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Perception of time duration by domestic hens

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Abstract

This experiment investigated the ability of the domestic hen to predict a time interval of several minutes when given a reliable signal. This was achieved using the peak procedure method, an extension of a fixed interval (FI) schedule that gives partial reinforcement to identify temporal expectation on both sides of a remembered time for food delivery. Five birds were individually trained to peck a computer controlled touch screen. The screen displayed a symbol to signal the start of a trial and the first peck to the symbol after the FI of 6 min had elapsed resulted in food being provided, the houselight in the roof of the pen illuminating, and the screen going blank. On probe trials the hens were not rewarded and the trial continued for 9 min. The birds obtained on average 90% of available rewards on non-probe trials. On probe trials the response rate increased gradually reaching a maximum around the time of expected reinforcement of 6 min. The birds showed a lowered level of response at the start of the interval. The percentage of the FI that had elapsed before 25% of the responses had occurred was consistently greater than 25%. The results indicate that domestic hens may have the ability to estimate the time to reward when given a reliable visual signal several minutes in advance. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Most animals learn and store information about space and time to predict the occurrence of events (Roberts, 1998) such as food availability. The ability to estimate time intervals has been demonstrated in a variety of species (Richelle and Lejeune, 1980), and it is

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thought that the capacity to detect, learn and use temporal information is an essential and basic process of animal behaviour and learning (Higa and Staddon, 1997). In experimental conditions this ability to estimate time intervals is assessed using a wide range of behaviours that can reflect a learned sensitivity to the duration of a stimulus such as light or tone, or the time between successive events (Higa and Staddon, 1997).

Previous studies on time perception in animals have concentrated on short time periods, typically up to 60 s, using a technique known as the peak procedure. This method has been used in a variety of species such as rats (Church et al., 1994), pigeons (Roberts et al., 1989), black-capped chickadees (Brodbeck et al., 1998) and goldfish (Talton et al., 1999). This is an extension of an operant fixed interval (FI) schedule giving partial reinforcement (Gibbon and Church, 1990). It was devised by Catania (1970) and used extensively in studies by Roberts (1981) to identify temporal expectation on both sides of a remembered time for food (Gibbon and Church, 1990). A peak procedure session consists of two types of trials: food (learning or FI) trials and non-food (testing or probe) trials. The learning trials are the same as standard FI trials. The subject is presented with a signal, and the first response after the fixed time interval is reinforced with food followed by the termination of the signal. On a probe trial the subject is presented with the same signal that continues for longer time than the FI (at least $1.5 \times$ FI length), the subject is not rewarded and all responses are recorded (Wearden and Doherty, 1995).

Typical results from these studies over FIs of up to 60 s are curves that are approximately normal in shape (Roberts, 1998), produced by averaging data from a number of trials in which animals begin responding at different times around the midpoint of the FI. Usually these are not quite symmetrical with slower decline at the end and some continued responding. The advantage of this behaviour is that the food reward is obtained reliably and the effort used in obtaining it is reduced, due to the low rate of response at the beginning of the interval. The frequent response near the end of the interval allows food to be obtained as soon as it becomes available (Roberts, 1998). Previous studies have shown that the point of maximum response rate rarely deviates by more than 10% of the FI value (Catania, 1970; Roberts, 1981).

On individual probe trials animals can show two types of response patterns. A scalloped pattern is produced when the animal pauses and then begins to respond, accelerating at a steady rate, producing a scalloped cumulative response curve (see Ferster and Skinner, 1957 for review). Alternatively, they may show a break and run pattern in which responding abruptly changes from a low rate to a high rate for a period of time around the time of reinforcement, and then abruptly falls to a low rate a short time after reinforcement would have been expected (Gibbon and Church, 1990; Richelle and Lejeune, 1980). However, this means that the classic peak procedure curve is only seen when many trials are amalgamated.

Over longer FIs the spread of the curves is considerably greater than the shorter FIs. The standard deviation of the curves shows that the variability of a 40 s FI curve is about twice as high as for a 20 s FI curve in both rats and pigeons (Roberts, 1998). This is recognised as an instance of Weber's law. This states that when making estimates of the size of measurements along a dimension that increases in magnitude (such as time), the variability of estimation increases proportionally to the magnitude of the measurement estimated (Cheng and Roberts, 1991; Gibbon, 1977). Longer intervals in the region of several minutes have not been well studied. One rare study of longer intervals suggests that pigeons have the ability to judge intervals of 8 min (Zeiler and Powell, 1994). However, there have few other studies using the peak procedure over longer intervals. Questions therefore arise about animals' ability to estimate longer intervals, from several minutes to several hours. We, therefore, investigated perception of longer intervals in domestic hens.

Studies investigating the ability of domestic hens to perceive temporal intervals have not previously been reported. The cognitive and timing abilities of species such as hens are of particular interest due to their commercial use in food production. This study was set up as a foundation to subsequent work investigating the applications of the ability to predict events from reliable signals in relation to the impact of commercial husbandry procedures on hen welfare. Hens are routinely subjected to husbandry procedures such as restraint for inspection, treatment and relocation, and to transport. These procedures last from a few minutes to several hours. In such aversive situations giving an animal the opportunity to predict the length of such a procedure may reduce the aversiveness of the situation. Initially however, it must be determined whether the hen is capable of perceiving the duration of a time interval of several minutes. This paper reports an initial experiment that tested intervals of 6 min, with the peak procedure.

The hens were trained to peck a computer controlled touch screen that rewarded the birds with food for the first peck delivered to a symbol displayed on the screen after the FI of 6 min. Probe trials lasting 9 min were given on a random 25% of trials. During the probe trials the computer system recorded the time of each peck to the screen. In this experiment the touch screen monitor provided a visual/light signal to indicate the start of each trial. A visual signal was chosen as previous studies with avian species have shown that pigeons learnt discriminations with light signals better than when given tone signals (Roberts et al., 1989).

2. Materials and methods

2.1. Subjects

The subjects for this experiment were 15 naïve Brown Leghorn hens, 26 weeks old, housed in two litter pens each 2.4 m $\times$ 2.4 m and maintained on a 14L:10D schedule. Initially all 15 birds were trained, but at 30 week of age the number of birds trained was reduced to the five most consistent performers. On training and testing days birds were maintained on a 22.5 h food deprivation schedule. This was achieved using timed feeders that were scheduled to open for 1.5 h during the evening allowing ad lib feeding for all the birds. The birds were allowed continuous ad lib access to feed when not being trained or tested.

Motivation to peck during tests was very high. To assess performance under a lower food deprivation schedule in the last week of the experiment, when the birds were 32 weeks of age, food deprivation was reduced to 21 h. Individual birds were identified using coloured leg bands.

2.2. Apparatus

The testing was carried out in a sound attenuated test room containing the touch screen apparatus. A bird was placed in a small plexiglass pen (35 cm × 35 cm × 40 cm) in front of the infrared touch screen monitor (Intasolve Ltd., Colchester, UK). The cage contained a food trough (35 cm × 2 cm) that received pelleted food from an electronic feeder positioned outside the touch screen pen. Each reward delivered by the feeder consisted of four pellets of commercial layer diet of identical composition to that received in the home pen. Water was provided in a small hopper hung beside the touch screen. The system was controlled by a computer (Acorn RiscPC700, UK; programme 'Arachnid', Paul Fray, Cambridge, UK) located in the room next door. A companion bird from the same home pen as the test bird was present throughout all trials in a wire pen within visual range of the test bird.

The light intensity inside the touch screen pen during testing was 5 lx, this increased to 9 lx when the signal screen came on. When the houselight located in the roof of the pen was illuminated and the signal screen was absent the light intensity was 15 lx.

2.3. Training

The 15 birds were individually exposed to an autoshaping program for 15 min per day over a number of sessions until they reached the criterion of obtaining 70% of available rewards on two consecutive days. This program displayed a symbol on the screen for 5 s, after which the houselight was illuminated, the screen went blank, and a food reward was given. If the bird pecked before the food was automatically given then they were rewarded immediately. The houselight remained on for 9 s (eat time) after which the inter-trial interval (ITI) of 20 s began, during which the screen was blank and the houselight off. On the third day of training the time for which the symbol was displayed before automatic food delivery was increased to 15 s to encourage the birds to peck the screen.

The second training program displayed a white circle with a small outer ring of colour around the edge, against a black screen with a large yellow border. The screen responded to pecks delivered to an area approximately 3 cm × 3 cm in the centre of the screen that corresponded to the area on the touch screen where the white circle was displayed. The yellow border was included to make the onset of the trial (start of the FI) obvious to the birds even if they were not directly facing the screen. When the bird pecked the circle symbol on the screen correctly the screen went blank, the houselight came on and the food reward was delivered. At this stage any birds that had failed to peck the screen correctly to receive a reward during training were assigned to be companion birds for the trial animals and were no longer trained.

Finally, the autoshaping feature was removed. If the bird failed to peck appropriately then no reward was given. The program was also given a variable ITI to prevent the birds from anticipating the onset of the next trial. This was chosen randomly by the computer from four set intervals: 12, 24, 36, 48 s, giving an average interval of 30 s.

The FI was increased to 2, 5, 8, 15, 30, 60, 120, 240 and then 360 s, depending on individual performance. The session length was increased as the FI increased. For FI of up to 15 s the session length was 20 min; this gradually increased to 85 min at FI 360 s.

Despite the increase in session length the number of trials per day was not constant, but gradually declined as the FI increased due to the time constraints of testing five birds per day using one set of apparatus. The first peck to the symbol after the FI had elaspsed resulted in the screen going blank, the houselight coming on, and the food reward being given. The removal of the symbol from the screen indicated to the birds no further rewards were possible until the start of the next trial that was signified by the screen coming on again displaying the symbol. Any pecks to the symbol on the touch screen prior to the end of the FI were not rewarded. The colour of the outer ring was altered when the FI was increased as an indication to the birds that the interval had changed. The first probe trials were given when the FI increased to 30 s. Probe trials occurred on a

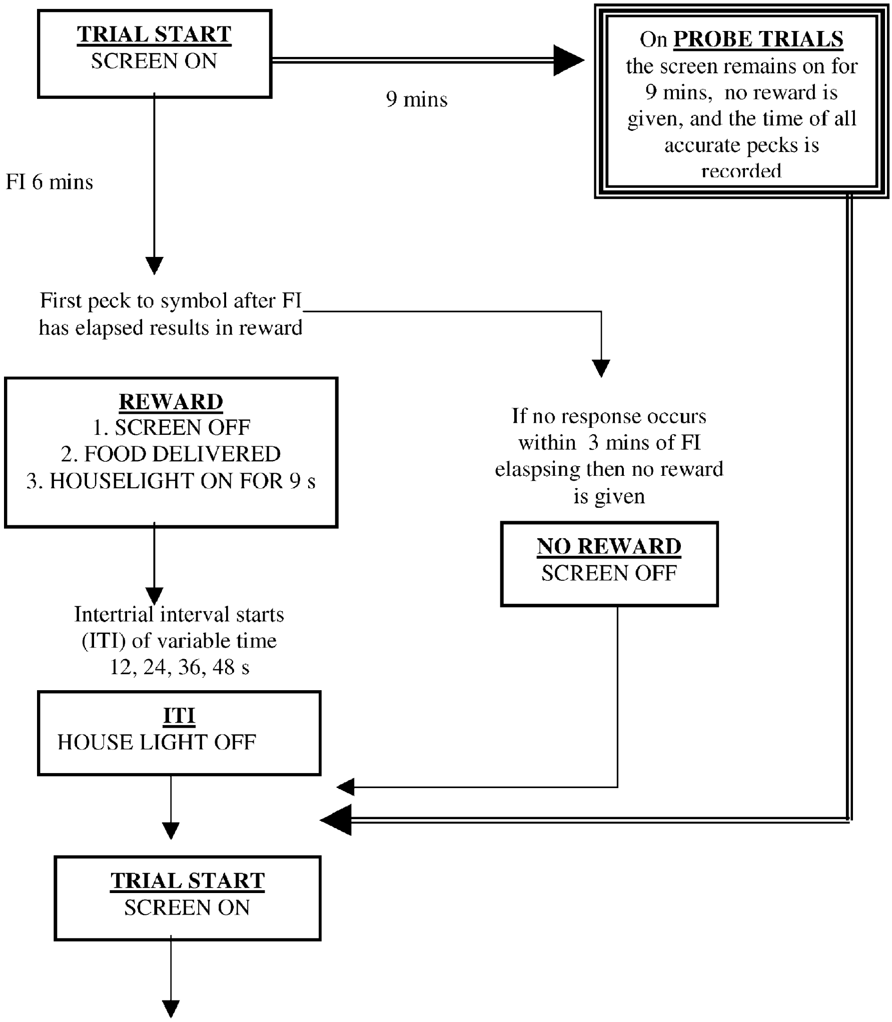

Fig. 1. Diagram showing the sequence of events on rewarded and probe trials at FI 6 min.

random 25% of trials with the constraint that a probe trial was not followed by a second probe trial.

2.4. Data collection and analysis

Data were collected for five birds at FI 6 min. The sequence of events during a trial is shown in Fig. 1. Each session lasted for 85 min, giving each bird 10–11 trials per session, of which 25% were probe trials. When the birds reached FI 6 min in the training program they were given 15 sessions (approximately 150 trials) in which the data collected were not subjected to any analysis. This experience gave the birds the opportunity to learn that if a reward was not given for pecks after the FI had elapsed, then a reward was unlikely and hence 'give up' pecking on that trial.

Data presented are from sessions 16–25, which corresponds to the last 2 weeks of testing. Session 16–20 are referred to as week 1 when food deprivation was for 22.5 h per day and the birds were 31 weeks of age. Sessions 21–25 correspond to week 2 when food deprivation was for 21 h per day and the birds were 32 weeks of age.

During a probe trial the computer recorded the time of each peck to the touch screen along with the co-ordinates of the peck on the screen. The co-ordinates of each peck were used to identify accurate pecks for analysis. Inaccurate pecks outside the co-ordinates of the responding area of the screen were disregarded. Data were then binned into 30 s blocks.

Quantitative data on patterning in the first half of each trial was provided by calculating the quarter life (QL) (Herrnstein and Morse, 1957). This calculates the delay in responding at the start of the interval that demonstrates that the subject has an understanding of the FI. The QL is the percentage of the FI that has elapsed before 25% of the responses have occurred (Zeiler and Powell, 1994). If the QL is greater than 25% of the FI there is relatively less responding in the first quarter of the FI than in the rest of the interval. QL data in weeks 1 and 2 were compared statistically using a sign test (necessarily one tailed because n was only 5).

3. Results

During data collection at 6 min FIs the birds gained an average of 90% (S.E. ±2.1%) of available rewards. Casual observations suggested that most lost rewards were due to other activities, particularly egg laying, disturbing performance. The birds remained healthy throughout the experiment and showed no evidence of weight loss.

On probe trials the rate of pecking was initially low, gradually increased, peaked around the usual time of reinforcement (between 5 and 7 min) and then started to decline (Fig. 2). The pattern of responses from individual trials showed no evidence of the break and run pattern, but was more typical of a scalloped pattern, the rate of responding slowly accelerating to a maximum around the time of reinforcement (Fig. 2a).

The birds in this experiment showed a lowered response rate at the beginning of each trial (Fig. 2). This is also demonstrated by the calculated quarter lives. If the response rate during the interval had been constant then the QL would have been 25% of the FI

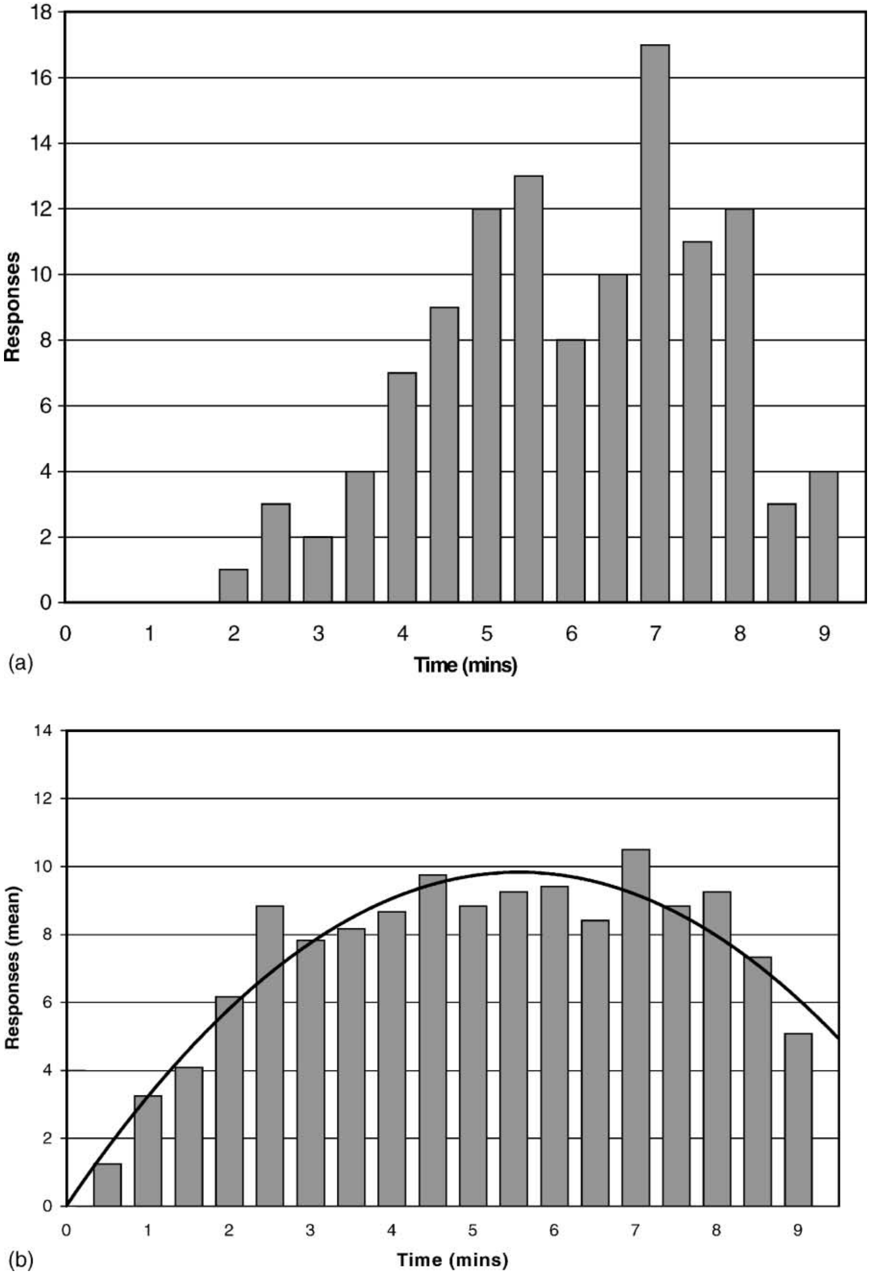

Fig. 2. Responses in 30 s bins in week 2: (a) in a single probe trial by individual W; (b) in all probe trials by individual W (polynomial trend line $R^2 = 0.89$); (c) in all probe trials by all five birds (polynomial trend line $R^2 = 0.92$).

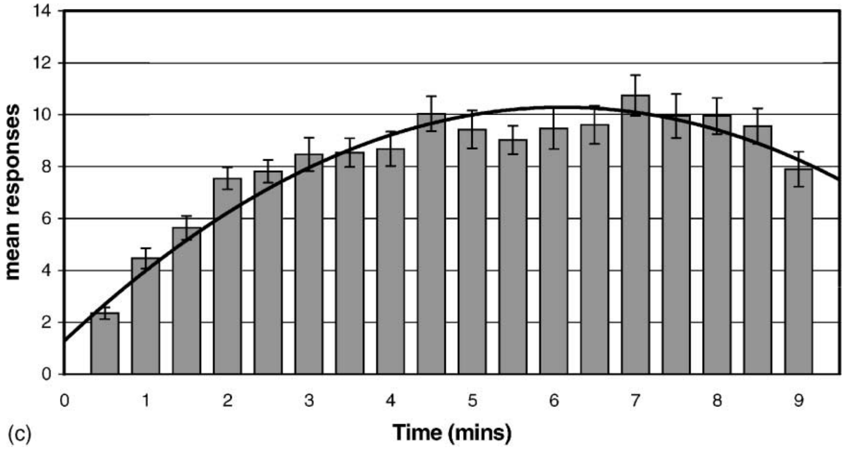

Fig. 2. (*Continued*).

(Herrnstein and Morse, 1957). A QL above 25% implies that there is relatively less responding in the first quarter of the FI than in the rest of the interval. The data from this study gave a QL that was consistently greater than 25% of the FI in both week 1 (mean QL 34%) and week 2 (mean QL 40%; Table 1). There was no significant difference between the QL in weeks 1 and 2 (one tailed sign test). The average wait time before the first peck in a probe trial was 31 s in week 1 and 51 s in week 2 (Table 1).

The maximum response rate varied between individuals, with a range from 6 to 15 pecks per 30 s bin (Table 1). The mean time of maximum response rate varied between individuals from 2.5 to 9 min in week 1 and 6.5–8 min in week 2 (Table 1). This suggests that the birds were showing an improvement in temporal performance during the last week of data collection. This could be due either to the reduced level of food deprivation in the last week of testing or to the increased experience at the 6 min interval. There was no significant difference (one tailed sign test) between the mean number of pecks per probe in week 1 (mean 140) and week 2 (mean 149).

Table 1
Mean maximum response rates, the time of mean maximum response rate, the mean time before the first peck, and the QL, for individual birds in weeks 1 and 2

	Mean maximum response (pecks per 30 s)		Time of mean maximum response rate (30 s bins)		Mean time before first peck (s)		QL (percentage of FI)	
	Week 1	Week 2	Week 1	Week 2	Week 1	Week 2	Week 1	Week 2
Bird B	15	15	7.3–7.59	7–7.29	17	41	30	43
Bird G	10	13	8.30–8.59	6.3–6.59	18	78	35	34
Bird R	5	8	2.30–2.59	7.3–7.59	50	46	41	41
Bird W	14	12	6.30–6.59/ 7.30–7.59	6.3–6.59	35	31	31	37
Bird Y	6	7	8.30–8.59	6.3–6.59	36	60	33	43

4. Discussion

The hens responded well to the touch screen training and showed peak procedure results similar to those of previous studies. The birds showed a lower level of responding at the beginning of the interval. This is demonstrated by the quarter lives that exceed 25% of the FI. This suggests that hens may be able to predict the time to reward when given a reliable predicting signal. The data produced did not show a precise peak at 6 min but rather a generalised curve, which peaked between 6 and 7.5 min. The broad curve seen in these results is due to a combination of several factors.

Firstly, increasing the length of the FI has been shown in previous studies to increase the spread of the response curve produced (Church et al., 1994; Roberts, 1998). This is consistent with Weber's law which states that over longer FIs the spread of the curves is considerably greater than over shorter ones (Roberts, 1998). The previous study (Zeiler and Powell, 1994) over time intervals of 8 min also encountered this effect. Zeiler and Powell (1994) suggested that at FI 8 min, 5 out of 20 bins could qualify to be the peak of the graph. In the present experiment a result of these broad response curves was that the probe trial interval of 9 min used in this study was not long enough for the data to show a decline in responding back to 0.

Secondly, the results suggest that the birds used in this study were continuing to improve performance during the last weeks of the experiment. The birds may have had insufficient experience at 6 min interval to enable them to judge it accurately. A previous study using pigeons on an interval of 8 min gave the birds 440 trials before the data were analysed (Zeiler and Powell, 1994). In comparison the birds in this study received approximately 150 trials before analysis. If the data collection in this experiment had continued for a further 10–20 sessions the birds might have improved further and produced a more clearly defined peak.

Thirdly, the data were also influenced by the motivation of the birds. The food deprivation schedule was imposed to ensure that the birds pecked the screen reliably. However, high levels of food restriction may have resulted in the birds becoming excessively motivated to peck, and consequently showing a poorer peak procedure performance. Increasing the time for ad lib food from 1.5 to 3 h did correspond with improved temporal performance in week 2. However, the increase in food allowance had no effect on the mean number of pecks per probe trial suggesting that this may have been the result of the birds having greater experience at the FI, rather than the increased food allowance. The method used in this study meant the first bird tested in a day experienced a shorter period of food deprivation prior to testing than the last bird to be tested, but had to wait longer after testing to eat again. These differences in deprivation experiences may have caused variation between individuals. It may be appropriate in future trials to take into account bird weight and feed individuals separately weighed amounts of food to maintain each individual at a particular percentage of its free feeding weight.

The high rate of pecking could be explained by the cost of making an operant response being relatively small but the cost of missing an available food delivery being very high (Wynne et al., 1996). The hens may adopt a conservative strategy of responding even when they judge there is only a low likelihood that food is available. Previous studies have shown that birds may find waiting to respond for a reward difficult. In schedules where pigeons must postpone their key pecks to obtain a larger reward they learn with difficulty and seldom attain a high level of 'self control' even when the required postponement is only a few seconds (Rachlin and Green, 1972; Ainslie, 1974).

Training the hens to perform this task was a time consuming procedure. Therefore, only the five fastest learning birds were tested at intervals of 6 min. This has implications for the interpretation of the results in that we cannot tell whether all hens are capable of performing this task. However, as five out of the initial 15 birds readily learnt the task, we suggest that this ability is could be present in a large proportion of the population.

The results indicate that domestic hens may have the ability to estimate the time to reward when given a reliable signal such as that given by the touch screen several minutes in advance. The ability to judge time intervals between events, stimuli, responses, and rewards, exerts an overwhelming influence on what associations are made and on how an animal learns (Higa and Staddon, 1997). It may also be influential in foraging strategies enabling animals to estimate the intervals between food acquisition in a particular patch and hence to judge the cost and benefits of moving to an alternative patch that may yield more frequent food supplies. It is therefore likely that the ability to judge temporal intervals would be a highly adaptive feature for domestic hens and their feral counterparts. Further studies are required into the perception of time intervals in the region of 10–60 min, and the ability of hens to generalise information learnt in one situation and apply that information to other situations. This would enable us to investigate whether we can utilise an animal's timing ability to reduce stress in aversive situations and hence improve welfare.

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