation between B and food was identical for these groups, the CR that it elicited should also have been of equivalent strength.

Experiment 3

In the previous experiments we have proposed that the first elements of the serial compounds being compared elicit a CR of equivalent strength because their temporal relation with food is, on average, the same. This is justifiable only if the second elements of the serial compounds possess equivalent properties as reinforcers for serial conditioning. It is conceivable, however, that stimuli with fixed durations (X and Y) are more effective reinforcers than stimuli that have variable durations (X and Y). As a consequence, the first elements of the serial compounds that preceded the fixed duration stimuli may have elicited a stronger CR than those that preceded the variable duration stimuli. Although we found no evidence to support this suggestion in the previous experiment, it is possible that an insensitive measure of associative strength was employed. Consequently, the present experiment was conducted to substantiate our previous findings, using a procedure in which it will not be possible to attribute the outcome to differences in the influence of the CR.

In this experiment a single group of subjects was initially given autoshaping with two stimuli: one of 10-s duration (X), and one of 30-s duration (Y). Subsequently they were given serial conditioning with three different serial compounds. One of these began with A, which could be followed either by the short duration CS (X) or by the long duration CS (Y). The second began with B, which always followed by X, and the third began with C, which was always followed by Y. According to the account offered by Collins and Pearce (1985), the OR elicited by B and by C should eventually be quite weak because, during each of these stimuli, subjects will be able to predict accurately the reinforcing value of the event that follows—X in the case of B, and Y in the case of C. The reinforcing values of events following A, on the other hand, will be impossible to anticipate correctly, and this CS should elicit a strong OR, which may result in its maintaining a higher response rate than either B or C.

Alternatively, if the rate of keypecking is determined solely by the strength of the CR, the predictions are quite different. B always precedes X, which should be the most powerful reinforcer for higher order conditioning due to its close proximity to food. Further, B itself has a closer temporal relation with food than do either A or C, which are, at least on some trials, separated from food delivery by the long duration CS (Y). Thus, on these grounds, B should elicit the strongest CR and, therefore, the fastest response rate.

Method

Subjects and Apparatus

The subjects were 16 experimentally naive male pigeons with a mean free-feeding weight of 443 g (range: 326–570 g). Deprivation conditions and apparatus were the same as for Experiment 2.

Procedure

Pretraining. All subjects received feeder training as described in Experiment 1. They then received eight sessions during which 36 auto-
shaping trials occurred with an ITI of 80 s. On half the trials one side key was illuminated for 10 s (X), and on remaining trials the other side key was illuminated with the same color for 30 s (Y). All trials terminated in food delivery. Side of presentation of X and Y was counterbalanced across subjects.

Prior to testing, all subjects received one exposure session during which there were five trials each of A, B, and C presented alone, randomly intermixed among 15 conditioning trials with each of X and Y. Stimuli A, B, and C were all illumination of the center key for 10 s and were distinguished from each other by their color. Thus there were four different colors used in this experiment: red, green, yellow, and white. These were completely counterbalanced across the stimuli A, B, C, X, and Y, where X and Y were the same color but distinguished by side of presentation. The ITI was 80 s.

Testing. All subjects received 16 sessions of serial conditioning in which A, B, and C served as the first elements of the serial compounds, and X and Y, as the second elements. Each session consisted of 36 trials, which occurred with an ITI of 80 s. Twelve of these began with B followed immediately by X, 12 began with C followed immediately by Y, and 12 began with A followed on half of its presentations by X and on remaining presentations by Y. All trials terminated with food delivery.

Procedural details, where omitted, were the same as for Experiment 1.

Results

Figure 4 presents the results for the final session of pretraining in which each of A, B, and C were presented alone intermixed among conditioning trials with X and Y, and for the 16 sessions of serial conditioning. The left-hand panel displays the mean rates of responding to the first elements of the serial compounds, A, B, and C. The effect of the exposure session was to produce a low rate of responding to A, B, and C. A one-way analysis of variance showed that there was no difference among the response rates to A, B, and C on this session, $F(2, 30) = 1.21, p > .20$.

As testing progressed, response rates to C, which was always followed by the long duration CS (Y) became very low. There was no overlap in individual response rates to C with either of A or B from Session 4 onward, and several subjects did not respond at all to this stimulus. Consequently, response rates to C were not subjected to statistical analysis. During the early stages of serial conditioning, subjects responded at a faster rate to B than to A, and there was an increase in response rates to both these stimuli. By Session 8, however, this relation had reversed. Stimulus A continued to elicit a fairly high response rate, but responding to B dropped to a lower level. Analysis of variance of these data for the 16 sessions confirmed a significant Stimulus × Session interaction, $F(15, 225) = 3.76, p < .001$, as well as an effect of sessions, $F(15, 225) = 2.34, p < .01$, but the effect of stimulus was not significant ($F < 1$). Subsequent tests of simple main effects revealed that responding was faster to B than to A on Session 2, $F(1, 15) = 15.07, p < .01$, but that on Sessions 11–16 responding was faster to A than to B, $F(1, 15) > 4.95, p < .05$.

The right-hand panel of Figure 4 displays mean response rates to X and Y. Only response rates during the initial 10 s of these stimuli are shown. On the final session of pretraining, responding was much faster to X than to Y. This observation is supported by analysis of variance, $F(1, 15) = 10.04, p < .01$. During serial conditioning response rates were much faster to X than to Y. It was possible, in this stage, that responding to the second element of the serial compound would be affected by the nature of the first element. Analysis of variance was conducted, therefore, with the individual response rates during the second elements of the four compounds (AX, AY, BX, and CY). This analysis for the 16 sessions revealed a significant effect of stimulus, $F(3, 45) = 9.18, p < .001$. The effect of sessions ($F < 1$) and the Stimulus × Session interaction ($F < 1$) were not significant. Subsequent multiple comparisons based upon the Newman-Keuls procedure (Keppel, 1973, p. 433) confirmed that for all comparisons of X with Y, responding was much faster to X than to Y ($p < .05$), and response rates to these stimuli were not affected by the type of stimulus that preceded them ($p > .05$).

Discussion

The first element of a serial compound that was followed on some trials by a short duration CS and on others by a long duration CS eventually elicited a higher rate of keypecking than either one that was always followed by a short duration CS or one that was always followed by a long duration CS. These findings appear to be quite consistent with the account of autoshaped keypecking proposed by Collins and Pearce (1985).

One result that was not predicted was the faster rate, initially, of responding to B than to A. This finding is quite compatible with the Collins and Pearce (1985) account, however. At first B might be expected to elicit a strong OR because conditioning should not be at asymptote and subjects cannot yet fully predict the consequences of this CS. This OR, combined with a relatively strong CR, due to the close association of B with food as well as the secondary reinforcing properties of X, should then result in a fast rate of keypecking. After several sessions of training, however, subjects should be able to predict reliably the reinforcing value of the event that follows B. This will produce a weakening of the OR and could account for the gradual loss of responding to B as training progressed.

The present results are difficult to interpret purely in terms of the strength of the CR toward the first elements of these serial compounds because, for reasons specified in the introduction to this experiment, such an account predicts a consistently faster rate of responding to B than to either A or C, and this was not the case. There is, however, a competing response explanation for these findings that needs to be considered. Conceivably, the response rates elicited by A, B, and C were affected in part by subjects moving to the other key in anticipation of X or Y. Such a disruptive pattern of responding might have been weakest during A because the location of the CS that followed it varied from trial to trial.

Experiment 4

To evaluate the above possibility, a single group of pigeons initially received autoshaping with each of three stimuli—X, Y, and Z—all of which appeared on the center key of a three-key pigeon panel. Stimuli X and Y were always of 10-s duration, and Z was always of 30-s duration. Subsequently they were given serial conditioning with two different serial compounds. One of these began with presentation of A on one side key followed by either X or Z. The other began with B on the other side key followed by either X or Y. This procedure ensured that during
A and B subjects should be equally likely to approach the location of the second element of the serial compound because this was always projected onto the center key. As in the previous experiment, however, A should elicit a strong OR because subjects cannot predict which of two stimuli with different values as conditioned reinforcers will follow this CS. On the other hand, B should elicit a weak OR because it is followed by stimuli of equivalent value as reinforcers. According to the account put forward by Collins and Pearce (1985), then, A may eventually elicit a faster response rate than B.

Collins and Pearce (1985) have claimed that the OR elicited by an illuminated key consists of keypecks that combine with the CR, also keypecking, to produce the observed rate of responding. Alternatively, it is possible that the OR consists simply of approaching a stimulus. A strong OR toward a keylight may result in fast approach and thus allow ample time at the key for subsequent conditioned responding. According to this interpretation, all keypecks are CRs, but the latency to the first response will be shorter for a stimulus that elicits a strong rather than a weak OR. In order to test this alternative, latencies to the first response elicited by the first elements of the serial compounds were measured. In addition, the number of responses elicited by A and B were recorded during successive 2-s intervals of these stimuli.

**Method**

**Subjects and Apparatus**

The subjects were 16 experimentally naive male pigeons with a mean free-feeding weight of 435 g (range: 337–552 g). Deprivation conditions and apparatus were the same as for Experiment 2.

**Procedure**

**Pretraining.** All subjects received feeder training as described in Experiment 1. They then received eight sessions of autoshaping with three stimuli—X, Y, and Z. There were 40 trials in each session, and the ITI was 80 s. Twenty trials consisted of yellow illumination of the center key for 10 s (X). Ten trials consisted of illumination of the center key with a second color for 10 s (Y). Ten trials consisted of illumination of the center key with a third color for 30 s (Z). Stimuli Y and Z were counterbalanced for color (red or green).

Prior to testing, the birds were given two exposure sessions during which the stimuli to be employed as the first elements of the serial compounds (A and B) were each presented alone on five trials randomly intermixed among 40 conditioning trials of the type presented on other pretraining sessions. Stimulus A consisted of white illumination of one side key for 10 s. Stimulus B consisted of white illumination of the other side key for 10 s. Stimuli A and B were counterbalanced for side.

**Testing.** Serial conditioning was conducted on the next 20 sessions during which A and B now served as the first elements of the serial compounds and X, Y, and Z served as the second elements. Each session consisted of 40 trials, which occurred with an ITI of 80 s. Twenty trials began with A followed on half of its presentations by X and on the remaining presentations by Y. Twenty trials began with B followed on half of its presentations by X and on remaining presentations by Y.

Procedural details, where omitted, were the same as for Experiment 1.

**Results**

One subject had to be discarded from the experiment because it failed to acquire any autoshaped keypecking.

Figure 5 shows the mean response rates for the final two ses-
Figure 5. Mean rates of responding during the first elements of the serial
compounds (upper panel) and the second elements (lower panel) during
the exposure (EXP) sessions and the test stage of Experiment 4.

Response rates only during the initial 10 s of these stimuli are
shown. On the final two sessions of pretraining, responding to
Z was much slower than to either of X or Y, and responding to
Y was slightly faster than to X. Analysis of variance revealed a
significant effect of stimulus, \( F(2, 28) = 28.35, p < .001 \). The
effect of sessions was not significant, \( F(1, 14) = 1.97, p > .10 \),
and neither was the Stimulus \( \times \) Session interaction, \( F(2, 28) =
1.96, p > .10 \). Subsequent multiple comparisons based on the
Newman-Keuls procedure for the two sessions combined
showed that the response rate to Z was significantly lower than
to either X or Y (ps set at .01). The difference in response rates
to X and Y was also significant (p set at .05).

These relations were maintained during serial conditioning.
Analysis of variance for the 20 sessions of serial conditioning
revealed a significant effect of stimulus, \( F(2, 28) = 26.53, p <
.001 \), but no effect of sessions, \( F(19, 266) = 1.02, p > .20 \), and
no interaction between these factors, \( F(38, 532) = 1.01, p > .20 \).
Subsequent multiple comparisons based on the Newman-Keuls
procedure for the 20 sessions combined showed that the rate of
responding to Z was significantly lower than to either X or Y
(ps set at .01) and that responding to Y was faster than to X (p
set at .05).

Because subjects responded reliably faster to A than to B on
Sessions 17–20, these sessions were chosen to study the ultimate
pattern of responding to these stimuli. Figure 6 displays the
mean number of responses made in each 2-s interval of A and
B, expressed as a percentage of the total responses made dur-
ing each stimulus, for these four sessions combined. There was
a substantial increase in the rate of responding across succes-
sive intervals, but of more importance is the finding that this
pattern of responding is the same in the presence of both stim-
uli. Analysis of variance for these data revealed a significant
effect of interval, \( F(4, 56) = 7.39, p < .001 \), but no effect of
Figure 7. Mean latency to the first response per trial elicited by the first elements of the serial compounds during the final four test sessions of Experiment 4.

Figure 7 displays, separately for A and B, the mean latency to the first peck for Sessions 17–20 of serial conditioning. If a subject failed to respond on any trial, a time of 10 s was recorded. It is evident that although response latencies varied over sessions, there was very little difference in the response latencies to A and to B. Analysis of variance for these data revealed a significant effect of sessions, \( F(3, 42) = 6.94, p < .001 \), but no effect of stimulus \( (F < 1) \) and no interaction between these factors \( (F < 1) \).

Discussion

After sufficient training, subjects responded faster to A, which was followed by stimuli of different durations (10 s and 30 s) than to B, which was followed by stimuli of the same duration (10 s). This difference essentially replicates that found between response rates to A and B in Experiment 3.

In this experiment the key on which the second elements of the serial compounds appeared was always the same; hence, it is difficult to attribute the different response rates to A and B to variations in the extent to which the location of the subsequent CS can be predicted and approached.

There remains, however, an alternative competing response explanation for our findings. Gibbon, Farrell, Locurto, Duncan, and Terrace (1980) recorded the proportion of keypecks occurring during successive fifths of 10-s stimuli that were either partially or continuously reinforced. When the stimulus was partially reinforced, responding accelerated at a fairly uniform rate over the 10-s period. During the continuously reinforced stimulus, on the other hand, responding initially accelerated but then decreased as the end of the stimulus approached. Gibbon et al. (1980) argued that because the latter part of the continuously reinforced stimulus had a very close relation with the arrival of food, animals tended to engage in consummatory behavior towards the food hopper, which interfered with keypecking during this period. Further, they suggested that this may have been responsible for their finding that the continuously reinforced stimulus elicited a lower response rate than did the partially reinforced stimulus.

A similar argument could be applied to this experiment. Stimulus B had a closer temporal relation with food delivery than did A, and it was followed by stimuli with greater reinforcing properties. It is possible that during the final few seconds of B, competing responses either toward the food hopper or toward the key on which the short duration stimuli appeared interfered with keypecking and that this was responsible for the lower response rate to this stimulus.

This argument is not supported by the present results. Responding to A and to B accelerated throughout the trial. Further, there was no difference in the proportion of responses made during corresponding 2-s intervals of these stimuli, and this proportion was actually greatest during the final 2 s. To explain these results it would be necessary to propose that competing responses were stronger during B from the moment of its onset, and thus they produced an overall detrimental effect on keypecking to this stimulus. If this were the case, then animals should also take a longer time to approach and peck B than A because during B they are more likely to be engaged in competing responses elsewhere. The finding that there was no difference in the latencies to peck A and B, then, makes such a proposal improbable. Also the results from Experiment 1 are not amenable to a competing response explanation because, firstly, A and B had the same relation with food and, secondly, both elements of the serial compounds appeared on the same response key.

One unexpected result was that the response rates elicited by the two short-duration stimuli (X and Y) were not the same: Subjects responded faster to Y. It is possible that because X appeared on twice as many trials as Y, trial spacing favored a slightly stronger CR towards Y (e.g., Jenkins, Barnes, & Barrera, 1981). Alternatively, X was always yellow, and this color may have been less effective at maintaining autoshaped keypecking than red or green. Regardless of the reason for this finding, it remains the case that the reinforcing values of the short-duration stimuli that followed B must have been virtually the same, whereas the reinforcing values of the short- and the long-duration stimuli that followed A must have been quite different. According to the account developed by Collins and Pearce (1985), then, A will elicit the stronger OR because it is less accurate than B as a predictor of its reinforcing consequences.

The latencies to the first response elicited by A and by B were not different. This suggests that the OR contributes to the overall response rate directly by producing keypecks and not by
making approach toward the stimulus faster and therefore allowing more time for conditioned responding.

General Discussion

The four experiments demonstrate that the rate of auto-
shaped keypecking is faster to the first element of a serial com-
 pound, which is followed by stimuli that have different temporal relations with food than to one which is followed by stimuli that share the same temporal relation with food. Throughout, these findings have been interpreted by referring to the account of autoshaped keypecking proposed by Collins and Pearce (1985). Before turning to this account, however, we shall first consider alternative explanations for our results.

According to most contemporary theories of learning, auto-
shaped keypecking is a classically conditioned response, the magnitude of which depends upon the strength of the association between the internal representations of the keylight CS and the reinforcing event, that follows it (e.g., Rescorla, 1980). We should consider first, then, whether the present results can be adequately explained in terms of differences in the strength of conditioned responding elicited by the first elements of these serial compounds. The first element of the serial compounds studied here may potentially be associated with two reinforcing events. One is food itself, and the other is the second element of the serial compound. To the extent that the first element was always paired with food and that the temporal arrangement of this pairing was the same for both serial compounds in Experiments 1 and 2, and actually closer for B in Experiments 3 and 4, these results cannot be explained in terms of the relation between the first element and the US.

The properties of the second element of a serial compound, however, may also have an important influence on conditioned responding to the first element. Turning to the first two experiments reported here, the variable-duration second elements may have been less effective reinforcers for serial conditioning than the consistent-duration stimuli. One possible reason for this is that during conditioning, animals make preparatory responses that increase the value of a reinforcer (Perkins, 1955). In this case, for example, approach to the food hopper at the end of a trial might increase the magnitude of the reinforcer by allowing more time for the consumption of grain. Perhaps animals make these preparatory responses only when the time of arrival of food is well predicted by the CS. Hence, the consistent duration stimuli may acquire superior reinforcing strength by virtue of their association with a US that is larger than that paired with the variable-duration stimuli.

The different response rates, in Experiments 1 and 2, elicited by the first elements of the serial compounds could, then, result from differences in the associative strengths of these stimuli, mediated in some way by their pairing with consistent- or variable-duration second elements. The findings reported in Experiments 3 and 4, on the other hand, are much harder to explain in terms of this account. The time of arrival of food was well predicted during all the second elements and, theoretically, it should always have been possible for animals to make preparatory responses at the appropriate times. Further, in both experiments, B eventually elicited a lower response rate than A, despite the fact that it was followed by a CS which had a duration that was either equivalent to or shorter than the duration of the stimuli that followed A.

To explain our results within an account which states that all autoshaped keypecks are conditioned responses, it would be necessary to claim that the findings from the latter two experiments are due to greater interference during B from competing responses that are incompatible with keypecking to this stimulus (see Experiment 4 for a discussion of this issue). Though we cannot entirely dismiss such a claim, the findings from Experiment 4 make it improbable.

In contrast to the difficulties encountered by the above interpretations, the findings presented in this article are easily explained in terms of the account of autoshaped keypecking proposed by Collins and Pearce (1985). This states that autoshaped keypecking comprises two types of response: the CR, which is determined by the strength of the CS-US association, and the OR, which is inversely related to the predictive accuracy of the CS. If the events following a CS are always of equivalent value, then that CS has high predictive accuracy and will elicit a weak OR. Conversely, if these events have different values, then the CS has poor predictive accuracy and will elicit a strong OR. Finally, there is limited evidence from conditioning with rats that orienting behavior may provide an important indication of the associability of a stimulus (Kaye & Pearce, 1984). It remains to be seen, however, if this is the case in pigeon autoshaping.

References


Received January 5, 1987
Revision received April 6, 1987
Accepted April 20, 1987