Search for Hidden Objects by Pigeons:

Place Learning Vs "Object Permanence"

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A thesis submitted to the School of Graduate Studies of the University of Ottawa as partial fulfilment of the requirements for the degree of Masters of Arts in Psychology

ISBN 0-612-11592-5

UNIVERSITÉ D'OTTAWA
UNIVERSITY OF OTTAWA

I dedicate this thesis to my parents, Bernadette and Norman Kuzniak, and to my two cats, Tiffy and Lucy.

ACKNOWLEDGEMENTS

This research was supported by a University of Ottawa Supplementary Research Scholarship from the School of Graduate Studies and Research and by a Scholarship from the Natural Sciences and Engineering Research Council of Canada.

I wish to thank my supervisor Catherine Plowright, as well as Alain Desrochers and Pierre Mercier who sat on my thesis committee for their advice and suggestions.

Thanks also to Martin Gillett at the University of Ottawa for developing the computer program used in Experiment 2.

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ABSTRACT

Mental representation of hidden objects by pigeons was tested for. Experiment 1 used a series of Piagetian tests of "object permanence" to measure pigeons' capacity to find a stationary food target behind a screen. Performance on these tests did not differ significantly from chance in spite of manipulations designed to enhance the motivational value of the hidden object. Experiment 2 used operant contingencies to test whether pigeons could mentally represent a moving dot on a computer monitor that temporarily "disappeared" behind a screen. Two target durations were used (12 and 24 seconds) for the dot to move across a computer screen. Pigeons were reinforced if their first keypeck occurred when the dot was hidden but not if it occurred when the dot was visible. Phase 1 consisted of target-12 trials, phase 2 consisted of target-24 trials, and phase 3 consisted of alternating sessions of target-12 and target-24 trials. Results demonstrate that while pigeons were able to use timing strategies to respond correctly with an unconstrained choice method, evidence for the use of mental representations by pigeons was inconclusive. Both experiments are discussed in terms of the mechanisms used by pigeons to find hidden objects.

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Introduction

A general problem for animals in nature (and sometimes in the laboratory as well) is how to find something that is no longer in view. Central place foragers such as chipmunks (Giraldeau, 1982) and bumble bees (Plowright, O'Connell, Roberts & Reid, in press) return from food collection to their dwellings and their young. Nectar feeders must often find flowers which have been occluded by foliage (Korneluk & Plowright, 1995). Food hoarding birds such as Clark's nutcrackers (Balda & Turek, 1984) and chickadees (Sherry & Vaccarino, 1989) retrieve food which they themselves have cached. Predators catch hidden prey (Etienne, 1973; 1984), and prey must avoid predators that lurk invisible.

This thesis addresses the question of the mechanisms underlying the search for hidden objects. Insofar as the mechanism underlying adaptive behaviour is of interest, this thesis contributes to the general area of the "Behavioural Ecology of Learning" which lies at the interface between behavioural ecology and psychology (Shettleworth, 1984; Kamil, 1983). Two mechanisms are contrasted: the first is learning of an association between a particular place and a particular object, which does not necessitate any mental representation of the hidden object. The second mechanism is just such a mental representation, which has been studied under the heading of "object permanence" by researchers in human cognition (notably by Piaget, 1976) as well as animal cognition (for review see Doré & Dumas, 1987). The term "object permanence" is unfortunate in that it encompasses a variety of cognitive skills underlying a variety of behavioural outcomes (Pepperburg & Funk, 1990). Nevertheless, much of the research on object permanence is relevant here and a description of standard Piagetian methods is given below, followed by a more detailed explanation of the two mechanisms underlying search behaviour which are the focus of this thesis.

Piaget first pioneered the study of object permanence to assess the development of mental representation in infants. According to Piaget's theory (1976) object permanence develops through six consecutive stages. During the first three stages infants are unable to represent a hidden object; the infants behave as though the object no longer continues to exist once the object is no longer perceived. Once stage four is reached in their development infants can retrieve a completely hidden object behind a screen. It is during stage five that the infant's behaviour becomes more flexible and the child is able to successfully recover an object hidden consecutively behind a series of screens. Finally in the last stage, the infant can infer the displacement of the object which it had not directly perceived. As an example of a test assessing stage 6, an object hidden in a container is moved behind one of 3 screens, and then moved behind another. The object is left behind the second screen and the container emerges empty (Piaget, 1976). This "invisible displacement task" (the object is displaced from the container while it is behind the screen and so the displacement is invisible to the subject) is the highest achievement because the solution of the problem requires mental manipulation of the object.

While it is not known whether object permanence in animals develops through a series of stages as in infants, the standardized tests used to assess infants' capacity to represent hidden objects has been modified (Uzgiris & Hunt, 1975) and applied to a variety of species such as cats (Doré, 1990; Dumas, 1992; Dumas & Doré, 1989; Triana & Pasnak, 1981), dogs (Gagnon & Doré, 1992; 1993; 1994), psitaccine birds (Pepperberg & Funk, 1990), ring doves (Dumas & Wilkie, 1994), chickens (Etienne, 1973; 1984; Krushinskii, 1962), hamsters (Thinus-Blanc & Scardigli, 1981), and several species of primates (Mathieu & Bergeron, 1981; Mathieu, Bouchard, Granger, & Herscovitch, 1976; Natale, Antinucci, Spinozzi, & Poti, 1986; Redshaw, 1978; Wise, Wise, & Zimmermann, 1974). By applying a series of object permanence tests, usually to fully mature animals, investigators have hoped to determine whether the particular species studied possesses the capacity to represent the spatial information of the hidden object in memory.

Animals can successfully retrieve a hidden object by one of two methods: they can rely on associative cues between an object and its occluder, as in place learning, or they can maintain a mental representation of the object to guide its search behaviour. Testing for mental representation in animals requires the use of an experimental strategy different from the one used to test for place learning (as described below).

Studies measuring birds' capacities to mentally represent a hidden object have been done with two species of bird from the same subfamily as the pigeon (the Columbinae; Goodwin, 1970); that of the chicken (Etienne, 1973; 1984; Krushinskii, 1967) and the ring dove (Dumas & Wilkie, 1984). As well, this capacity has been studied in other unrelated species of bird; birds of the psitaccine family (Pepperberg & Funk, 1990) and birds of the corvidae family (Krushinskii, 1967).

Search Behaviour in Birds Using Place Learning

Cheng and Sherry (1992) have demonstrated that pigeons and chickadees can find hidden objects using visual landmarks. In their study, birds were trained to find food items covered with wood chips located near the edge of a large tray. Located near the hidden target was a landmark that was shifted occasionally. It was found that when the landmark shifted, the birds' searching behaviour shifted accordingly. This type of behaviour demonstrates how a hidden target can be found by birds using place learning; limiting their search behaviour to an area around a landmark.

Evidence for the use of place learning as a mechanism underlying search behaviour has also been reported by Etienne (1984) using chicks. Chicks were successful in finding a hidden target only in situations where the target was reliably paired with a specific location. When a mealworm was placed in a transparent tube and then disappeared, either by being moved to an opaque middle of the tube or by being passed through a screen at either end of the tube so that the worm disappeared on the other side, chicks pursued the worm only while it was still visible. With extended training the chicks learned to go behind a screen. However, it was the wrong screen as often as the correct one. Furthermore, they would occasionally run behind a screen even before the object had disappeared. Again, this study demonstrates successful search behaviour of a hidden target controlled by place learning.

Search Behaviour in Birds Requiring Mental Representation

To our knowledge Krushinskii (1967; 1990) was the first to study mental representation and food searching behaviour in several species of bird. Three methods were used to study birds' ability to extrapolate movement of a target. The first method required birds to follow a moving trolley filled with food. Once the birds were reliably following the trolley, it was manoeuvred through a flap into two opaque tunnels with a space between them. The response recorded was the direction, distance and duration of the search behaviour.

The second method involved the use of screens. Two vertical opaque screens were placed next to each other with a space between them. A flexible opaque flap hung down one side of the screen at right angles to its front view. Two targets, one bowl containing food and one containing no-food, were placed in the space between the two screens in front of the flaps. Once the birds had eaten for a few seconds, both targets were moved simultaneously through the flaps; one target moved behind one screen and the other target behind the other screen.

The third method was similar to the first. A food target was moved towards a platform in full view of the animal and then through a flap and under it so that it became invisible. Once the target was hidden, the animal was released and allowed to search for it.

With each method, it was found that in most cases pigeons and chickens, birds of the same subfamily, do not attempt to search for the hidden food. Birds of the Corvidae family, however, exhibited vigorous search behaviour in all tasks. For example, using the first task described above, birds of this family spontaneously ran to the middle of the tunnel and then to the end on the disappearance of the trolley.

In a similar study by Dumas and Wilkie (1994), successful search behaviour has been demonstrated in ring doves. In this study, two screens were placed beside each other with a space as above. A food target was placed in front of the screens, and the birds allowed to eat from it. The target was then moved behind one of the two screens while the bird was following it. It was found that in these conditions where the doves were already following the target before its disappearance, the birds could successfully search for the hidden target. However, in conditions where search behaviour was not already initiated, the doves were unsuccessful (success was not greater than chance). These findings are somewhat discrepant with Krushinskii's (1967; 1990) where pigeons, a similar species, as a general rule did not exhibit any search behaviour under similar conditions.

However, there is some evidence to suggest that pigeons can mentally represent hidden objects. Using a methodology adapted from mental rotation experiments in humans, Neiworth and Rilling (1987) have conducted a series of experiments studying mental representation in pigeons. Three types of trials were presented; perceptual, imagery, and violation (as described below). The birds were trained to match a keypeck to one key on perceptual and imagery trials and to match a keypeck to another key on violation trials.

The stimulus consisted of a clock hand that rotated at a constant velocity of 90 degrees per second. On perceptual trials, the clock hand rotated at a constant velocity and stopped at one of two orientations (135 degrees or 180 degrees). On imagery and violation trials, the clock hand rotated at a constant velocity to the 90-degree orientation, disappeared, and then reappeared at one of two orientation (135 degrees or 180 degrees). On imagery trials, the clock hand reappeared at the position consistent with the delay and velocity of the stimulus. In violation trials, the clock hand reappeared at a position inconsistent with the delay and velocity of the stimulus.

Once 80% correct responding was obtained, transfer to novel trials was high and the results suggest that pigeons can successfully extrapolate movement of an object using mental representation.

Evidence on the ability of pigeons to extrapolate movement is contradictory based on the results of studies by Neiworth and Rilling (1987) and Krushinsky (1967; 1990). The discrepancy suggests that successful search behaviour depends on the method used. In Krushinsky's (1967; 1990) experiments the predominant finding was the pigeons' inactivity, or lack of search behaviour. This suggests, based on the Neiworth and Rilling's (1987) findings, that perhaps in Krushinsky's (1967; 1990) study the testing situation was too unfamiliar or unmotivating, or some other factor was inhibiting their behaviour.

In this thesis two experiments are reported. In experiment 1 pigeons were presented with a stationary food target that was then hidden behind a screen. Pigeons were required to search for the hidden target by walking behind the correct screen. A number of manipulations were undertaken (see below) to enhance the motivational value of the hidden object so that the following prediction could be tested: if the birds retained a mental representation of the target then they would search for it and be able to retrieve it.

Experiment 2 presented pigeons with a moving computer generated dot that disappeared behind an occluder. They were rewarded for keypecking when the dot was invisible. The experiment had been designed to, ultimately, test whether the pigeons could anticipate the emergence of the dot which would have constituted strong evidence for a mental representation of the hidden dot. However, as described below, the most that the pigeons were capable of after almost a year of testing was to learn to keypeck when the object was hidden.

Therefore, experiment 1 tested pigeons' capacity to search for a hidden target that was static; a methodology adapted from the Piagetian studies discussed above. Experiment 2 investigated pigeons' ability to extrapolate movement of a hidden target. Both methods were designed to eliminate the successful use of place learning for responding towards the hidden target.

Experiment 1

The aim of this experiment was to assess pigeons' capacity to retrieve a hidden food target behind a screen. The procedures used in this experiment were similar to the ones used by Dumas and Wilkie (1994) and Krushinskii (1967) to assess search behaviour in various related species of birds, with the exception that in the present study the target was stationary and hidden at the time search behaviour was initiated. Otherwise, the object could be found just by "stumbling upon it" after moving in the same direction. The results from this experiment are used to compare the capacity of similar species of bird to find hidden food; that of the pigeon and dove. Finally, it will provide some additional empirical data to supplement the different empirical findings regarding pigeons' and ring doves' capacity to mentally represent hidden objects.

Method

Subjects

All subjects were White King pigeons with various operant training histories. Twenty-two birds were used during pretesting. One subject was excluded from test 1 due to illness, while two others were excluded from tests at different times during experimental testing due to lack of responding. This lack of responding was typically characterized by the bird exhibiting "nervous" behaviour, for example trembling, and becoming immobile while in the holding pen. In test 6, eight birds were run as a basis for a pilot study involving a 2 minute time-out for unsuccessful searches and the addition of visual markers (see procedure below).

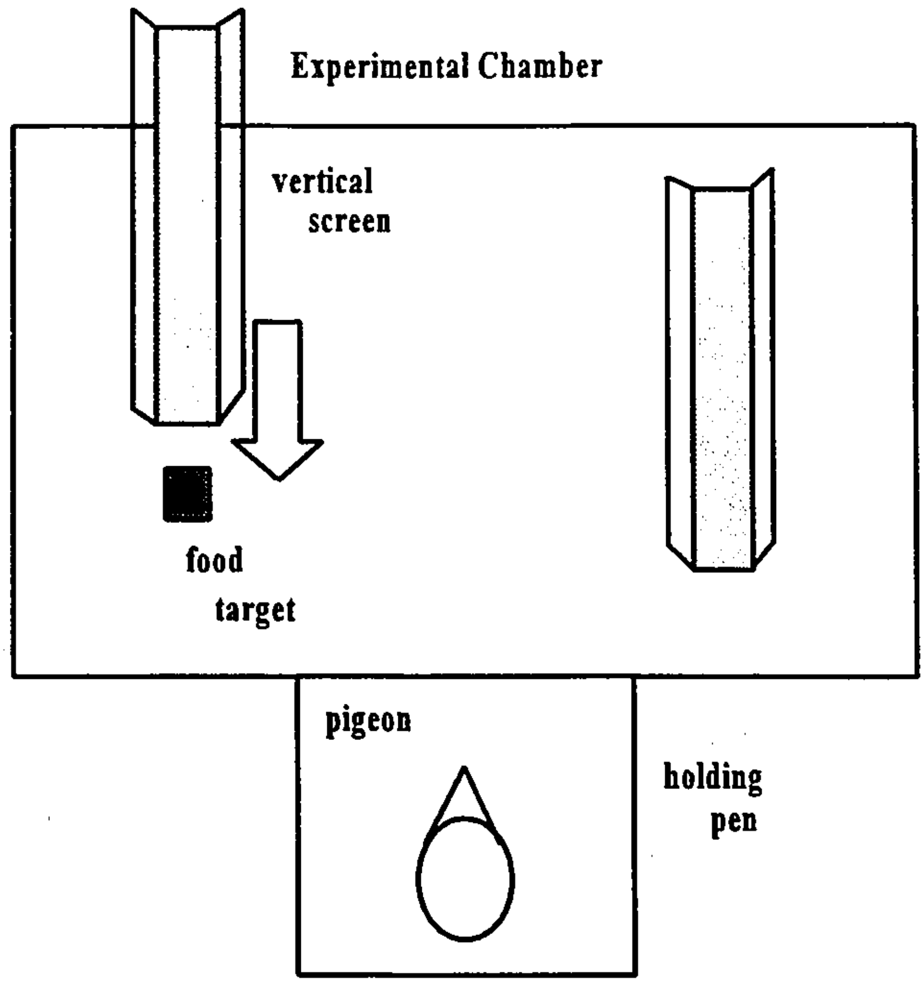
The birds were kept at 85% +/- 2% of their free-feeding weight by food obtained during the experimental sessions. Water and grit were available on a continual bases while birds were in their home cages.

Apparatus

A white opaque plexiglass T-maze served as a testing chamber (see Figure 1). The horizontal cross of the chamber served as the testing area, measuring 103 cm x 52 cm x 44 cm, while the vertical stem acted as a holding pen, measuring 31 cm x 21.5 cm x 44 cm. A clear plexiglass divider separated the cross and stem and could be raised and lowered by a pulley

Figure Caption

Figure 1: Diagram of the T-maze used in Experiment 1.


Experimental Chamber
vertical screen
food target
pigeon
holding pen

system. The chamber was fitted with a clear plexiglass top with slots cut out through which two black opaque plexiglass screens could be lowered. Two slots were cut on both the right and left sides of the top at two distances; one at 15 cm (near) from the holding pen and the other at 26 cm (far) from the holding pen. The screens were three-sided (6 cm x 6 cm x 6 cm) and measured 40 cm in height. A clear plastic dish filled with mixed grain served as the target in test 4; for all other tests an opaque food dish served as the target.

For test 6 cardboard coloured disks of various colours were affixed to one screen and a cardboard rectangle approximately 2 cm x 40 cm was affixed to the other. As well, a clear plexiglass rectangle 25.5 cm wide and 38 cm high was attached on each side of the divider on the inside of the experimental chamber to act as a chute. The chute prevented the birds from immediately hopping out of the holding pen in the direction of a particular screen by forcing the birds to enter the centre of the testing chamber at the beginning of each trial.

Pretraining and Procedure

Pretraining for tests 1 to 3 consisted of placing each bird in the holding pen and raising the divider to allow the bird access into the experimental chamber where food was placed in front of a screen. After 7 sessions when each bird would walk freely into the experimental chamber and eat, testing commenced.

Because of birds' overwhelming tendency to choose visible targets over hidden targets even in conditions where the incentive value of the hidden target was greater (i.e. greater amount of food, shorter distance, or no other alternative), an additional session of pretraining that differed from the one described above was run prior to running tests 4 to 6. The birds were trained to follow the food target while it was being moved behind a screen and then allowed to eat while behind the screen. By the end of 7 sessions all birds were following the target and eating behind the screen. Most Piagetian tests of object permanence make it a point not to train subjects to search for the target behind a screen during pretraining (Doré, 1990; Dumas & Doré, 1989), thus eliminating any association between the screens and the target before testing. The goal in this case however, was to eliminate any aversion that the birds might have to going behind the screens and to shape their behaviour as closely as possible to finding the hidden food during testing without actually "giving them the right answer". Place learning was still ruled out since the position of the hidden food was varied across trials during testing.

Each testing session consisted of 4 trials which began with the bird being placed in the holding pen. Once the bird was facing towards the experimental chamber, the food target was placed in position and the screen(s) lowered as required by each test. The left and right position of the target was counterbalanced across trials for each session. At the end of each trial, the bird was manoeuvred back into the holding pen and the divider lowered until the next trial which commenced immediately after.

Hidden targets consisted of placing the food dish at one of the two distances and lowering a screen through the top in front of it. A food dish simply placed in front of a screen acted as the visible target.

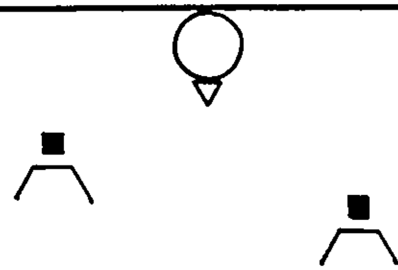
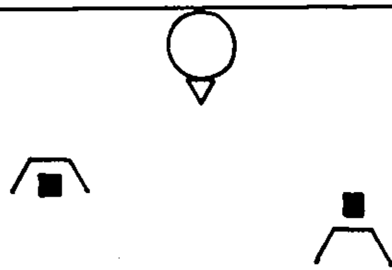
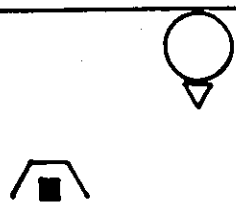
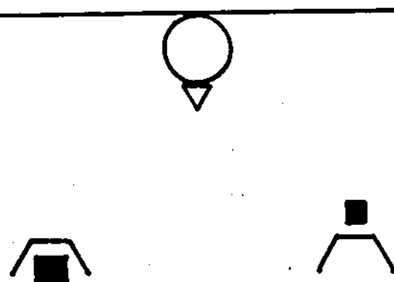
The screen that the bird approached first was recorded.

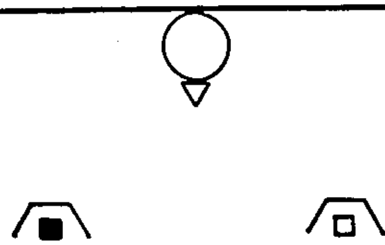
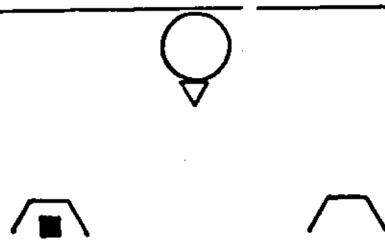
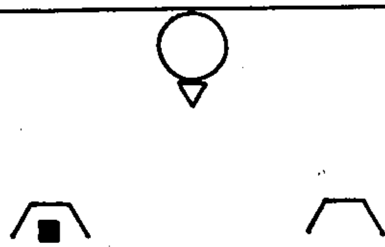
Testing Procedure

Two screens were used in all tests except test 2 in which only one screen was used. In tests 1 and 3, birds were presented with a choice between a visible and a hidden target. In all other tests a visible alternative was not presented (see Table 1). The value of the visible target

Table 1

Procedures Used in Experiment 1: Pigeons' Search Behaviour for Hidden Food

Test	Procedure	Prediction	Result
Pretest		Choose near target	Chose near target
Test 1		Choose hidden target	Chose visible target
Test 2		Choose hidden target	Inactive **
Test 3		Choose large hidden target	Chose small visible target

Test	Procedure	Prediction	Result
Test 4		Choose hidden target with food	Chance performance
Test 5		Choose hidden target with food	Chance performance
Test 6*		Choose hidden target with food	Chance Performance

* A two-minute time-out acted as a penalty for incorrect choices.

** Most birds did not attempt to search for the target (see Table 2).

■ Denotes a dish with food. □ Denotes an empty dish.

<u>Note</u>. Predictions about search behaviour towards hidden food targets were based on pigeons being able to represent hidden objects.

was always diminished in relation to the hidden target by increasing the distance or decreasing the food amount. In tests 4 to 6 two screens were used. However, only one of the screens hid a food target; the other screen hide either an empty dish or nothing. In all tests, the tasks presented to the subjects were analogous to visible displacement tasks which correspond to stage 4 object permanence tests. The difference in the present study was that the screen was moved in front of the target rather than the target moved behind the screen. Birds were not administered sequential visible displacement tests as is typical in Piagetian studies measuring object permanence. This approach was adopted based on evidence suggesting that pigeons do not exhibit search behaviour using a similar type of methodology (Krushinsky, 1967; 1990). The goal of the present experiment was to assess pigeons' search behaviour under the simplest conditions that would give them the greatest opportunity to exhibit searching behaviour.

Pretest: Birds were presented with two visible food targets of equal amount (approximately 2.5g) at a distance of 15 cm and 26 cm to determine whether they could perceive and respond to the distances used in the present experiment. Three sessions were run.

Test 1: On any given trial, birds were presented with a near-hidden target and a far-visible target or a far-hidden target and a near-visible target so that distance and occlusion were deliberately confounded. Three sessions were run to test the prediction that if pigeons were able to represent a hidden object then they would choose the near-hidden target over the far-visible target (since pigeons prefer near food over far food as shown from the results of the pretest).

Test 2: The target was positioned at the near distance and a screen lowered in front to determine if pigeons, when given no alternative, could retrieve a hidden target from behind a screen. If they could retrieve the food, then aversion to the screen could be ruled out as an explanation for failures in the other tests. Two sessions were run.

Test 3: The purpose of this test was to determine if food amount would affect the searching behaviour in these birds. Birds were presented with a large food amount (approximately 2.5g) that was hidden and a very small food amount (one corn kernel) that was visible. The distance for both was far. Two sessions were run.

Test 4: Test 4 was the first test using 2 screens with no visible target alternative. Two clear food dishes served as targets. One dish contained food and the other was empty and both targets were hidden. Thus birds were forced to choose between two hidden targets and the test was used to determine if they could recall which contained the food. One session was run.

Test 5: Again, two screens were presented to the birds but in this test only one target with food was used. This eliminated the birds having to notice two targets and focused their attention on one. Again, one session was run.

Test 6: Test 6 was a repeat of test 5 except that a 2 minute time-out acted as a penalty for going to the incorrect screen (for instance, the screen not hiding food). Visual markers made from cardboard were affixed to the two screens to make them more discernable to the birds. An alley was also added to the apparatus for this test to force the birds to walk straight out of the holding pen before making a choice and thereby reducing the chance of choices being made based on the birds orientation to a screen before the trial began. Ten sessions of 4 trials each were run.

Statistical Analysis

A G-test was used to analyse the frequency data of experiment 1 (Sokal & Rohlf, 1969). Since the values of G are completely additive, both pooled frequencies and heterogeneity can be tested. Pooled frequencies test the goodness of fit of our expected ratio of chance (50:50) to the group performance of the birds. The test for heterogeneity reveals any individual differences and allows the ratios from subjects that are not homogeneous to be identified (see Appendix A for an example of a calculation).

Results

The results of the pretest show that the birds could perceive and respond to the distances used in this study. Choices did differ significantly from chance, the birds always choose the visible food target and no individual differences were found (see Table 2 for G-tests).

Performance on test 1 did differ significantly from chance. However, this effect was due to the overwhelming number of choices by all birds to respond to the visible target. All birds chose the visible target 12 out of 12 times. In test 2 individual differences were apparent in search behaviour by the birds. Most birds remained inactive and did not search for the hidden target. Eight out of 20 birds did exhibit some searching behaviour towards the target and 4 out of 20 birds were successful in finding the target 5 out of 8 times (see Table 3).

Manipulating the food amount so that the food value of the hidden target was always greater than that of the visible target did not lead to birds choosing the hidden target. Once again, birds consistently choose the visible target over the hidden one. No individual differences were found.

In summary, the first three tests suggest that targets which are visible are a more powerful determinant of pigeons' search behaviour than ones that cannot be directly perceived. The targets in tests 4, 5, and 6 were always hidden and a visible target was never presented as an alternative. Performance for each of these tests did not differ from chance level and individual differences were not found.

Table 2

Results of Tests of Significance for Behaviour Differing from Chance

Object Permanence Test	Statistical Test	DF	G
Prestest	Pooled	1	333.15*
	Heterogeneity	21	19.334
Test 1	Pooled	1	349.348*
	Heterogeneity	20	0.00
Test 3	Pooled	1	141.142*
	Heterogeneity	19	21.428
Test 4	Pooled	1	0.0528
	Heterogeneity	18	7.268
Test 5	Pooled	1	0.039
	Heterogeneity	18	10.771
Test 6	Pooled	1	0.114
	Heterogeneity	7	1.804

*p<.05

Note. The expected ratio used to calculate tests of significance differing from chance was 50:50

Table 3

Proportion of Successful Search Behaviours Exhibited Towards Target

Bird	Pre-test	Test1	Test2	Test3	Test4	Test5	Test6
1	12/12	0/12	0/8	0/8	2/4	2/4	20/40
2	12/12	0/12	0/8	0/8	1/4	1/4	20/40
4	12/12	0/12	0/8	0/8	2/4	2/4	24/40
7	12/12	0/12	0/8	0/8	3/4	0/4	20/40
9	12/12	0/12	5/8	1/8	3/4	3/4	21/40
10	12/12	0/12	3/8	4/8	2/4	2/4	20/40
11	12/12	sick	sick	0/8	2/4	2/4	19/40
12	12/12	0/12	0/8	0/8	3/4	2/4	19/40
13	12/12	0/12	5/8	1/8	2/4	1/4	
14	12/12	0/12	1/8	1/8	2/4	2/4	
16	12/12	0/12	5/8	2/8	2/4	2/4	
17	12/12	0/12	2/8	2/8	3/4	2/4	
18	12/12	0/12	1/8	1/8	2/4	2/4	
20	12/12	0/12	0/8	0/8	2/4	2/4	
21	12/12	0/12	0/8	0/8	2/4	2/4	
22	12/12	0/12	0/8	0/8	1/4	1/4	
24	12/12	0/12	5/8	1/8	1/4	2/4	
25	12/12	0/12	0/8	0/8	2/4	2/4	
26	12/12	0/12	*	*	2/4	2/4	
5	12/12	0/12	0/8	0/8	**	**	
6	12/12	0/12	0/8	0/8	**	**	
19	9/12	0/12	0/8	**	**	**	

* Data are not available for this bird for these sessions since the bird was not run due to nervousness. The bird was re-instated for sessions 4 and 5.

** These birds were dropped from further testing due to nervousness.

Note. Observations about "nervous" behaviour were based on the birds' trembling and being immobile.

Discussion (Experiment 1)

The present study is the first to provide empirical data on pigeons visual-spatial memory using Piagetian methodology. It was demonstrated that pigeons consistently choose visible targets over hidden targets even when the hidden food is closer and/or larger than the visible food. When no food was visible and one screen concealed food, the birds choice behaviour did not differ from chance. Pigeons appear to rely on perceptual visual cues when searching for food and seem unable to represent the spatial position of an object that has been hidden in conditions where place learning is not a factor.

In a similar study of object permanence in the ring dove, the birds were able to recover a completely hidden object only if search behaviour was initiated before the target was completely hidden (Dumas & Wilkie, 1994). In the present study with pigeons, the target object was stationary at the time of search. The fact that the ring doves were already in the process of following the food and moving in the direction that the target was to be hidden may account for the differences in the performance of the ring dove and pigeon. In fact, Piaget's theory on object permanence does identify successful search that is initiated before the complete disappearance of an object as being earlier in the development of visual mental representation in infants than successful performance on tasks where search behaviour is initiated after the complete disappearance of the object (Piaget, 1976). It would appear that in either case, that visual mental representations of a hidden target are weak and short-term in both species using this type of task.

As in Krushinsky's (1962; 1990) studies described earlier, pigeons in the present study failed to recover hidden targets. The tests used in Krushinsky's experiments were slightly different in that again, the target was moving. But the fact that this factor appears to have facilitated the performance of ring doves (Dumas & Wilkie, 1994) in recovering hidden targets leaves its significance uncertain. If indeed, moving in the direction of the hidden target before it disappears facilitates performance, then pigeons should have performed better in Krushinsky's study. However, the distance that the pigeons would have had to extrapolate the trajectory of the still moving target in his tunnel experiments was in fact very long (2 m). If the representation of the object was weak or unstable to begin with, one would expect that it would fade relatively quickly and before the reemergence of the trolley. Nonetheless, in our lab we have replicated the results of Krushinsky's (1962; 1990) tunnel experiments using a slightly modified apparatus with varying, and much shorter, distances in which a food trolley disappeared through an opaque tunnel (Kilian, 1995). The procedure had been modified and a control added so that one group of birds was presented with the visible trajectory of the target before being presented with the hidden trajectory of the target. As expected, birds could recover and anticipate the location of a moving visible target. The pigeons, however, behaved much like the chicks in Etienne's (1973) study when presented with a moving hidden target: they darted to the end of the tunnel in anticipation of food even when the trolley was filled with only grit and no food. This behaviour suggests that the birds relied on a rule: go to the end of the tunnel to find the food. This strategy is similar to place learning and there was no evidence that they actually mentally represented the food target.

To date, several studies on similar species of birds such as the chicken (Krushinsky, 1962; Etienne, 1973; 1984), the ring dove (Dumas & Wilkie, 1994) and the pigeon (Krushinsky, 1967; 1990; Kilian, 1995) have failed to reveal a mental representation of hidden food, even though numerous manipulations have been undertaken to reveal the workings of such a representation. If pigeons do have the capacity to mentally represent objects and are indeed able to recover completely hidden objects in conditions where place learning is unsuccessful, then procedures more sophisticated than the ones used so far may be needed.

Experiment 2

One of the behavioural criteria for demonstrating object permanence is the ability to mentally represent the displacement of a moving hidden target (Etienne, 1984). In experiment 1 as well as other studies (Dumas & Wilkie, 1994; Etienne, 1973; Krushinsky, 1967; 1990) pigeons fail to recover hidden targets when given a choice between two potential hiding places. However, in a different experimental paradigm there is evidence that pigeons can anticipate the position of a hidden object.

Neiworth and Rilling (1987) presented pigeons with a clock hand stimulus that rotated at a constant velocity to determine whether a visual representation could control their choice behaviour. The birds were presented with 3 types of trials. On perceptual trials the clock hand was always visible, while on imagery trials the clock hand would disappear at the 90-degree position for a certain delay, and then reappear at a position consistent with the delay. On violation trials, the clock hand did not reappear at a position consistent with the delay.

The birds in this study were required to discriminate between a clock hand that rotated at a constant velocity (perceptual and imagery trials) and ones that violated this rule of constant velocity. It was found that accuracy on novel trials was high and consistent with the accuracy obtained on training trials. The results of this study suggest that not only are pigeons able to process visual information that is not immediately perceptible, but that they can transform this information in memory to successfully anticipate the position of a moving object. This finding is inconsistent with evidence from Piagetian studies that suggest pigeons are unable to mentally represent hidden objects even under the simplest conditions. It is not immediately apparent as to what the critical difference was in the task used by Neiworth and Rilling (1987) that led to the pigeons successfully representing the object.

The purpose of experiment 2 was to investigate whether pigeons could estimate the location of a hidden moving target using a simplified version of Neiworth & Rilling's (1987) method. Pigeons were presented with a computer generated dot moving at a constant velocity in a straight line that could also be interpreted as an operant version of Krushinsky's (1962; 1990) study with the moving food trolley through a tunnel.

Pigeons were trained to respond when a target disappeared behind an occluder. Two target durations were used: the target moved across the computer screen within 12 seconds or 24 seconds. In the first case the dot disappeared after 3s and reemerged after 6s, and in the second case it disappeared after 6s and reemerged after 12s. Once consistent responding to each of the targets had been established, presentations of the two target durations were alternated. Correct responding on the alternating trials would eliminate the possibility of the birds using a single timing mechanism to predict when the target would disappear. A timing mechanism in this case would consist of the birds following a FI of 3-6s or 6-12s based on the type of trial being presented. In the case of an FI of 3-6s, the birds could follow a simple rule, "wait 3-6s seconds, then keypeck" to obtain reinforcement. When the target duration was 24s, the FI rule of 3-6s would no longer work: only waiting 6-12s before keypecking would yield a reward. By alternating trials, attending to the visual stimulus of the moving target would be necessary for correct responding.

Alternating trials would not guarantee that the birds mentally represent the hidden target however. The birds could adopt a strategy in which the different velocities of the targets are discriminated and based on this discrimination, the same timing strategies available during the initial phases of training could be used again.

To test whether pigeons are able to mentally represent a hidden target would require that the birds anticipate its location behind the screen. The present study had been designed as a series of gradual approximations to a final task requiring the birds to anticipate the re-appearance of the target just as it was reemerging from behind the screen. As discussed below, the final objective was not attained after almost a year of training and testing and only the tasks leading up to this stage were mastered by the birds.

Method

Subjects

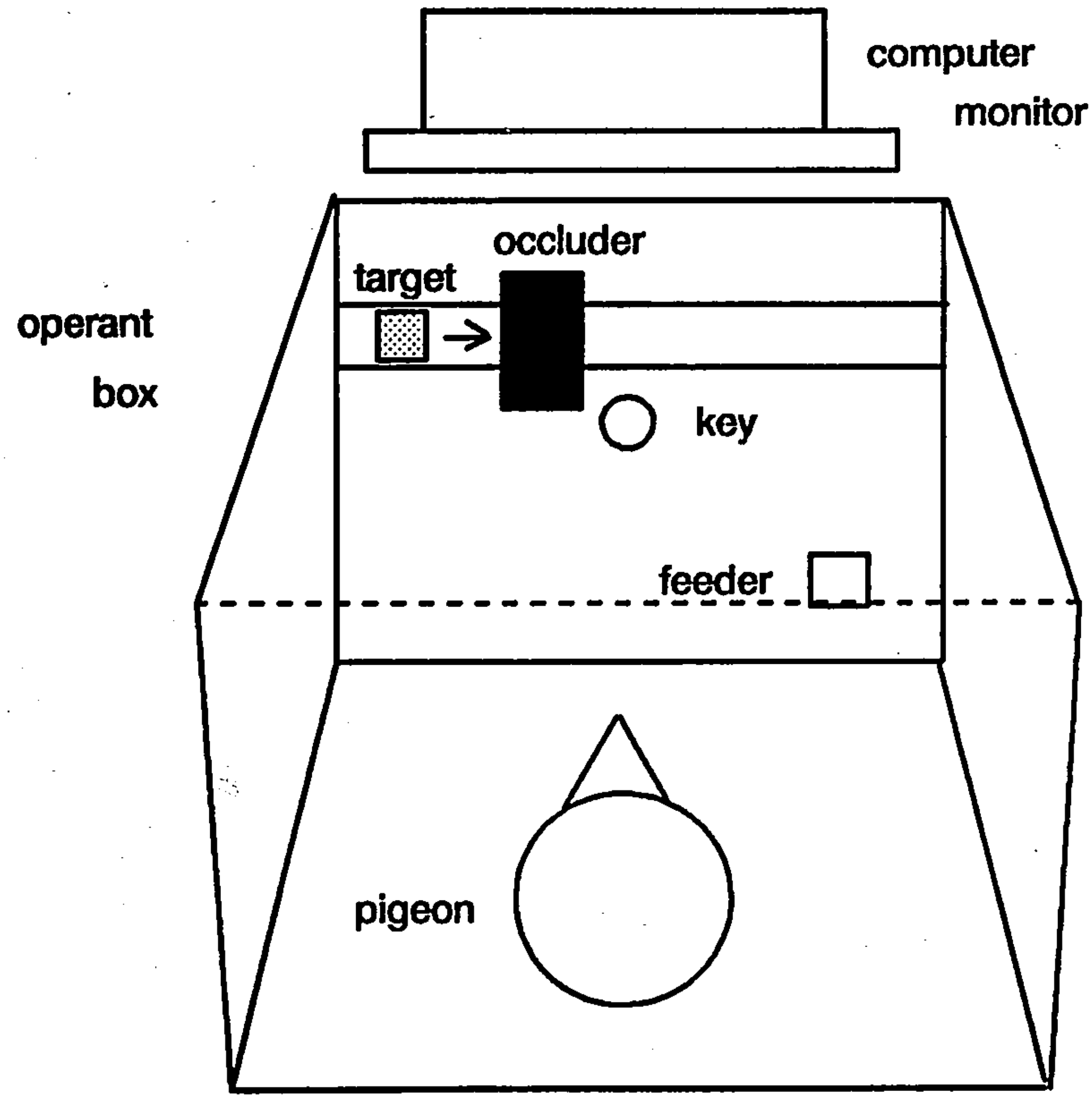
Five White King pigeons served as subjects. All birds had participated in Experiment 1 and had operant and keypecking experience. The birds were maintained at 85% +/- 2% of their free-feeding weight and given mixed grain after experimental session as needed. Water and grit were available at all times outside of testing periods. One bird was excluded due to inconsistent keypecking.

Apparatus

One 46 cm x 47 cm x 51 cm operant chamber made from opaque plexiglass was used (see Figure 2). On one side there was a clear plexiglass viewing slot 27 cm long and 6 cm wide and one circular key 2 cm in diameter 2 cm centred below the viewing slot. On the outside of the chamber facing the viewing slot, a computer monitor was aligned so that the moving target could

Figure Caption

Figure 2: Diagram of the apparatus used in Experiment 2.


computer
monitor
occluder
target
operant
box
key
feeder
pigeon

be viewed by the bird. The target was blue and approximately 2 cm square. The target moved at a velocity of 2 cm per second during the 12 second target condition and 1 cm per second during the 24 second target condition. The program for creating the moving dot was written in "C". Thirty-six cm from the left corner of the chamber and 4 cm from the bottom on the same side as the keylight, a 5 cm x 4 cm x 6 cm food tray was connected to a pellet dispenser.

A 386 computer controlled the experimental parameters and recorded the birds responses using Med-associates software (Tatham & Zurn, 1989).

Pretraining and Procedure

Each trial began with the experimenter pressing a key that controlled the start of the target across the monitor. The start of the target was synchronized with the parameters of the med-associates software which recorded the pigeons responses. A visual cue (a 1 second appearance of a numeric symbol) programmed using the Med-associates software appeared at the beginning of each trial on a separate monitor and acted as a signal for the experimenter to start the target.

Pretraining consisted of two phases. Phase 1 consisted of 10 sessions of auto-shaping until birds were reliably keypecking again; all birds had keypecking experience from prior experiments. In phase 2 birds were put on an auto-shaping program to train them to look through the viewer and keypeck while the keylight and target were on. After 28 sessions this method was aborted since it was found that the keylight alone was controlling the birds responding and not the target. Instead the birds were hand-shaped (i.e., reinforced for gradual approximations) to orient their head towards the viewing slot while the target was on. The keylight in the experimental chamber was deactivated and only the activation of a push-button by the experimenter delivered a reward. In this manner, birds were shaped to first look at the target and then keypeck to obtain reinforcement. The birds were unable to activate the feeder by keypecking alone. After nine sessions all birds were orienting towards the viewer before keypecking.

The experiment proper consisted of three phases. Phase 1 consisted of 100 trial per session. The target was on for 12 seconds per trial and moved across the screen at a constant velocity. A 6 cm x 6 cm opaque cardboard occluder was attached to the computer screen 6 cm from the left edge of the viewing slot. The target was visible moving across the screen for 3 seconds then disappeared behind the occluder for 3 seconds and then reappeared for the remainder 6 seconds of the trial. At the beginning of each trial a red keylight was activated and deactivated with a keypeck by the bird or the end of the 12 seconds. A keypeck during the 3 seconds that the target was behind the occluder produced a reinforcement of three-20 mg Bioserve pellets, and the termination of the keylight. The keylight remained on during the entire trial when no keypecks were produced.

The criterion used to determine when the second phase would begin was 60% correct responding for 3 consecutive sessions. The justification for this criterion is as follows. Random responding in which the birds were equally likely to respond at any second would give a chance rate of 25% (disappearance for 3s in 12 or 6s in 24). However, based on the birds' own average initial response rates in phase 1, it was determined that a criterion of 20% represented correct responding due to chance. This base rate of 20% is lower than the expected 25% because the probability of pigeons responding is highest during the first few time bins of a trial (Cheng, 1992): pigeons tend to respond early. If the pigeons use perfectly a mental representation of the moving target however, then correct responding should be 100% in the time bins corresponding to the target being occluded. For the purposes of this experiment, since the rate of correct responding increased very slowly for bird 24, a criterion was chosen at the midpoint of 20% correct responding (chance) and 100% correct responding (mental representation used to perfection).

In Phase 2, the contingencies were exactly the same except that the target was on for 24 seconds and the target was visible for the first 6 seconds, invisible for the next 6 seconds, and then visible once again for the remaining 12 seconds. Each session consisted of 50 trials in this phase but was equal in the length of time as the sessions in Phase 1.

In Phase 3, sessions defined in Phase 1 and Phase 2 were alternated.

Data Analysis

On each trial the first keypeck was scored as correct if it occurred when the target was behind the occluder, and incorrect if it occurred when the target was visible. If no response occurred during the trial, the trial was discarded. The proportion of correct responses was computed as (total number of correct responses) / (total number of trials on which a response occurred).

Since the dependent variable is binary (correct or incorrect response), the data were not normally distributed, and so a logistic model which specifies a binomial error term was fitted to the proportion of correct trials. The analysis was conducted with the use of GLIM [Generalised linear interactive modelling--for details of the model fitting procedure, see Baker & Nelder (1978)], and a sample output is shown in Appendix B. In all the analyses reported below, the effect of session was tested for significance, and a X^2 test statistic was used.

Results

The results for each bird were analysed separately since large individual differences in performance were found. For phases 1 and 2, results were analysed to test whether performance improved significantly across sessions. For phase 3 results were analysed to test for a transfer of learning from phases 1 and 2 to phase 3. Twenty percent of correct choices served as the baseline for this comparison based on the average initial performance of all birds in phase 1.

Bird 10 showed gradual and significant improvement in phase 1 across 125 sessions (see Figure 3). Correct responding improved significantly ($X^2_{(1)} = 140.7$, p. < .001) and Figure 3 illustrates that while learning did occur, it was very slow in comparison to the other 3 birds (see below). This particular bird never reached criterion for moving to phase 2.

Bird 13 reached criterion performance for phase 1 within 55 sessions (see Figure 4). Rate of correct responding increased significantly from baseline ($X^2_{(1)} = 42.19$, p. < .001). In phase 2, performance dropped down to near baseline performance in phase 1 but responding improved significantly ($x^2_{(1)} = 10.90$, p. < .001). Performance in phase 2 was not as strong as it was in phase 2 (see Figure 4) and this bird never reached criterion for phase 3.

In phase 1, bird 24 reached criterion performance within 55 sessions, however as Figure 5 shows, in phase 2 performance hardly improved above the 20% baseline across the last 65 sessions. However, the improvement in performance across sessions was significant for both phase 1 ($X^2_{(1)} = 207.49$, p. < .001) and phase 2 ($X^2_{(1)} = 8.88$, p. < .001).

Bird 16 was the only bird that showed learning in all three phases (see Figure 6). As with birds 13 and 24, clear and gradual improvement in performance is shown for phase 1 ($X^2_{(1)} = 105.66$, p. < .001). As well, for phase 2 performance drops back to near baseline but quickly improves to criterion within 20 sessions ($X^2_{(1)} = 15.19$, p. < .001). In phase 3 in which alternating sessions of phase 1 and 2 target speeds were presented, performance stayed well above the 20 %

Figure Caption

Figure 3: Proportion of correct responses averaged over 5 sessions for bird 10 during phase 1. Horizontal axis gives last session for each block of 5 sessions.

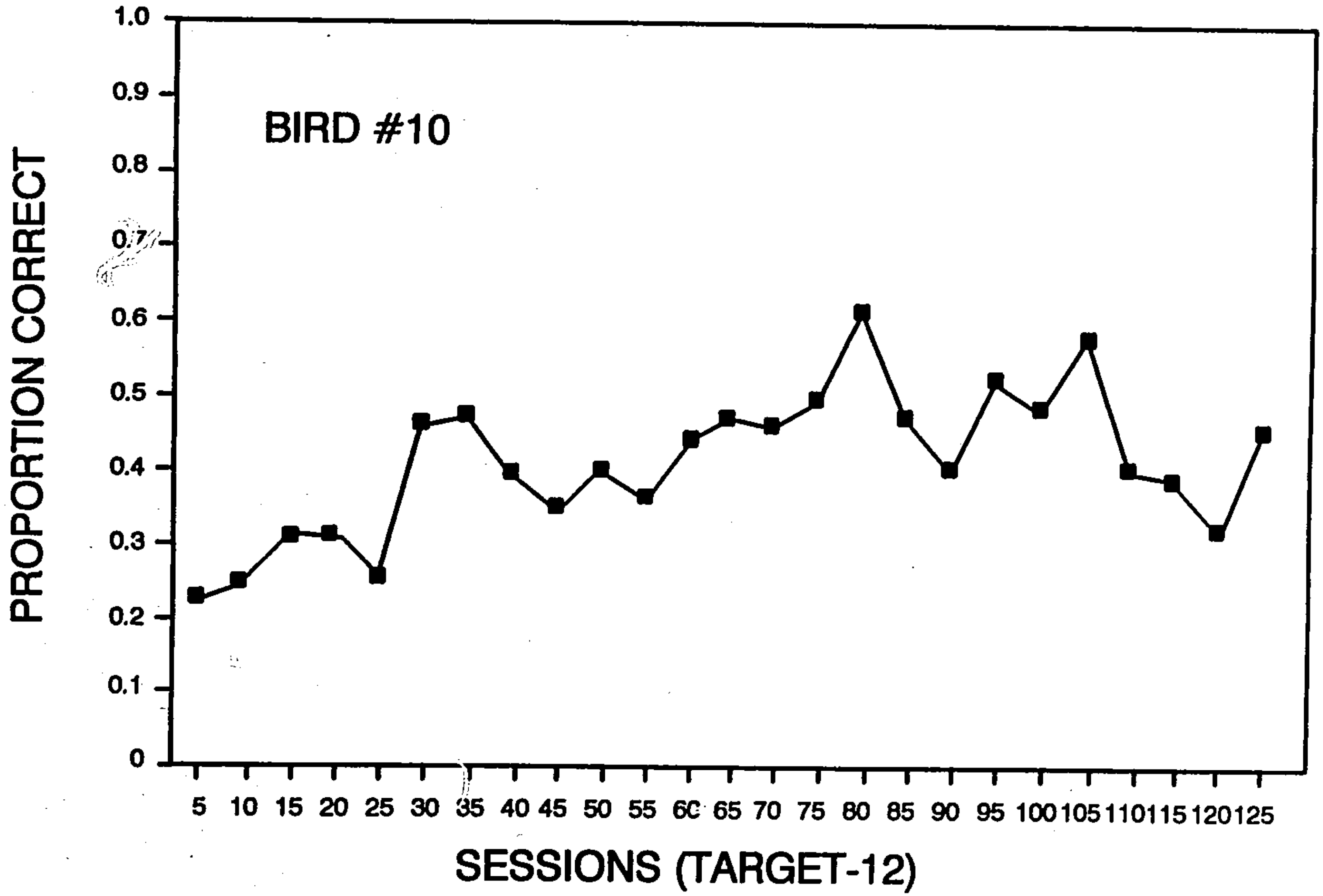

BIRD #10
PROPORTION CORRECT
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125
SESSIONS (TARGET-12)

Figure Caption

Figure 4: Proportion of correct responses averaged over 5 sessions for bird 13 during phase 1 and phase 2. Horizontal axis gives last session for each block of 5 sessions.

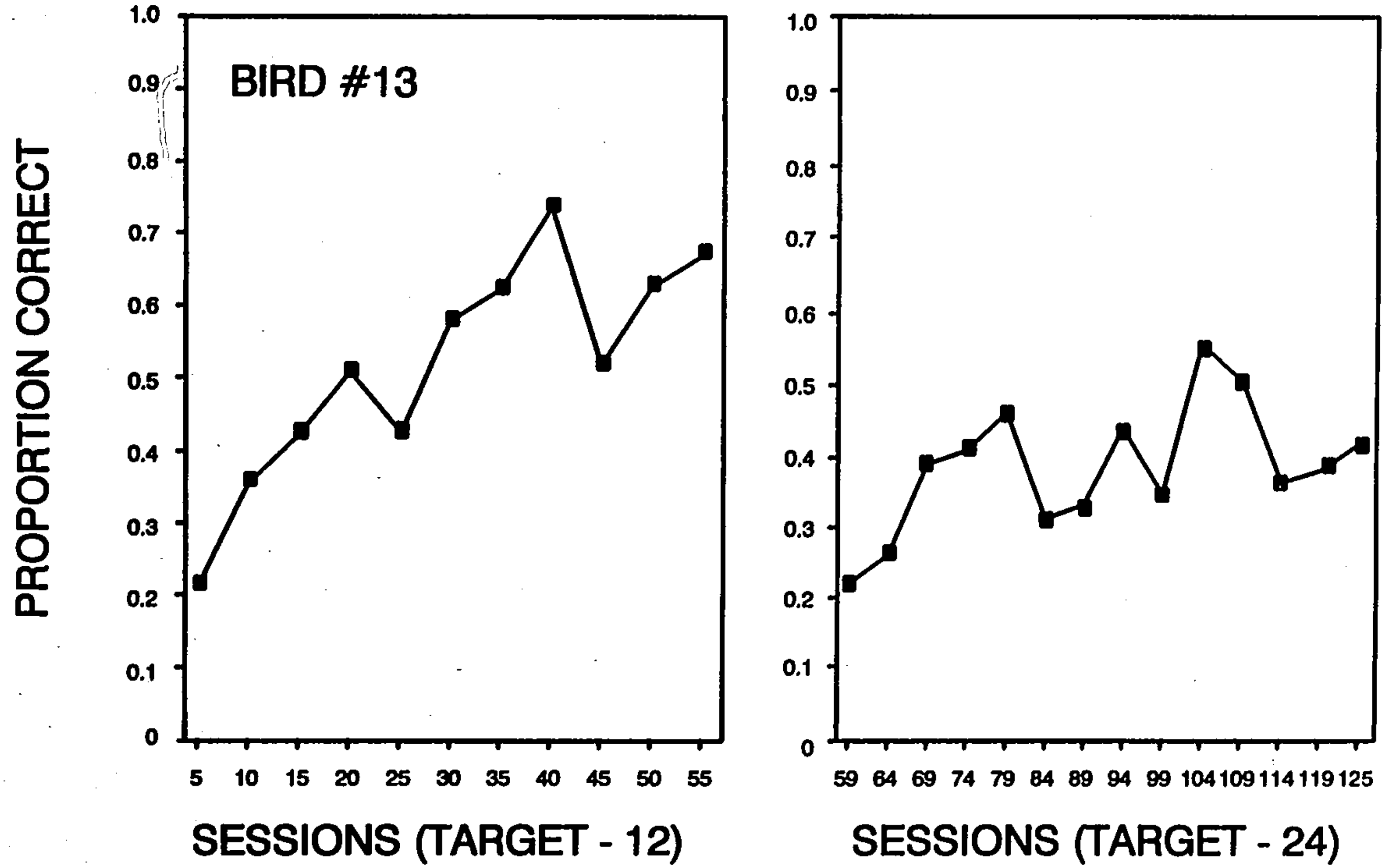

BIRD #13
PROPORTION CORRECT
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5 10 15 20 25 30 35 40 45 50 55
SESSIONS (TARGET - 12)
59 64 69 74 79 84 89 94 99 104 109 114 119 125
SESSIONS (TARGET - 24)

Figure Caption

Figure 5: Proportion of correct responses averaged over 5 sessions for bird 24 during phase 1 and phase 2. Horizontal axis gives last session for each block of 5 sessions.

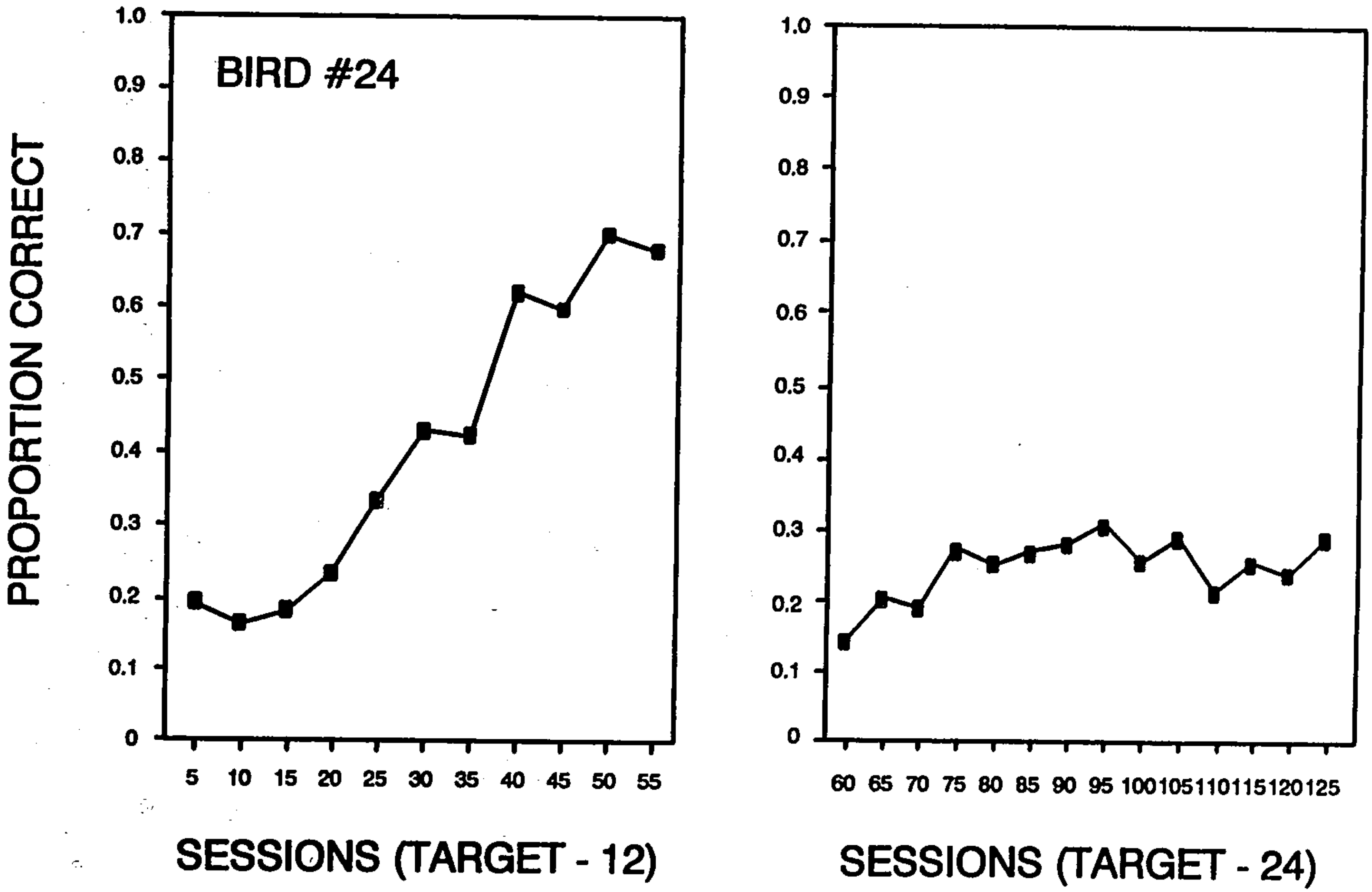
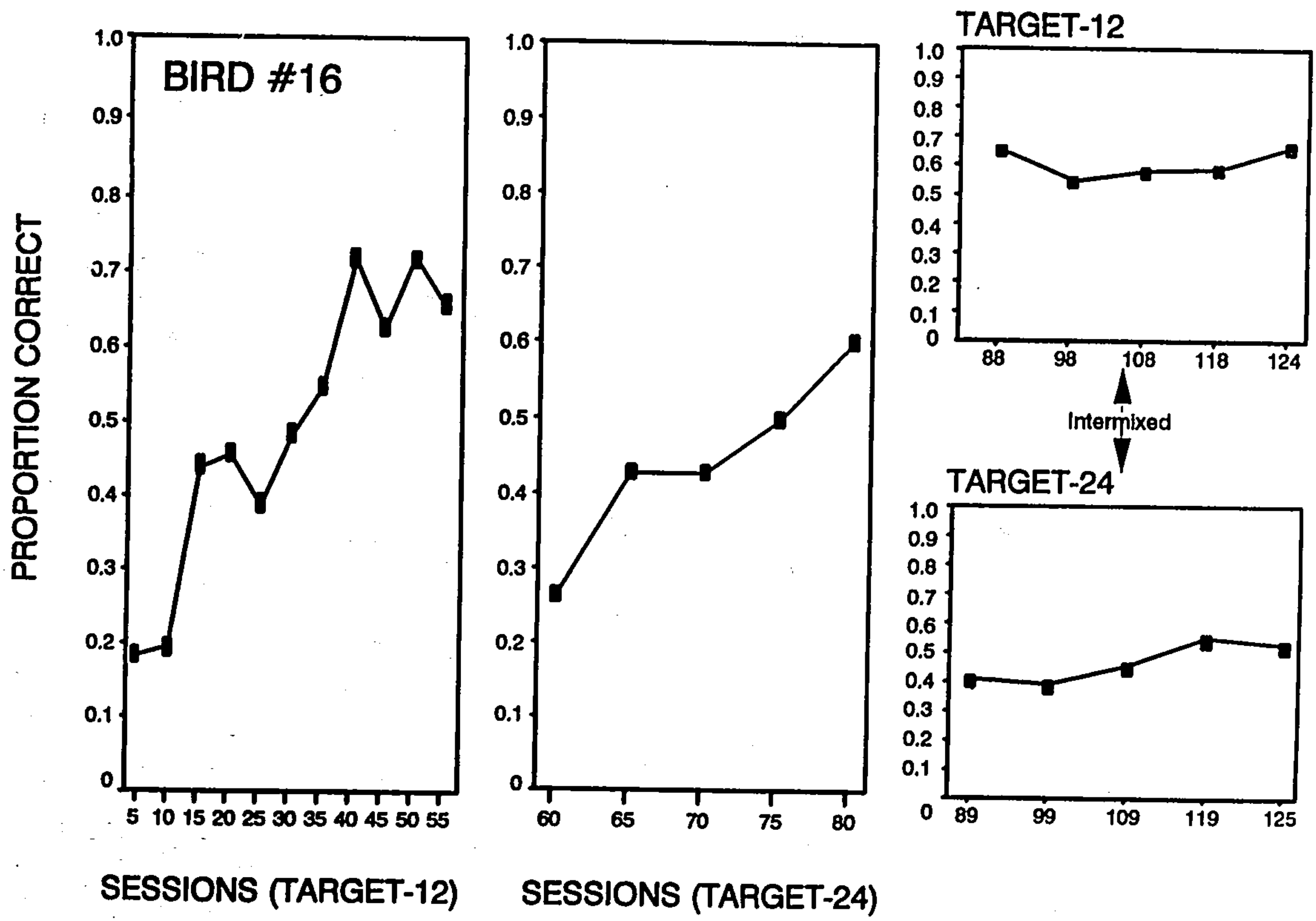

BIRD #24
PROPORTION CORRECT
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5 10 15 20 25 30 35 40 45 50 55
SESSIONS (TARGET - 12)
60 65 70 75 80 85 90 95 100105110115120125
SESSIONS (TARGET - 24)

Figure Caption

Figure 6: Proportion of correct responses averaged over 5 sessions for bird 16 during phase 1, phase 2, and phase 3. Horizontal axis gives last session for each block of 5 sessions.



BIRD #16
PROPORTION CORRECT
SESSIONS (TARGET-12)
SESSIONS (TARGET-24)
TARGET-12
Intermixed
TARGET-24

baseline of correct responses and shows complete transfer of learning from the two initial phases.

In phase 3, for bird 16, the 2 types of trials were analysed separately. Target-12 trials show a high proportion of correct responding from the beginning and performance remained steady across sessions. No significant change was found across sessions. For target-24 trials however, performance dropped in the initial sessions and then gradually increased showing a significant improvement in performance ($X^2_{(1)} = 9.08$, $p. < .005$).

Discussion (Experiment 2)

In this experiment, all birds learned to perform at least some of the requirements which would have lead to a test of the representation of a moving hidden object. All subjects were shaped to attend to the moving target and all subsequently learned to keypeck at above chance rate when the target, moving across the computer screen in 12s, had disappeared. Nevertheless, learning to respond whenever the target disappeared proved to be an arduous process - so much so that after almost a year of testing only one of the four subjects could reliably respond when the target disappeared regardless of which of the 2 target velocities was presented (phase 3), while the other three birds were "left behind" in phases 1 and 2 of the experiment.

Two possible strategies could be used to perform successfully in phase 3 (both velocities intermixed) of experiment 2. One strategy would be to attend to the moving target and peck when the target moved behind the occluder. Alternatively however, the bird could have used a modified timing strategy whereby the different target conditions (corresponding to phases 1 and 2) were discriminated based on the different velocities of each target. In this case, the bird could modify its timing strategy based on the discerned velocity of the presented target (i.e., fast target: wait 3-6s; slow target: wait 6-12s).

A timing strategy most likely controlled responding for phases 1 and 2 in the present study. Phase 1 and phase 2 correspond to a FI 3-6s and FI 6-18s respectively. Poorer performance in phase 2 by birds 13 and 24 may be due to the longer interval birds were required to wait before pecking to receive reinforcement.

These results in phase 1 of the present study suggest that the parameters for responding were not unreasonable. Three out of the 4 birds readily reached criterion performance in phase 1. The large individual differences in performance by the three birds in phase 2 is not easily understood. Performance in phase 2 by bird 16 is very similar to its performance in phase 1 with a shorter duration required to reach criterion. The results of phases 1 and 2 for this bird suggest that some global learning of the task may have occurred during phase 1 and that this learning may have transferred to phase 2 resulting in a shorter interval of time required to reach criterion.

However, this type of strategy is not apparent for birds 13 and 24. One factor may be the increase of the FI interval in phase 2. The task in phase 2 required the birds to wait 6 seconds before responding which was double the time interval in phase 1. As already mentioned, there is evidence to suggest that pigeons consistently prefer to respond early in keypecking tasks (Cheng, 1992). This tendency may have been strong enough to inhibit performance for at least two of the birds in this study.

A second factor that may have contributed to the wide variations found in this study and related to the first factor of early responding is the response method used. With the methodology used in the present study, an infinite number of responses were available during the presentation of each trial. For instance, at any point along the continuum of 0 to 12 or 24 seconds the birds were free to respond. This coupled with pigeons tendency to respond early may have contributed to a greater risk of error than would have been present if a different procedure was used such as the forced choice method. The task of matching a keypeck to the simultaneous movement of the target may have been a contributing factor to the error rate as well.

General Discussion

Results from experiment 1 failed to reveal that pigeons are able to successfully recover a hidden food target. The birds always choose the visible target over the hidden target. When birds were presented with only invisible food targets without a visible food target alternative, the birds performed at chance. These results are similar to those reported by other studies using similar types of procedures studying mental representations in pigeons (Krushinsky, 1990), as well as related species such as the ring dove (Dumas & Wilkie, 1984) and the chicken (Etienne, 1973).

Experiment 2 demonstrates that pigeons are able to exhibit timing strategies using unconstrained choice procedures for at least one FI, while 2 out of 4 birds showed behaviour controlled by two different FIs. At least one bird was able to demonstrate transfer of learning to alternating trials in phase 3. This transfer of learning can be attributed either to the birds learning a conditional discrimination or to learning to respond when the target was invisible.

The procedure used in experiment 2 was adopted specifically so that the birds would have to respond at the anticipated moment of the reappearance of the target. This type of procedure explicitly requires that the birds "mentally" track the target while it is moving behind the screen in order to anticipate its reemergence. Using this procedure, it was very difficult to obtain transfer of learning from the training target velocities to conditions where alternating velocities of the training targets were presented. None of the four birds in our study graduated to the final phase where completely novel target velocities could be presented, even after extensive training.

Reaction time was an important variable using this type of procedure in experiment 2 as well. Reaction time was a critical component of the birds' response behaviour since they were required to respond within a specific time frame (e.g., while the target was behind the occluder). This factor would have been even more critical if any of the pigeons had progressed to the final phase where responding would have been required within a time frame of seconds before the reemergence of the target from behind the screen. The advantage of this procedure though, is that there is a one-to-one correspondence between the invisible target moving along its trajectory and the visual mental representation necessary to track the moving target. By matching the imaged trajectory of the target with the unseen physical trajectory of the target, an organism able to transform visual mental representations would have been able to accurately estimate the location of the hidden target based on their internal representation. Again, the fact that pigeons perform poorly on this type of task suggests that they did not mentally represent the trajectory of the object in this experiment.

One of the goals of experiment 2 was to present pigeons with a simplified version of the task used in Neiworth & Rilling's (1987) study on visual mental representation in pigeons. The results of their study suggest that pigeons are able to mentally represent a hidden moving target and immediately transfer this learning to novel positions. These results are in contrast with other studies that have investigated mental representation in pigeons using visual stimuli (as discussed below), including the present one.

<u>Relationship to Studies of Mental Rotation</u>

The presentation of a moving dial to study movement estimation in pigeons by Neiworth and Rilling (1987) was an adaptation of the methodology used in studies of mental rotation in humans (Shepard & Cooper, 1982). Mental rotation is the classic test for analog mental representation in humans. Subjects are presented with a pair of three dimensional objects and are required to determine whether the two objects are the same or mirror-images. Typically, as the angular difference between the orientations of the two objects increases, so does the time required by the subject to respond. This linear relationship between reaction time and angular difference indicates that subjects perform these tasks by "mentally rotating" an internal representation of the object until they find a match or mismatch with the comparison object.

Hollard and Delius (1982) and Neiworth and Rilling (1987) have both demonstrated that pigeons are able to match stimuli of different orientations on mental rotation tasks. Hollard and Delius (1982) adopted the same procedure used in mental rotation experiments using humans described above, to compare the reaction times of humans and pigeons. The subjects were required to mentally represent transformations of objects and their reaction times measured. It was found that in contrast to human responding, the pigeons' reaction times did not increase as angular disparity between the objects increased. Based on these results, it was concluded that the pigeons were not mentally representing the transformation of the object. Instead, the pigeons reaction times were interpreted as reflecting a more efficient form of parallel processing that could not be identified from that particular experiment.

Therefore, two previous studies have tested whether pigeons mentally represent transformations of objects and have provided conflicting evidence: Neiworth and Rilling's (1982) study suggests that they do, and Hollard and Delius' study suggests that they do not. The difference between these two studies was that the former study had used moving stimuli, while the latter study had used static stimuli. Cerella (1977), based on a study of transformational invariance in pigeons, hypothesizes that pigeons do not recognize static stimuli as transformed versions of the same object. As well, Neiworth (1992) has demonstrated that, in conditions where dynamic cues for movement are removed, pigeons are unable to estimate the movement of an object.

A second difference between the two studies was the dependent variable used. Typically, conclusions about the presence of representations in subjects are based on reaction-times in mental rotation studies. As already stated, when this measure is used to test whether or not pigeons are able to mentally represent transformations of objects, the available evidence suggests that they do not. In contrast, Neiworth and Rilling (1987) required pigeons to match a keypeck to a particular key based on the type of trial presented (as described above). It is possible that this type of procedure makes it more difficult to refute whether or not a rule-governed or timing strategy is being used since it does not necessarily measure a one-to-one correspondence between the perceptual stimuli and the imagined stimuli as has been hypothesized with reaction time studies (Shepard & Copper, 1982).

Novel test trials were presented to the animals in Neiworth and Rilling's (1987) study to test whether a mental representation was being used to estimate the objects movement. Low transfer to the novel trials would indicate that the birds were using a strategy other than mental representation (e.g., a timing strategy). High transfer to the novel trials would indicate that the strategy used was mental representation. Curiously, the birds exhibited unusually high transfer to the novel trials. Performance on the novel trials actually increased over performance on the training trials from approximately 80% correct responding for the latter to approximately 100%

correct responding for the former. Possible reasons for the facilitative effect of the novel trials on the pigeons performance in this experiment were not discussed. However, improvement in responding would not have been predicted based on the use of mental transformation or imagery. These unexplained leaps in performance raises the possibility of an artifact in their results and casts some doubt on the conclusions of Neiworth and Rilling's (1987) study.

Whether or not pigeons mentally represent transformations of objects remains uncertain. Discrepancies in pigeons' performance between Hollard and Delius' (1982) and Neiworth and Rilling's (1987) study could possibly be attributed to the fact that the former study presented pigeons with static stimuli (as discussed above). An obvious solution to the question of whether this variable was the critical difference in pigeons' performance between the two studies would be to replicate Hollard and Delius' (1982) experiment using moving stimuli.

In answer to the question of how pigeons find hidden food, all of the literature on pigeons shows that they are very adept at associating places and/or times with food (Cheng & Sherry, 1992; Spetch, Cheng, & Mondloch, 1992). While pigeons seemed unable to use a mental representation to find hidden food in experiment 1, pigeons easily associated a time with the delivery of food and/or the disappearance of a moving target in experiment 2. No evidence for the representation of hidden objects was obtained - in spite of extensive manipulations (experiment 1) and extensive training (experiment 2). The mechanistic question that needs to be resolved is which of the various cognitive abilities which "object permanence" comprises is deficient in pigeons. While attention and memory would seem up to the task in these studies, other skills remain to be studied: as discussed above, transformational invariance would seem a good candidate.

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Appendix A

Raw Data and Analysis of Test 6 Using a G-test

Table 1

Raw Data Summed Over 2 Sessions: S+ Corresponds to Successful Search Behaviour and S- Corresponds to Unsuccessful Search Behaviour

Birds	S+	S-	Sum
1	20	20	40
2	20	20	40
4	24	16	40
7	20	20	40
9	21	19	40
10	20	20	40
11	19	21	40
12	19	21	40
Sum	163	157	320 = n

Table 2

f ln f Transformations of the Original Data in Table 1

Bird	S+	S-	Sum	f ln f (Table 1)
1	59.915	59.915	119.83	147.555
2	59.915	59.915	119.83	147.555
4	76.273	44.361	120.634	147.555
7	59.915	59.915	119.83	147.555
9	63.935	55.944	119.879	147.555
10	59.915	59.915	119.830	147.555
11	55.944	63.935	119.879	147.555
12	55.944	63.935	119.879	147.555
Sum	491.756	467.835	959.591	**1180.44**
f ln f	830.281	793.831	Sum **1624.112**	1845.863 = n ln n

Calculations:

a. The sum of the transforms of all frequencies = 959.591

b. The sum of the transforms of the column sums of Table 1 = 1624.112

c. The sum of the transforms of the row sums Table 1 = 1180.44

d. The transform of n, the total number of items in the study = 1845.863

e. For each class compute ln p

$\ln \hat{p}_1 = 2.30259 \log \hat{p}_1$

$= 2.30259 \log (1/2)$

$= 2.30259 (-0.30103)$

$= -0.69315,$

$\ln \hat{p}_2 = 2.30259 \log \hat{p}_2$

$= 2.30259 \log (1/2)$

$= 2.30259 (-0.30103)$

$= -0.69315$

1. Test for Homogeneity:

G(h) = 2[quantity **a** - quantity **b** - quantity **c** + quantity **d**]

= 2[959.591 - 1624.112 - 1180.44 + 1845.863]

= 2[0.902]

= <u>1.804</u>

This value is compared to a x^2 -distribution with (a-1)(b-1) = (2-1)(8-1) = 7 degrees of freedom.

Since $x^2_{.05[7]}$ = **14.067**, we failed to find any individual differences between subjects.

2. Goodness of Fit for 1:1 Ho:

$G(p) = 2[\sum^{a} f \ln f - \sum_{i=1}^{a}(\sum f_i \ln \hat{p}_i) - n \ln n$

= 2[quantity **b** - $\sum^{b} f_1$ x quantity **e** - $\sum^{b} f_2$ x quantity **e** - quantity **d**]

= 2[1624.112 - 163(-0.69315) - 157(-0.69315) - 1845.863]

= 2[0.057]

= 0.114

This value is compared to a x^2-distribution with a - 1 (number of parameters estimated from the sample = 2 - 1 - 0 = 1 degrees of freedom). Since $x^2_{.05[1]}$ = **3.841**, the obtained ratio does not differ significantly from the expected ratio.

3. Total G = G(h) + G(p)

= 1.804 + 0.114

= 1.918

With b(a - 1) = 8(2 - 1) = 8 degrees of freedom and $x^2_{.05[8]}$ = **15.507**, there is no evidence that the data do not fit the expected ratio.

4.

Tests	df	G
Pooled	1	0.114
Heterogeneity	7	1.804
Total	8	1.918

Note. To obtain f ln f transformations of Table 1 in the present Appendix, use statistical Table G (Sokal & Rohlf, 1969).

Appendix B

Sample GLIM Output

```
[0] Glim 3.77 update (copyright) 1985 Royal Statistical Society, London

[0]

[i] ? $input 13 80$

[i] File name? csherall.glm

[i] $uni 500$

[i] $c sheri's experiment 2$

[i] data bird phase session correct tot dum$

[i] $dinput 11$

[i] File name? csherall.prn

[i]     10    1    1    20    94    9

[i]     10    1    2    20    96    9

[i]     10    1    3    16    84    9

......

[i]     13    2    55   24    98    9

[i]     13    2    56   14    100   9

......

[i]     16    3    80   69    102   1

[i]     16    3    81   44    100   2

[i]     16    3    82   72    102   1

[1] $cal block=%tr((sess-1)/5)+1$
```

```
[1] $cal X+%if(%eq(Bird,10),1,0)$

[i] $cal z=%IF(%EQ(PHASE,1),1,0)$

[i] $CAL W=Z*X$

[i] $weight w$

[i] $c observations restricted to Bird 10 phase 1.$

[i] $yvar correct$

[i] $err b tot$

[i] $c error binominal--number of correct choices out of total$

[i] $fit :+session$

[0] scaled deviance = 885.52 at cycle  2

[0]               d.f. = 124     from 125 observations

[0]

 chi-squared value for effect of session = 140.7 with 1 df

[0] scaled deviance = 744.87 (change = -140.7) at cycle  3

[0]               d.f. = 123     (change =  -1   ) from 125 observations

[0]

[i] $stop$
```