Threat assessment by domestic ducklings using visual signals: implications for animal–machine interactions

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Abstract

There are increasing opportunities for robots to work amongst animals in agricultural systems. One potential application is in herding animals prior to catching or transportation. An effective herding robot must be able to interrupt ongoing animal behaviour without causing panic or flight reactions. The extent to which different approaching stimuli interrupted the feeding behaviour of pairs of domestic ducklings was examined to assess their suitability as herding stimuli. Experiment 1 assessed the responses of ducklings to an approaching human the most likely current herding stimulus, a vertical cylinder (a stimulus with the minimum features of a simple robot) and a model fox simulating the more natural features of a predator. Interruption of feeding was greatest in response to the human and least to the cylinder. Experiment 2 found no significant difference in the extent to which feeding was interrupted when facial appearance and head orientation of the model fox were manipulated. Experiment 3 examined whether biologically realistic features of the model fox affected duckling response. At a distance of 7 m, photographs of the model fox interrupted feeding behaviour as much as the model itself. However, at a distance of 1 m, the model fox caused significantly more feeding interruption than an intact photograph. A fragmented photograph caused the least interruption of feeding behaviour. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Duck; Robot; Feeding behaviour

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1. Introduction

Information about the responses of animals to approaching stimuli is of practical use when considering the design of machines to work amongst animals. Autonomous robots have much potential in animal agriculture, where they could relieve humans of dangerous, difficult or monotonous tasks (Wathes, 1994), e.g. for inspection and herding. The dynamic responses of animals to machines and robots are unknown but are important if animal welfare is not to be compromised through inappropriate design or operation. Animals have not encountered machines in their evolutionary history, and have therefore not developed behaviours that are necessarily adaptive in their presence: machines do not intentionally represent historical enemies and may not evoke any fear responses. Milking robots, for example, do not form part of the evolutionary precepts of a cow, and the limited studies to date have shown rapid adaptation within a few days (Prescott et al., 1998). Mechanised broiler catchers can reduce injury and may induce a lower stress response than manual collection (Duncan et al., 1986; Lacy and Czarick, 1998). Animals may adapt more readily to predictable machines than to an often unpredictable and inconsistent stockman: if a stimulus is highly predictable, its aversiveness is substantially diminished (Hemsworth et al., 1993).

Effective herding robots have to pose a sufficient threat on approach to interrupt ongoing animal behaviour without causing panic or flight reactions. In our experiments, different stimuli were evaluated for their effectiveness in interrupting feeding behaviour as they approached pairs of ducklings at a constant velocity. Domestic ducklings were used as a model species in these experiments because they have been used successfully in pilot studies of a herding robot (Vaughan et al., 2000). Three stimuli were compared in the first experiment. A human was selected as the stimulus that domestic birds are most likely to encounter in current commercial practice and also for comparison with related work (Henderson, 1999). The second stimulus was a vertical cylinder, which had a similar appearance to the herding robot developed by Vaughan et al. (2000). A model fox (Vulpes vulpes) was also chosen as it represented a more naturalistic and predatory stimulus with features that could potentially be added to a robot for more effective herding. Experiments 2 and 3 were specific investigations of the relevance of different features of the model fox in interrupting duckling feeding behaviour.

2. Materials and methods

2.1. Animals

Three batches each of 36 female ducklings (Pekin × Aylesbury) were used. Day-old birds were supplied by a commercial producer and randomly allocated to one of three flocks upon arrival. Each flock of 12 ducklings was housed in an identical adjacent pen. Visual contact was not possible between flocks. All flocks were subject to identical husbandry procedures; each pen was cleaned out daily in the morning during training/experimental sessions.

All flocks were fed once a day at the same time relative to the experimental treatment. Each flock was tested before its usual feeding time so that birds were
motivated to feed during testing; all individuals had been food-deprived for 22–23 h at time of testing. This created a standardised situation at the beginning of each trial (Jones et al., 1981) with all birds facing the front of the test pen and performing the same behaviour. The amount of food fed to each flock was increased according to the age of the birds: d1–5 ad libitum; d6–8 300 g; d9–13 400 g; d14–15 500 g; d16–17 700 g; d18–20 800 g; d21–25 900 g. Any food used during training sessions was deducted from the daily ration.

2.2. Experimental facility

The indoor experimental facility (Fig. 1) comprised a circular arena (7 m diameter, 3-m-high sides); three home pens (approx. 2 m × 3 m) where the ducklings were housed, each containing two automatic drinkers, wood shavings litter, a heater, and two food bowls; a pre-test pen (1.5 m × 2.5 m) containing a water drinker, where birds could be held prior to testing; a passageway linking the pre-test pen and the test pen with guillotine doors that could be operated remotely; a test pen (1 m²) with three solid wooden sides (1 m high) and one Perspex front facing into the arena; a post-test pen (1.5 m × 2.5 m), linked to the test pen by a passageway and a guillotine door; and a start box for the stimulus with a guillotine door on the front wall facing into the arena. A video camera, positioned in front of the test pen, recorded the behaviour of the ducklings, whilst a camera mounted on the wall of the arena tracked the position of the stimulus. The facility was lit by fluorescent tubes and all windows were blacked out. Light intensity was 17–18 lux in the arena, 13–14 lux in the test pen, and 24–25 lux in the home pens.

2.3. Test procedure

All flocks were subject to a schedule that familiarised birds with the experimental pens and the operation of the guillotine doors, and trained them to feed in the test pen. On days when no procedure was used, the ducklings were undisturbed, apart from the presence of a stockman to feed and clean out the pens once daily.
2.4. Flock training (9–11 days old)

Flock training was performed with each flock once a day for 3 days between 11:00 and 12:30 h after all birds had been food-deprived for 23–24 h. The order of flock training was rotated according to a Latin square design. A flock was first allowed to move into the pre-test pen containing 50 g chick crumb. After 10 min, the experimenter approached the pre-test pen and opened and closed the guillotine door between the pre-test pen and test pen 10 times to familiarise the birds to the door’s movement. The door was then left open and the flock was allowed to move into the test-pen. If the flock did not move into the test-pen after 1 min, the experimenter gently herded the birds through the door. A bowl containing 50 g chick crumb was located at the front of the test pen, i.e. adjacent to the Perspex screen. Once all the food in the test pen had been consumed, the flock was herded into the post-test pen where a small bowl of water was located. After 10 min, the flock was herded back to its home pen where a bowl containing 300 g chick crumb was located.

2.5. Pair training (14–18 and 21–22 days old)

Pair training was performed with each flock once a day for 7 days between 11:00 and 12:30 h. The order of flock training was rotated according to a Latin square design. A flock was allowed to move into the pre-test pen containing 50 g chick crumb. After 10 min, the guillotine door in the pen was opened, and two birds were allowed to move into the test pen. If, after 2 min, no pair had entered the test pen voluntarily, the flock was gently herded towards the door until two birds had entered the test pen. Pairs of birds were allowed to present themselves for testing to reduce the amount of human handling required: thus different pair combinations were trained together. All birds were colour-marked individually on day 16, to enable a record of pair combinations to be made. Each pair remained in the test pen for 2 min, where 200 g chick crumb was available in a bowl at the front of the pen. Each pair was then allowed to move into the post-test pen, which contained 100 g chick crumb and a bowl of water. This process was then repeated with the remaining birds. After the last pair of birds had entered the post-test pen, the flock was kept in this pen for 5 min and was then allowed to return to its home pen, where it was given 200–500 g chick crumb, depending on the age of birds. Any food remaining in the test pen was added to the home pen feed.

2.6. Stimulus presentation (23–28 days old)

The experiment proceeded only after each duckling in the pair had fed for at least 1.5 min in the test pen during pair training. This training criterion was set to increase the likelihood that birds would be feeding at the start of the trials. The order of presentation of the three stimuli followed a Latin square design. Each pair of birds was tested once a day for 6 days and was exposed to each of the three stimuli twice. During each trial, a flock moved into the pre-test pen where it received 25 g chick crumb. After 5 min, the first pair moved into the test pen, where 300 g chick crumb was located in a bowl at the front of the pen. After 1 min, the stimulus appeared in the start box at the opposite side of the arena. After 3 s, the stimulus was moved towards the
ducklings in a straight line at 0.5 ms\(^{-1}\). At each 0.5 m interval, which was marked on the ground, the stimulus was paused and proceeded only after both birds had resumed feeding. The stimulus approached to within 0.5 m of the front of the test pen and was then moved backwards across the arena at 0.5 ms\(^{-1}\). When the stimulus reached its original starting position (7 m from the ducklings) and both ducklings had resumed feeding, the door in the test pen was opened and the pair moved into the post-test pen. This test procedure was then repeated for the remaining five pairs in the flock and then with the other two flocks.

2.7. Behavioural data and analysis

The extent to which each stimulus interrupted feeding behaviour was assessed by recording cessation and resumption of feeding. The data recorded were each bird’s latency to resume feeding at each 0.5 m interval of the stimulus approach. Mean values were calculated for each pair, since the two birds in the test pen clearly influenced each other. The relationship between the latency and the stimulus–duck distance was analysed using a parallel curve analysis, in which an asymptotic regression was fitted to the data using the means derived from an analysis of variance (full details are given in Henderson, 1999). The fitted curve was \( y = a + br \). Each term in the regression is related to an aspect of duckling behaviour: \( y \) is the mean latency to resume feeding at distance \( x \); \( a \) is the asymptote that corresponds to the initial latency of response when the stimulus first appears; \( b \) is the intercept and is the predicted latency to resume feeding when the stimulus is at 0 m; and \( r \) is the rate of change of the response and corresponds to change in fear as the stimulus approaches. There were four stages to the analysis of the three sets of data, one for each stimulus: (i) one common curve was fitted to the data sets, i.e. \( a \), \( b \) and \( r \) were the same for each of the three stimuli; (ii) parallel curves were fitted to the data sets, i.e. separate \( a \) but common \( b \) and \( r \); (iii) curves were fitted with separate \( a \) and \( b \) but common \( r \); and (iv) curves were fitted with separate \( a \), \( b \) and \( r \). At each stage, the improvement of the model over the previous stage was evaluated by changes in the sums of squares; a reduction suggested an improvement in the model. The criterion for the model of best fit was a statistically significant improvement, indicated by a \( p \)-value of less than 0.05.

2.8. Experiment 1 — Compound stimuli: a human, a fox and a cylinder

Experiment 1 investigated ducklings’ responses to three herding stimuli: a human wearing white overalls, a 50-cm-high taxidermist’s model fox and a 50-cm-high black vertical cylinder. The model fox and the cylinder were mounted on top of a small radio-controlled vehicle so that they could be moved remotely across the arena. The human carried a Dictaphone, which played a recording of the radio-controlled vehicle noise whenever it moved, to allow a comparative assessment of duckling response to visual features only. All stimuli approached at 0.5 ms\(^{-1}\).

2.9. Experiment 2 — Facial features

Experiment 2 investigated the responses to particular features of the model fox that might be responsible for enhanced duckling response relative to the cylinder. In
particular, the rôle of facial features was investigated by presenting the head of the model fox in a forward or sideways orientation and by manipulations of the ears and mouth of the model (Fig. 2).

2.10. Experiment 3 — Visual complexity

Enhanced duckling response to the model fox relative to the cylinder could be a response to greater visual complexity. Experiment 3 investigated whether the response
was dependent on biological features such as depth, texture or realistic alignment of facial features. The herding stimuli were the model fox, a life-size photograph of the model measuring 53 cm × 50 cm, and the same photograph divided into 272 squares (3 cm²) that were then rearranged in a random pattern (Fig. 3). The two photographic stimuli were wrapped around the vertical cylinder and all stimuli were carried on the radio-controlled vehicle.

3. Results

The data for the latency to resume feeding were skewed and were transformed using a log₁₀ transformation. As many of the values were zero, which represented cases when birds continued to feed as the stimulus approached, a period of 0.5 s was added to all values prior to transformation. The results of the analysis of variance supported the regression analysis (see Henderson, 1999).

3.1. Experiment 1 — Compound stimuli

The rate of change of latency to resume feeding was non-linear over the distance of approach of the stimuli. For all stimuli, following an initial startle reaction when the stimulus appeared at 7 m, latencies to feed rose until the stimuli were approximately 4 m from the birds. Once the stimuli were within 3.5 m, the latencies increased dramatically for all stimuli. To take into account the effect of the startle response at 7 m, the regression analysis was performed with these data removed. The best fitting model was the second in which the parameter $a$ was estimated separately for each stimuli (Table 1, $p < 0.001$, percentage variance accounted for 95.8%; SE of observations estimated as 0.0696).

The fitted curves for the best fitting model are shown in Fig. 4. Inspection of the graph and estimated parameters shows that there was a significant difference between the initial responses of birds to the stimuli at 6.5 m (different value of $a$). The longest initial latencies occurred with the human and the shortest with the cylinder. After this initial response, the responses varied in the same way as the stimuli approached (same $b$ and $r$), and the longest latencies continued to be found in response to the human. Latencies increased as the stimulus approached with the greatest rate of increase once the stimuli were within 3–4 m. When the stimuli were at the closest distance (1 m), the longest latency occurred for the human stimulus.

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Response curve</th>
<th>Latency (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1 m</td>
</tr>
<tr>
<td>Human</td>
<td>log₁₀$y = 0.56 + 2.29 (0.48)$</td>
<td>45.6</td>
</tr>
<tr>
<td>Fox</td>
<td>log₁₀$y = 0.41 + 2.29 (0.48)$</td>
<td>32.2</td>
</tr>
<tr>
<td>Cylinder</td>
<td>log₁₀$y = 0.33 + 2.29 (0.48)$</td>
<td>26.9</td>
</tr>
</tbody>
</table>
3.2. Experiment 2 — Facial stimuli

For all stimuli, latencies to feed increased slowly from 7 m to approximately 4 m. The fourth model was the best fit to the asymptotic regression, i.e. when all parameters were estimated separately (Table 2, percentage variance accounted for 92.8%, SE of observations estimated as 0.0474).

The fitted curves are shown in Fig. 5. As in Experiment 1, the rate of increase in feeding latencies was relatively flat until approximately 4 m. From a distance of 4 to 1 m, the latencies to feed increased dramatically. In contrast to Experiment 1, no startle response was seen when these stimuli appeared at 7 m. There was no significant difference in the initial response of birds to the stimuli at 7 m. As the stimuli

Table 2
Experiment 2 — Equations for response curves for each stimulus and predicted latencies to resume feeding (see Fig. 5)

<table>
<thead>
<tr>
<th>Stimulus</th>
<th>Response curve</th>
<th>Latency (s)</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>1 m</td>
</tr>
<tr>
<td>Fox — forwards open mouth</td>
<td>$\log_{10} y = 0.08 + 1.06 (0.59')$</td>
<td>5.07</td>
</tr>
<tr>
<td>Fox — sideways</td>
<td>$\log_{10} y = 0.13 + 1.57 (0.38')$</td>
<td>5.30</td>
</tr>
<tr>
<td>Fox — forwards closed mouth</td>
<td>$\log_{10} y = 0.15 + 1.65 (0.32')$</td>
<td>4.80</td>
</tr>
</tbody>
</table>
approached, there was, however, a significant difference in the rate of change of latency to resume feeding. Feeding latencies in response to the fox with a sideways head orientation and the fox with flat ears and a closed mouth were almost identical as distance changed, but there was a larger r value for the ‘predatory’ fox with erect ears and an open mouth, indicating a faster increase in latency to resume feeding as this stimulus approached. The increased rate of change of feeding latency for the ‘predatory’ fox was most noticeable when the stimulus was within 5 m. When the stimuli were at the closest distance (1 m), the longest latency occurred in response to the ‘predatory’ fox, but all responses were very similar and probably not biologically relevant.

3.3. Experiment 3 — Stimulus complexity

Latencies to feed for all stimuli increased slowly from 7 m to approximately 4 m. The best fitting model in the asymptotic regression was the third in which the linear
parameters ($a$ and $b$) were estimated separately (Table 3, $p < 0.001$, percentage variance accounted for 96.5%; SE of observations estimated to be 0.0527).

The fitted curves for the best fitting model are shown in Fig. 6. As in Experiments 1 and 2, the responses were relatively flat until approximately 4 m. From 4 to 1 m, the latencies increased dramatically. As in Experiment 2, no startle response was seen when these stimuli appeared at 7 m. There was no significant difference in the initial response of birds to the stimuli at 7 m nor in the rate of change of feeding latency as the stimuli approached from 7 to 1 m (common $r$). When the stimuli were at the closest distance,
the longest and shortest latencies occurred in response to the fox and the fragmented photograph, respectively.

4. Discussion

The overall pattern of duckling response in the three experiments was similar, indicating that the protocol developed was robust and that similar behavioural responses were measured. In the first experiment, the approaching human caused the greatest interruption of feeding behaviour at all distances. The human was the only live stimulus and differed from the other stimuli in features such as height, realistic walking movement and facial features. Birds may also have responded to information about humans acquired previously during routine husbandry. The cylinder, which was similar in appearance to the herding robot developed by Vaughan et al. (2000), evoked the lowest latencies to resume feeding at all distances. The most likely reasons for this were that the cylinder was largely featureless, lacking any biologically relevant features (e.g. eyes), its shape did not represent any type of animal, it was less colourful and comprised a visually less complex image than the human or the fox. It was interesting to note that, despite no aversive prior handling, the ducks perceived the human as a greater threat than the inanimate stimuli, supporting previous results with sheep (Bouissou and Vandenheede, 1995) and adding weight to the argument that robots might reduce the fear reactions of handled animals.

Experiments 2 and 3 were designed to determine which visual features of the model fox were responsible for the enhanced duckling response relative to the model cylinder. It is known that many prey species are sensitive to postural (McConnell and Bayliss, 1985) and facial features of conspecifics (Kendrick et al., 1996) and potential predators (Curio, 1975). House sparrows (Passer domesticus), for example, respond more to a human face oriented towards them than to a sideways face (Hampton, 1994). In Experiment 2, there was a trend for the greatest interruption of feeding behaviour to occur in response to the model fox in a ‘predatory’ forward facing posture, but this was a weak effect. Another possibility was that the fox simply provided a more complex visual stimulus than the cylinder. This was examined in Experiment 3 using photographic images. Some animals appear to recognise stationary photographic stimuli (Vandenheede and Bouissou, 1994), although it is often unclear whether images are perceived as representative of real animals (Bradshaw and Dawkins, 1993). In Experiment 3, the ducklings interrupted their feeding behaviour more in response to the intact photograph than the fragmented photograph, suggesting that the intact photograph may have represented a real fox more closely. In contrast, there was no evidence that visual complexity was threatening per se. Visual complexity is the mean difference between two adjacent areas of an image on the red–green–blue colour space scale (Foley et al., 1990). Thus, the intact image of the fox, comprising a complete area of a red colour, had a lower complexity than the fragmented image with many adjacent areas of different colours and/or luminance.

Neither photograph elicited the same degree of response as the model fox, suggesting that even the intact photograph lacked certain relevant features, which might include a
three-dimensional appearance, reflectivity of fur or colour balance. The photographs used were matched to the trichromatic colour vision of humans and may have given a false colour representation to birds (Cuthill and Bennett, 1993).

Stimulus movement was dependent upon bird behaviour in these experiments. While birds did not feed, the stimulus remained motionless, but as soon as the ducklings fed, the stimulus moved. In some respects, this made the protocol more robust. If birds associated their behaviour with stimulus movement, they could increase their latencies to feed as a tactic to prevent further stimulus approach. In all experiments, the latency to resume feeding increased non-linearly as the stimuli approached. At distances of greater than 4 m, the response was mild, possibly because the ducklings could not see objects clearly at this distance. However, this seems unlikely as ducks are known to have high visual acuity, good colour vision in all wavelengths and 360° visual coverage in the horizontal plane (Martin, 1986) and can recognise conspecifics at 70–80 m (Reiter, 1997). It is more likely that the ducklings were able to assess when the approaching stimulus began to pose an inescapable threat and increased their vigilance sharply at this point.

The results are relevant to the future design of machines that are to work amongst animals (Vaughan et al., 2000). Visual features of approaching stimuli clearly influence duckling response and interrupt ongoing feeding behaviour to different degrees and are therefore likely to be relevant in designing effective robots. The most suitable design is likely to depend upon the task and its frequency. For example, if a robot is required to herd a group of animals once only (e.g. along a raceway in an abattoir), then a simple, relatively non-threatening appearance is likely to be both adequate and humane. A different design would be necessary if the machine had to control the same animals repeatedly in order to avoid habituation (Henderson, 1999). In this case, the machine should have features that allow variable levels of threat to be imposed: it might resemble a predator and be able to alter its size, for example. Variable features would allow “force” to be applied to a flock only when necessary, thus reducing unnecessary distress.

The question of whether the use of machines and automated systems rather than humans in livestock production is better for animal welfare is complex. It has been suggested that, if applied appropriately, automation can improve animal welfare (Appleby and Hughes, 1993; Wathes, 1994). This study, which found a relatively high disruption of behaviour in ducks exposed to a human, but not to a simple non-biological stimulus, supports this. However, if machines undertake most of the routine husbandry chores in livestock husbandry, then occasional human contact may become stressful (Wathes, 1994). It is therefore crucial to adopt an integrated approach to the application of automation in agriculture (Appleby and Hughes, 1993).

Acknowledgements

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References