Learning & Behavior (2021) 49:373–378
https://doi.org/10.3758/s13420-021-00478-1

Visual alternation by pigeons: Learning to select or learning to avoid

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Accepted: 12 July 2021 / Published online: 29 July 2021

Abstract
In the visual alternation task, pigeons learn to alternate between two stimuli (e.g., red and green) that vary randomly in location from trial to trial. The task is inherently difficult because animals tend to return to a stimulus to which they have just received reinforcement for responding. Williams (1971, *Journal of the Experimental Analysis of Behavior, 15,* 129–140) suggested that pigeons learn this task by learning to avoid the stimulus most recently chosen. The present experiment tested this hypothesis by involving three groups. The Standard Group replicated Williams' design. For the New Correct Group, following a correct (reinforced) response, on the next trial, the color of the new correct stimulus changed. For example, if it had been green, it changed to either blue or yellow, but the color of the new incorrect stimulus (the one that was just correct) remained the same (i.e., red). For the New Incorrect Group, following a correct response, on the next trial, the color of the new incorrect stimulus changed. For example, if it had been red, it changed to blue or yellow, but the color of the new correct stimulus remained (i.e., green). The Standard Group replicated Williams's finding that pigeons can learn the alternation task. Consistent with Williams's hypothesis, pigeons in the New Correct Group showed evidence of learning the alternation task, whereas pigeons in the New Incorrect Group showed little evidence of learning. Acquisition of the visual alternation task suggests that pigeons are cognitively flexible enough to overcome their natural tendency to repeat their most recently reinforced response to a stimulus.

Keywords Alternation learning · Learning to select · Learning to avoid · Pigeons

The alternation task involves the simultaneous presentation of two stimuli. Acquisition requires that the subject use its response to a particular stimulus as a cue to respond to the other stimulus. Learning theory (e.g., Thorndike, 1898) suggests that the acquisition of stimulus control depends on differential reinforcement in the presence of a stimulus. If responding to one stimulus has just been reinforced, on the next trial, subjects must learn not to repeat responding to that stimulus. If the stimuli involved in this task are spatially defined (e.g., choose left, then choose right) subjects can use their postural orientation as a cue to select the other stimulus (Boutros et al., 2011; Hearst, 1962; Kundey & Rowan, 2009; Travis-Neideffer et al., 1982). If the stimuli are nonspatial, and they vary in location from trial to trial, the use of location cues would not be useful. Research with primates suggests that the visual (nonspatial) version of this task is difficult to acquire (e.g., Ettlinger & Wegener, 1958; Nissen & Taylor, 1939; Pribram & Mishkin, 1956; Schusterman, 1962).

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Thus, it may seem surprising when Williams (1971) demonstrated that pigeons can acquire the nonspatial alternation task Williams's alternation task involved red and green stimulus lights that changed their spatial location randomly from trial to trial. Williams found that acquisition of the task depended on the number of pecks required of the pigeons to register each choice response. When few pecks were required (1 or 5 pecks) the pigeons showed minimal acquisition of the task, never getting much above 60% correct in 55 sessions of training. When the choice response requirement was 15 pecks, however, the pigeons showed good acquisition of the task, achieving almost 90% correct (see Sacks et al., 1972). Although Gagliardo et al. (1996) found that pigeons could learn a Y-maze version of the single alternation task more quickly than the choice key version, it is likely that the Y-maze version of the task involved more salient visual cues and more proprioceptive cues than the choice key version in which the cues were small key lights and little body movement was required.

According to Williams, acquisition of the visual alternation task requires that the pigeons learn to avoid making a response to the stimulus to which responding has just been reinforced. Williams proposed that learning to avoid the stimulus just chosen is what makes the task difficult for pigeons.

Consistent with Williams's hypothesis that the pigeons must learn to avoid responding to the stimulus just chosen, Williams (1975) found that pigeons could not learn a double alternation version of this task. That is, they could not learn to choose the same visual stimulus twice before choosing the other visual stimulus twice. In fact, he found that they could not learn the double alternation task even if the double alternation was based on a spatial discrimination (e.g., two choices of the left response key followed by two choices of the right response key).

Williams's (1971) hypothesis suggests that the pigeons learned to use reinforced pecking to one stimulus as a cue to avoid pecking that stimulus (or as a cue to peck the other stimulus). It is possible, however, that instead, the pigeons learn, after reinforced pecking to one stimulus, to anticipate choice of the other, the to-be-correct, stimulus on the next trial. Finally, it is possible that the pigeons learn both to avoid the stimulus just pecked and to peck the stimulus that they just avoided.

Thus, the purpose of the present experiment was twofold. First to replicate the results of the Williams experiment that found pigeons can learn a visual alternation task in which the visual stimuli change spatial location (left-right) randomly from trial to trial (Standard Group). The second purpose of the present experiment was to test more directly Williams' hypothesis about the learning mechanism responsible for alternation learning. We did this by asking for a second group (New Correct Group) whether learning the alternation task would be affected if, following a reinforced response to one stimulus, the color not chosen (the one that would be correct on the next trial) changed. If the pigeons had learned to avoid the stimulus just chosen, pigeons should be able to learn this task because the stimulus just chosen would still be present to be avoided. For a third group (New Incorrect Group) we asked whether learning the alternation task would be affected if, following a reinforced response to one stimulus, the color of that stimulus changed but the color of the other stimulus (the stimulus that was most recently incorrect but would next be correct) did not change. In this case, Williams' hypothesis would predict that these pigeons would have great difficulty acquiring this version of the alternation task because avoiding the stimulus just pecked would not be possible.

It is also possible that the pigeons could learn both to avoid the stimulus just pecked and to peck the stimulus just avoided. If so, the pigeons should be able to learn to alternate, regardless of whether following a reinforced response to one stimulus, that color changed or the color not chosen changed. In other words, the pigeons could learn to base their choice on both the color of the now correct stimulus (previously incorrect) or in terms of the color of the now incorrect stimulus (previously correct).

Method

Subjects

The subjects were 12 adult white Carneau pigeons (*Columba Livia*) purchased from the Palmetto Pigeon Plant (Sumter, SC). All subjects had had prior experimental experience with color discriminations, but had no prior experience with an alternation task. The subjects were maintained at 85% of their free-feeding weight via food obtained during experimental sessions, and additional feedings after experimental sessions, when necessary. Subjects were housed in individual wire cages (28 × 38 × 30.5 cm) under a 12:12-h light:dark cycle and had constant free access to grit and water. Subjects were maintained in accordance with a protocol approved by the Institutional Animal Care and Use Committee at the University of Kentucky.

Apparatus

The experiment was conducted in a standard operant chamber (28 × 32 × 32 cm). Three keys (2.5 × 2.5 cm) on the response panel were horizontally spaced 0.8 cm from each other, and 25.5 cm from the wire mesh floor. A 12-stimulus in-line projector mounted behind each key could project red, green, yellow, or blue colors via 28 V lamps on the left and right response keys. A feeder mounted on the response panel provided 2-s mixed grain reinforcement through an illuminated 5.1 cm × 5.5 cm rectangular cut out on the panel, equidistant between the right and left side response keys.

Procedure

Pretraining The pigeons were randomly assigned to one of three groups, Standard, New Correct, and New Incorrect. Each pigeon was given three sessions of pretraining. Pretraining consisted of single stimulus training with the stimuli appropriate to the group's conditions (Standard, red and green, New Correct and New Incorrect, red, green, yellow, and blue) presented randomly on the left and right keys. The number of pecks required for reinforcement were five on Session 1, 10 on Session 2, and 15 on Session 3. All pigeons were then given alternation training as specified below.

Alternation training For all pigeons, on Trial 1 of each session, a red light appeared on one key and a green light appeared on the other. Fifteen pecks (FR 15) to either key resulted in reinforcement and a simultaneous 4-s intertrial interval. If a pigeon switched keys before 15 pecks were made, the peck counter reset to zero and it was not counted as an error.

Standard Group For pigeons in the standard alternation group (Standard Group), on Trial 2, reinforcement was provided if the pigeons responded (FR15) to the color not selected on Trial 1. Incorrect pecks were not counted as errors unless 15 consecutive pecks were made to the same incorrect color. The counter reset if the pigeon switched stimuli before 15 pecks were made. If the color responded to on Trial 2 was the same as the color pecked on Trial 1, the trial was repeated (a correction trial). Correction trials continued until the pigeon pecked (FR15) the color not chosen on the preceding trial. On a correction trial, correct choice of the color not chosen on the preceding trial was reinforced, but for purpose of calculating accuracy was not counted as a correct alternation. Colors varied in location (left and right) randomly from trial to trial. Each session consisted of a total of 50 reinforced trials, including corrected trials.

New Correct Group Pigeons in the New Correct Group were trained as were pigeons in the Standard Group, with the exception that following reinforcement on Trial 1, the color of the old incorrect stimulus changed to either blue or yellow (randomly selected). For example, if on Trial 1, the pigeon had chosen the red stimulus (rather than the green stimulus), on Trial 2, the pigeon would have a choice between the red stimulus and either a blue stimulus or a yellow stimulus. In this case, on Trial 2, the blue or yellow stimulus would be correct. If the pigeon successfully pecked the new correct stimulus, following reinforcement and the intertrial interval, Trial 3 began. On Trial 3, what was the red stimulus (now the new correct stimulus) changed to one of the two colors not presented on Trial 2. The color that replaced the correct stimulus was selected from a list without replacement. Thus, for pigeons in the New Correct Group the color of the key just pecked could serve as a cue to peck the other color on the next trial. Trials proceeded in this way through the session, with repeat trials, as with the Standard Group.

New Incorrect Group Pigeons in the New Incorrect Group were trained as were pigeons in the Standard Group, with the exception that following reinforcement on Trial 1, the color of the old correct stimulus changed to either blue or yellow (randomly selected). For example, if on Trial 1, the pigeon had chosen the red stimulus (rather than the green stimulus), on Trial 2, the pigeon would have a choice between the green stimulus and either a blue stimulus or a yellow stimulus. In this case, on Trial 2, the green stimulus would be correct. On Trial 2, once the pigeon had successfully chosen the correct stimulus (the color not chosen on Trial 1), following reinforcement and the intertrial interval, Trial 3 began. On Trial 3 the new incorrect stimulus changed again to one of the two colors not presented on Trial 2. Thus, pigeons in the New Incorrect Group could use the color of the key not pecked on the preceding trial as a cue to peck that color on the next trial. Again, the color that replaced the correct stimulus was selected from a list without replacement. Trials proceeded in this way through the session with repeat trials, as for the Standard Group. For all groups, sessions were conducted 6 days a week for 75 sessions.

Transfer On the session following the last training session, pigeons in the Standard Group were transferred to the New Correct procedure for five sessions, and then to the New Incorrect procedure for five sessions. On the session following training, pigeons in the New Correct Group were transferred to the Standard procedure for five sessions, and then to the New Incorrect procedure for five sessions. Following training, pigeons in the New Incorrect Group were transferred to the Standard procedure for five sessions. They were not transferred to the New Correct procedure because accuracy on the training task was not better than chance.

Results

Acquisition

In a two-alternative discrimination task, one would expect chance to be at 50% correct. However, pigeons often tend to repeat a response to a stimulus if reinforcement had followed just having made a response to that stimulus. Thus, with this alternation task, initially one might actually expect pigeons to alternate at a level below chance. Group New Incorrect did in fact start below chance and never reliably exceeded chance. Group New Correct, on the other hand, did learn, but the pigeons in this group did so slowly and never got above 65% correct. The pigeons in the Standard Group also learned slowly but after considerable experience learned the task quite well. The learning functions for each subject in each group, as well as the group learning functions, appear in Fig. 1.

A two-way mixed-factors analysis of variance (ANOVA) performed on the acquisition data, with sessions as the repeated measure and group (New Correct, New Incorrect, and Standard) as the between groups factor, indicated that there was a significant effect of Group, $F(2, 9) = 7.71, p = .01, \eta_p^2 =$ 0.63, and Session , $F(14, 126) = 3.60, p < .001, \eta_p^2 = 0.29$. but the Group × Session interaction was not significant, $F(28, 126) = 1.29, p > .05, \eta_p^2 = 0.22$.

A one-way ANOVA performed on the pooled data from the last block of five sessions indicated that there was a significant group effect, $F(2, 9) = 8.19$, $p = .009$ $\eta_p^2 = 0.65$. Planned comparisons indicated that the Standard Group accuracy was significantly better than the New Correct and New Incorrect Groups combined, $F(1, 10) = 10.38$, $p = .009$ $\eta_p^2 = 0.51$, and that the New Correct Group was significantly better than the New Incorrect Group, $F(1, 6) = 8.86$, $p = .02$ $\eta_p^2 = 0.60$.

For the Standard Group, with the exception of the one pigeon that learned to 80.0% correct and then dropped to

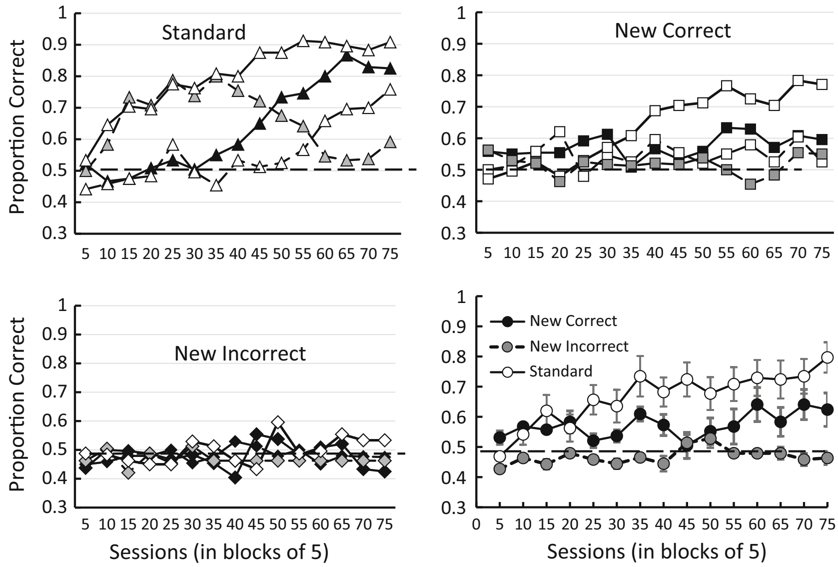

Fig. 1 Proportion correct over sessions (in blocks of 5) for each pigeon in each group: Standard (upper left), New Correct (upper right), New Incorrect (lower left), and the means for each group (lower right). Error bars indicate ±1 standard error of the mean

56.5% on the last block of five sessions, the other three pigeons' accuracy on the last block of five training sessions (240 trials) was 75.8%, 82.7% and 90.8%. For all four of the pigeons, accuracy was significantly above chance at the .05 level by a binomial test.

For the New Correct Group, accuracy on the last bock of training sessions was 55.2%, 56.5%, 60.2%, and 77.7%. For three of the four pigeons accuracy was significantly above chance (55.8% correct) at the .05 level by a binomial test.

For the New Incorrect Group, accuracy on the last bock of training sessions was 42.5%, 46.3%, 47.5%, and 53.3%, not significantly above chance for any of the four pigeons by a binomial test.

It should be noted that there are two kinds of learning involved in this task. We were interested in whether the pigeons could learn the alternation task, however, given that the task involves a correction procedure, initially the pigeons could learn a simple, lose-shift response pattern (see Randall & Zentall, 1997). That is, if pecking one key is not reinforced, the pigeon could switch to the other key without learning anything about the visual stimulus alternation task. This response pattern would work following an error but not following a correct response, so it would not alter the percentage correct. It would, however, show up as a decrease in the number of repeat errors (errors following an initial error, before a correct response). A plot of repeat errors as a function of session appears in Fig. 2. Although there was a larger number of repeat errors made by the pigeons in the New Incorrect Group on the first block of five sessions, the difference in repeat errors among the groups decreased quickly.

A two-way mixed-factors ANOVA performed on repeat errors, with sessions as the repeated measure and group (New correct, New Incorrect, and Standard) as the between groups factor, indicated that there was a significant decline in repeat errors over sessions, $F(14, 126) = 7.96$, $p < .001$ $\eta_p^2 = 0.47$. This indicates that in general the pigeons learned not to repeat errors. There was also a significant group effect, $F(2, 9) = 5.65$, $p = .03$ $\eta_p^2 = 0.56$; however, the Group × Sessions interaction was not significant, $F < 1$. The Standard Group showed the greatest decline in repeat errors with the New Correct Group close behind but by the end of training the Standard Group was making only about 12 repeat errors per session, whereas the New Correct Group was making more than 20 repeat errors per session. The New Incorrect Group started out making the largest number of errors (almost 50 repeat errors per session), and they never got below an average of 30 errors per session.

A one-way ANOVA performed on the pooled data from the first block of five sessions indicated that there was a significant group effect, $F(2, 9) = 5.21$, $p = .03$ $\eta_p^2 = 0.54$. Although the Standard Group repeat errors were not significantly lower than the New Correct and New Incorrect Groups

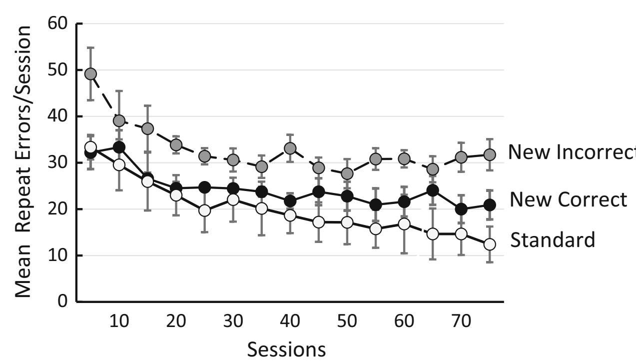

Fig. 2 Number of repeat errors as a function of training for the three training groups. Error bars indicate ±1 standard error of the mean

combined, $F(1, 10) = 1.20$, $p = .30$ $\eta_p^2 = 0.11$, the difference in repeat errors between the New Correct and New Incorrect Groups was significantly different, $F(1, 6) = 6.44$, $p = .04$ $\eta_p^2 = 0.52$.

Transfer

The transfer data are presented in Fig. 3. When the Standard Group was transferred to the new correct procedure, they suffered a small, nonsignificant drop in accuracy, $t(6) = 1.45$, $p = .20$, Cohen's $d = 1.18$; however, when they were transferred to the new incorrect procedure, they dropped to chance, $t(6) = 6.43$, $p < .001$, Cohen's $d = 5.27$. When the New Correct Group was transferred to the standard procedure, they suffered no drop in accuracy; however, when they were transferred to the new incorrect procedure, they too dropped to chance, $t(6) = 2.42$, $p = .04$, Cohen's $d = 1.98$. When the New Incorrect Group was transferred to the standard procedure, they continued to show chance accuracy.

Discussion

In spite of a pigeon's tendency to repeat choice of a stimulus to which responding has just been reinforced, consistent with the results of Williams (1971), the pigeons in the Standard Group, as well as to some extent, those in the New Correct Group showed significant learning of the visual alternation task. Pigeons in the Standard Group reached a mean accuracy of 77% correct, somewhat less than Williams' two pigeons, which reached 86% correct. Although one of the pigeons showed early signs of learning the task, its accuracy dropped to near chance with later training. It is not clear why this occurred. The other three pigeons in the Standard Group performed more like Williams' pigeons. That is, they acquired the task to a high level of accuracy.

The results of training suggest that learning to avoid the visual stimulus to which choice was most recently reinforced was critical to task acquisition. One of the pigeons in the New Correct Group learned the task well, while the other three pigeons performed consistently above chance. Removal of the to-be-correct stimulus did impair acquisition for pigeons in the New Correct Group, however, as can be seen by the difference in accuracy between the New Correct and Standard Groups. For pigeons in the New Correct Group, it may be that the unpredictability of the color of the stimulus to be selected contributed to the difficultly of the task. Alternatively, the pigeons in the New Correct Group learned to avoid the formally correct color but they also learned something about the old incorrect stimulus, as well, and when that color changed, it was more difficult for them to learn the task compared with the pigeons in the Standard Group. It is also possible that the difference in accuracy between the Standard Group and the New Correct Group could be attributed, at least in part, to the fact that the pigeons in the New Correct Group had stimuli of four different colors while the pigeons in the Standard Group had only two. In contrast to the pigeons in the New Correct Group, the pigeons in the New Incorrect Group showed little evidence of above chance accuracy. Thus, consistent with Williams (1971) hypothesis, the presence of the previously correct stimulus appears to be necessary for learning the alternation task.

The number of repeat errors mirrored the learning functions. Although the pigeons could have reduced the repeat errors to zero without actually learning the alternation task, by switching to the other stimulus following the absence of reinforcement, they did not appear to be able to do that. Apparently, the tendency to repeat a response to the stimulus most recently selected is difficult for pigeons to reject.

Transfer: The transfer data confirm that the basis for alternation learning appears to be learning to avoid the stimulus just selected. For the Standard Group, when the new correct stimulus was replaced, alternation accuracy showed only a small drop in accuracy. However, when the new incorrect stimulus (the old correct stimulus) was replaced, alternation accuracy dropped to chance. Similarly, for the New Correct Group, transfer to the standard procedure resulted in no decrement in alternation accuracy but transfer to the new incorrect procedure resulted in chance accuracy. As the pigeons in the New Incorrect Group failed to learn the alternation task, they

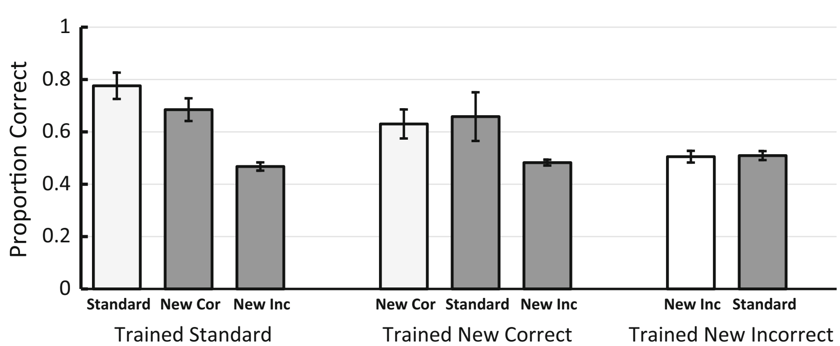

Fig. 3 Proportion correct for each training group following training and when they were transferred to the other conditions. For comparison purposes, accuracy on the last training session for each group is presented in unfilled bars. Error bars indicate ±1 standard error of the mean

did not benefit from transfer to the standard procedure over the five sessions of the transfer test.

The results of the present experiment suggest support for Williams' (1971) hypothesis that pigeons learn the alternation by learning to avoid selecting the stimulus that was just correct. Because pigeons tend to select the stimulus to which a response has just been reinforced, in the alternation task such a tendency would generally lead to an error. This tendency to repeat a reinforced response may explain why the alternation task is relatively difficult for pigeons to learn.

Virtually all of the research on alternation learning by animals has been done with rats and pigeons. Although there is considerable evidence that both rats and pigeons can learn a spatial single alternation task (Boutros et al., 2011; Hearst, 1962; Kundey & Rowan, 2009; Travis-Neideffer et al., 1982), there has been little research on single alternation learning of visual stimuli with rats. The difficulty of the visual alternation task likely results from the fact that the felt position of the animal's body cannot serve as a spatial cue to make the next response. In fact, because the visual cues are randomly alternated, any tendency to use the spatial cues as the basis for choice on the next trial would likely interfere with learning.

For humans, a simple alternation task is quite easy to learn. In fact, even young children can learn a double alternation task in which a stimulus is correct for two trials before the alternative stimulus is correct (e.g., Balling & Meyers, 1971; Hunter & Bartlett, 1948). For pigeons it is clearly quite difficult (Williams, 1975). The natural response for most organisms is to repeat a response to a stimulus to which it has been rewarded for a response in the immediate past. To acquire the alternation task, however, the pigeons must learn to use its pecking response to a particular stimulus as a cue to *avoid* pecking it again. Pigeons can learn to do that; however, when that cue is no longer present, pigeons do not appear to be able to learn the task (the new incorrect procedure). When that cue is present, but the new correct stimulus changes, pigeons can learn to alternate—but it is more difficult (because it is unexpected, or because it plays some role in learning what to do on the next trial). Thus, the present study adds to our understanding of the cognitive flexibility of pigeons, and how they learn to use cues that are incompatible with their associative tendencies.

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