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Discrimination of intentional and random motion paths by pigeons

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Abstract Twelve pigeons (*Columba livia*) were trained on a go/no-go schedule to discriminate between two kinds of movement patterns of dots, which to human observers appear to be “intentional” and “non-intentional” movements. In experiment 1, the intentional motion stimulus contained one dot (a “wolf”) that moved systematically towards another dot as though stalking it, and three distractors (“sheep”). The non-intentional motion stimulus consisted of four distractors but no stalker. Birds showed some improvement of discrimination as the sessions progressed, but high levels of discrimination were not reached. In experiment 2, the same birds were tested with different stimuli. The same parameters were used but the number of intentionally moving dots in the intentional motion stimulus was altered, so that three wolves stalked one sheep. Despite the enhanced difference of movement patterns, the birds did not show any further improvement in discrimination. However, birds for which the non-intentional stimulus was associated with reward showed a decline in discrimination. These results indicated that pigeons can discriminate between stimuli that do and do not contain an element that human observer see as moving intentionally. However, as no feature-positive effect was found in experiment 1, it is assumed that pigeons did not perceive or discriminate these stimuli on the basis that the intentional stimuli contained a feature that the non-intentional stimuli lacked, though the convergence seen in experiment 2 may have been an effective feature for the pigeons. Pigeons seem to be able to recognise some form of multiple simultaneously goal-directed motions, compared to random motions, as a distinctive feature, but do not seem to use

simple “intentional” motion paths of two geometrical figures, embedded in random motions, as a feature whose presence or absence differentiates motion displays.

Keywords Motion perception · Motion · Intention · Feature-positive effect · Pigeons

Introduction

In the natural environment, animals are constantly exposed to moving stimuli and it is essential for them to deal with the information in an appropriate way. For instance, when pigeons encounter animals that they have never seen before, they must be able to recognise immediately whether these animals are potential predators. In such situations, it is important to identify predators by means of a general concept, namely, the similarity and dissimilarity with other exemplars of predator, rather than from previous knowledge of the individual. Static visual cues such as body size, shape, and colour are, of course, important information. However, predatory animals are diverse and some of them often look similar to non-predatory animals. So, it is not always efficient to categorise based solely on static visual cues. For instance, both cats and peregrines are predators for pigeons but they have few similarities in their features. On the other hand, cats are very similar to dogs, but dogs are not predators of pigeons. So, how can animals reliably discriminate whether or not the animal they meet is likely to hunt them?

Responding to the psychological processes of a potential predator as revealed through its style of movement may be a realistic strategy. It is plausible that animals can discriminate actively predatory animals using cues from their movements, for these will necessarily tend to be similar regardless of species: predators such as lions, tigers, cats, and snakes all normally rush at their prey after quietly approaching it. Thus, there are biological grounds for believing that animals may encode and conceptualise movements as intentional if they resemble the “purposeful” or stalking behaviour of a predator.

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Is such discrimination possible for typical prey species? The extensive investigations into visual cognition in pigeons provide evidence that it may be. Emmerton (1986) investigated the recognition of complex movement patterns displayed on an oscilloscope. In her study, pigeons were trained to discriminate between two different trajectories of Lissajous figures (figures described by the trajectory of a single dot moving with vertical and horizontal dimensions). Generalisation tests showed that recognition was highly stable against variations such as axis rotations or changing contour. Bischof et al. (1999) also showed that pigeons could discriminate between different patterns of movement. In their study, two stimuli were presented on the two separate monitors in the operant chamber. On each trial, the stimulus on one of the monitors consisted of dots in random motion (0% coherence): each dot moved by 1 pixel in a random direction (up, down, left, or right) in each frame. The stimulus display on the other monitor showed dots in motion that was coherent at some percentage: coherent dots all moved consistently in the same direction, whereas the rest of the dots moved randomly. Pigeons were trained to discriminate those two types of stimuli, and showed over 70% correct responses when the percentage of coherent motion was above 50%.

One of the problems of the studies cited so far is a lack of ecological validity, in that the stimuli involved were entirely artificial. However, Dittrich and Lea (1993) investigated pigeons' discrimination of movement in more natural stimuli. They trained pigeons to discriminate movie clips of pigeons moving from still frames from the same movies. One group of pigeons were trained to peck at moving images and another group to peck at still images. Results indicated that pigeons in the movement-positive group showed higher performance than the pigeons in the movement-negative group. This suggests that movement is a distinctive and salient feature for pigeons, so that there was a strong feature-positive effect (Jenkins and Sainsbury 1970) connected with the movement.

Dittrich et al. (1998) further investigated pigeons' recognition of natural movement by using biological motion stimuli that contained only movement cues. The stimuli consisted of arrays of moving point lights that represented points on the bodies of living things (Johansson 1973). For example, several point lights placed on the joints of the human body are perceived as a walking man by humans when they are moving but not when they stop moving. Therefore, biological motion may be perceived as particular patterns of movement and then encoded as movement of animals even though it is a simple geometric stimulus. Dittrich et al. (1998) successfully trained pigeons to discriminate between different patterns of other pigeons' movement (pecking and walking) displayed both as video movies and as point light stimuli presented on a video screen. They found some evidence of transfer from video movies to point light stimuli, though they could not demonstrate transfer in the reverse direction.

These results imply that pigeons can respond to moving dot stimuli as if they were fully detailed depictions of scenes. Yet this capacity may be limited to natural move-

ments: Omori (1997) trained some pigeons to discriminate moving displays of pigeons from those of artificial objects (a toy walking dog). Transfer from full-detail to point-light stimuli was only found with the natural movements.

Thus pigeons can discriminate stimuli on the basis of the kind of motion they show and can do this with movement information alone, at least when the movements are natural. Does this extend to the perception of intentional movement? Intentional motion is defined as the purposeful movement of living things or, as in this study, artificial motions that mimic purposeful movement through the goal-directed movement of some element in respect to other elements. For instance, when predators try to catch their prey, their movement is generally of a stalking nature as they approach the prey, so we perceive the behaviour as intentional. As emphasised by Dittrich and Lea (2001), pigeons can use movement cues to categorise the different patterns of movement according to categories that correspond to human concepts. Therefore, movement cues might well help in the detection and conceptualisation of intention in predators, based on particular movements.

Humans can identify intentional movement from very limited cues. Heider and Simmel (1944) showed people a film of simple geometrical figures in motion. With high consistency the situation in which the figures moved was described by adult humans in terms of intentional social interactions of animate beings, using words such as chasing or fighting. Therefore, intention can be thought of as a perceptual illusion that we perceive from certain movement patterns (Dittrich and Lea 1994). Bassili (1976) hypothesised that the intention is perceived in the presence of certain spatial and temporal configurations between objects. In his study, five different kinds of movement between a black and a white circle were generated by computer, and their patterns were varied in terms of spatial and temporal configurations: changes in direction of the two objects, and the way that two circles interacted with each other. He concluded that these spatial contingencies influence participants' perception of intention, and the temporal contingency between two objects was crucial for the perception of an interaction between the figures.

Unlike Bassili (1976), Dittrich and Lea (1994) assumed that perception of intention should be attributed to a conceptual integration based on visual features of movement. Therefore, they examined how the operations of parameters of purposeful movement change participants' perception of intention. In their study, human participants were shown an array of moving dots. All but one of the dots moved randomly: the distinctive dot (which Dittrich and Lea called the "wolf") moved systematically or "purposefully" towards one of the randomly moving dots (the sheep). When the movement of the wolf was more direct and faster than that of the distractors, participants reported it was more probably intentional. Thus, it is the movement that gives us the perception of intention and is interpreted accordingly. Therefore, Dittrich and Lea concluded that the perception of intention is produced by the semantic representation of movements and it is constructed in the same way as other natural concepts.

An interactive process of intentional motion perception was hypothesised by Dittrich and Lea (1994). They assumed as a first stage a bottom-up process in which a specific motion feature is selected, and as a second stage a top-down process in which the movement is encoded and integrated as conceptually intentional information. The studies investigating biological motion perception in pigeons (Dittrich et al. 1998; Omori 1997) imply that birds can react to movement cues as they would to fully detailed scenes of conspecifics in motion. We hypothesised that intention might also be recognised by pigeons as a category based on motion features.

Accordingly, in experiment 1, we investigated whether pigeons can discriminate between two different movement patterns using the same type of stimuli as Dittrich and Lea's (1994). Twelve pigeons were trained and tested on a conventional go/no-go discrimination with moving dot stimuli generated by computer. One type of stimulus (intentional) consisted of a wolf that moved towards one particular sheep out of three, whereas the other type of stimulus consisted of four sheep (non-intentional). Stimuli consisting of such geometric figures produced the illusion of animated purposeful objects in human participants if and only if there was a wolf present (Dittrich and Lea 1994), so we predicted that pigeons should be able to discriminate between different movement patterns and show generalisation to the different patterns of purposeful movements.

When two stimuli are differentiated by the presence or absence of a feature that is informative and salient, it is typically found that it is much easier to demonstrate a feature-positive discrimination than the corresponding feature-negative discrimination even though the stimuli are exactly the same in the two conditions (Jenkins and Sainsbury 1970; Dittrich and Lea 1993; Watanabe, Lea, Ryan and Ghosh, unpublished data quoted from Dittrich and Lea 2001). Therefore, it was expected that if pigeons perceived the stalking dots as intentional, there would be a feature-positive effect in this experiment, with an "intention-positive" discrimination giving faster learning than an "intention-negative" discrimination.

In experiment 2, similar stimuli were used, but the numbers of wolves and sheep were altered with the intention of making the task easier, as birds showed only weak discrimination in experiment 1.

Experiment 1

In the first experiment, the intentional motion stimuli were those where a single stalker element was set to move faster than the distractors and to stalk a target directly. These stimuli simulated predatory motion: the stalker was called a wolf and its target a sheep. The other two distractors were sheep as well (target sheep and distractor sheep moved in the same way). Birds were given a discrimination task to examine whether they could distinguish between these different patterns of movements.

Methods

Subjects

The subjects were 12 experimentally naïve pigeons (*Columba livia*), from the flock maintained by the University of Exeter. They were kept at or above 80% of their free-feeding weight by the delivery of hemp and conditioner during the experimental sessions and by supplements of mixed grain, given after their experimental session and on non-testing days. The pigeons were held in individual cages for at least 30 min before and after the training sessions; at other times they were housed in an indoor aviary, measuring 2.2×3.4×2.4 m. The aviary was equipped with pigeonholes in units of 16, and ad lib access to water and crushed oyster shells was available. The birds were maintained on a 12:12 h light:dark cycle, with half-hour simulated dawn and dusk periods. Six of the birds were employed in a pilot study with stimuli consisting of black dots on a white background during six sessions. Stimuli and procedure were similar to those of the main experiment. However, since the birds showed no sign of learning to discriminate the stimuli, the colours of the stimuli were reversed before the training sessions reported here began. There were no differences in the results of the birds given and not given pilot training, so data have been merged for presentation here; data from the pilot sessions are not included.

Apparatus

Two identical three-key operant chambers, 69×49×39 cm, were used. Each consisted of a plywood box, with a three-key intelligence panel (Campden Instruments Ltd, London), 33.5×35 cm, set into the front wall. The centre key was made of transparent Perspex, with a diameter of 2.8 cm, and was positioned on the front wall of the operant chamber, 24 cm above the floor. The other two keys, positioned at the same height and on either side of the centre key, were not used in this experiment. A shutter operated by a rotary solenoid was situated behind the key so as to prevent the pigeon from viewing the stimuli during intertrial intervals. Below the centre key, on the outside of the panel, there was a solenoid-operated food hopper containing a 1:2 mixture of hemp and conditioner. A 1.0 W white light in the hopper aperture served as a signal for food being accessible. The panel was also equipped with a 3.5 W houselight situated 2.5 cm above the response key. The houselight served as a signal to the bird that the session was in progress; it turned on at the beginning of a session and turned off 8 s after the last trial. White noise was provided by a 35-ohm loudspeaker mounted on the back of the aluminium panel, and noise was also generated by a ventilation fan. Stimuli were presented on a 15-inch monitor (HEI, HL-5854B) using a program written in Borland Delphi 3 and running under the Windows 95 operating system on a PC-compatible computer (Tiny, PII-333 Mhz, using ATI Rage Pro Turbo graphics cards).

There was a separate computer and display for each test chamber. The display screen was positioned 35 cm from the key. The monitors were set to a resolution of 800×600 pixels. Both the chambers and the computer monitors presenting the stimuli were housed in a single darkened room. The equipment inside the testing room was connected, via a local network, to another computer outside the testing room. This PC-compatible microcomputer (Viglen 4DX266), running under the Windows 3.1 operating system, sent stimulus parameter information to the computers inside the testing room and also controlled all the events and recorded responses from the test chamber via a program written in Borland Delphi 1.

The pigeons' behaviour could be regularly monitored via CCD camera, fitted with a wide-angle lens and placed outside each chamber; the camera's view was provided through a window, 10×10 cm, in the left wall. Video monitors placed outside the test room had a direct link with the cameras inside the testing room so that the bird could be observed without interference during sessions.

Stimuli

The stimuli consisted of arrays of white moving dots on a black background. All the dots were drawn at identical size (a diameter of 30 pixels) on the monitor. The stimulus generation program was developed from the program used in Dittrich and Lea (1994) and was modified in this study with regard to the appearance of dots and the parameters that determined the movement of dots. Two types of stimuli were used in this experiment: intentional motion stimuli consisted of wolf dots and sheep dots, whereas non-intentional motion stimuli consisted of sheep only. The movement of sheep dots was essentially at random, whereas the movement of each wolf was determined to stalk a particular sheep.

At the beginning of each trial of both intentional and non-intentional motion stimuli, the dots were randomly distributed within the central three-quarters of the display area, whose size was 600×450 pixels. The movements of the sheep and the wolf took place in a series of cycles, each of which lasted for 10 ms, as follows: in each cycle, each sheep moved by a number of pixels that was randomly varied from 0 to 5 pixels. Its direction of movement was given by its direction of movement in the previous cycle plus a random element that was determined from a rectangular distribution from a +90° to -90° range. All random selections were performed separately and independently. In the intentional motion stimuli, a single wolf dot was initially placed in the opposite quadrant to its target sheep. It moved according to parameters of constant step size of 9 pixels in every 10 ms and its direction of movement was determined towards the current position of its target distractor directly. If the wolf reached the position of its target sheep, the two dots merged, and the wolf effectively disappeared; a new wolf then appeared in the opposite quadrant of the display and started to track the same target. Given the stimulus parameters used, this

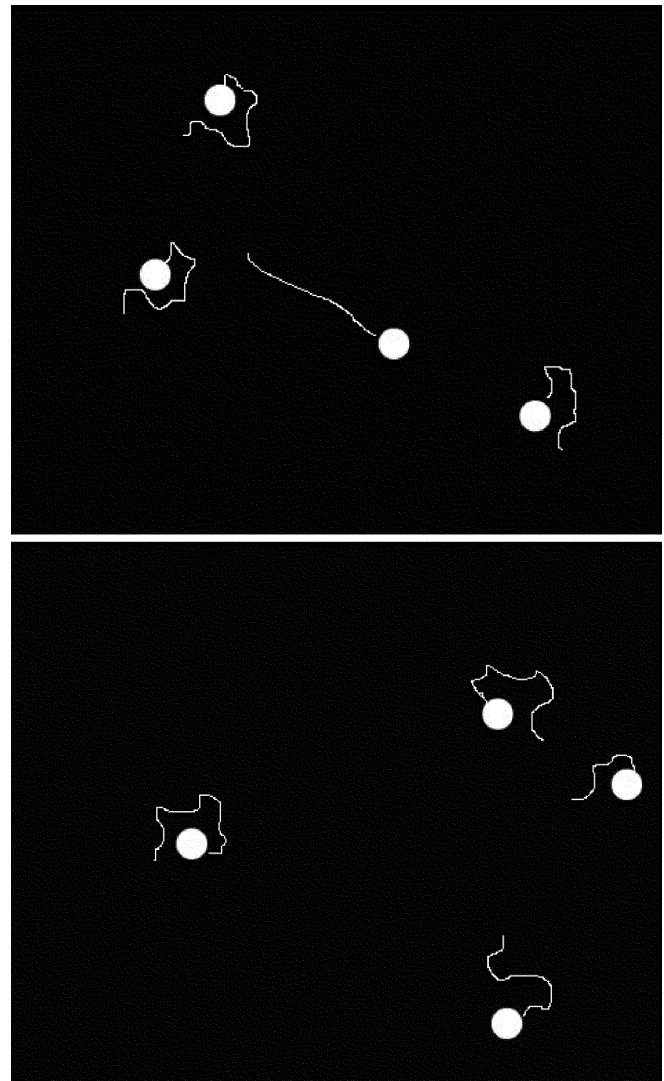


Fig. 1 Examples (reduced size) of still images of two displays of the kind used in experiment 1, showing the trajectories of the moving dots from the beginning of the trial (trajectories did not appear on the screen). *Top* The dot near the centre of the rectangle is the stalker or "wolf"; its target "sheep" is at the bottom-right side of screen. *Bottom* All the dots are sheep

could be expected to happen two or three times within each trial using an intentional stimulus. The parameters of the sheep and the wolf were unchanged throughout this study. In training sessions, the number of dots was set to four: namely three sheep and a wolf in the intentional motion stimuli and four sheep in the non-intentional stimuli. Figure 1 shows examples of intentional and non-intentional motion stimuli.

Procedure

The pigeons were first trained by standard procedures to find food in the hopper and then to peck the centre key when the shutter was opened to show the monitor with a

white screen. The schedule of reinforcement used was gradually extended to a fixed interval of 12 s, with a 10-s timeout after food reinforcement during which the shutter was closed. Reinforcement normally consisted of a 3-s hopper operation. Both the left and right keys were inoperative throughout the experiment.

Once pecking was established, training sessions were given to the birds. For discrimination training, a tandem 10-s fixed-time (FT), 3-s variable-interval (VI) schedule was used. Each trial began with the opening of the shutter to reveal a stimulus on the monitor. Pecks were not reinforced during the first 10 s of each trial (FT 10 s). In positive stimulus trials, pecks were reinforced by a 3-s presentation of the food hopper according to the VI 3-s schedule following the completion of the FT 10 s, whereas pecks to the negative stimuli were never reinforced. The trial was terminated by either the presentation of food or the expiry of the variable extinction period. The responses during the FT period of both positive and negative stimuli were counted and the ρ statistic of Herrnstein et al. (1976) to the positive stimuli was used as a discrimination index. The ρ value in each session was calculated as the U value of the Mann–Whitney test divided by the product of the numbers of positive and negative stimuli, both 40 in this case. Each session consisted of 80 trials separated by intertrial intervals varying in duration from 5 to 10 s; the shutter was closed during intertrial intervals. Positive and negative stimulus trials were presented in a pseudo-random sequence, generated afresh for each session, constrained so that no more than three positive or three negative trials were presented consecutively. Sessions were normally given once a day, six times in a week. The plan was to conduct training sessions until the birds reach a criterion of $\rho \geq 0.8$ in two consecutive sessions, or until no further improvement was shown if this criterion was not reached; unless the criterion was reached, the number of training sessions was to be divisible by 3 to allow analysis of early, middle, and late training periods. The 12 birds were allocated at random into two groups. In the wolf-positive group, the stimuli containing the wolf were positive and those containing only sheep were negative; in the wolf-negative group, the stimuli containing only sheep were positive and those containing the wolf were negative. Half the birds in each group were trained in each of the experimental chambers.

Results and discussion

After 33 sessions, no bird had reached the criterion, but all birds were showing some consistent discrimination, and performance appeared to have reached an asymptote. Training was therefore terminated. The group means of the ρ value in each session are shown in Fig. 2, and a small but clear improvement in performance across sessions can be seen.

To compare the rate and extent of learning between groups, the sessions were divided into 3-session blocks, each consisting of 11 sessions, and the average of the

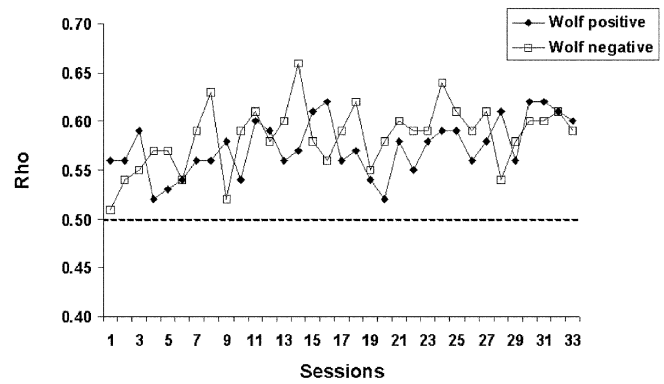


Fig. 2 Group mean results from experiment 1. The *horizontal axis* indicates the sessions and the *vertical axis* indicates mean of the ρ discrimination index. Birds showed some improvement of discrimination but there was no significant difference between groups

ρ values in each block was calculated for each bird. The blocked data were examined by means of a mixed model ANOVA, in which the group (wolf-positive and wolf-negative) and the experimental box used in the training sessions were treated as between-subject factors and session block was treated as a within-subject factor. There were significant effects of session block ($F_{2,16}=3.64$, $P=0.049$) and of the interaction between session block, group, and box ($F_{2,16}=3.88$, $P=0.042$) but not of group ($F_{2,16}=0.24$, $P=0.64$) or any two-way interaction. A t -test conducted on the ρ values on session 33 (mean=0.594) showed that the performance was significantly higher than chance level ($t_{11}=7.956$, $P<0.001$). These results imply that the birds showed some improvement of discrimination as the sessions progressed but with no group differences, so no overall feature-positive effect was found in this experiment. The three-way interaction between session block, group, and box was examined in detail, and separate analyses were undertaken for each box. However, no significant interaction was found between session block and group in either box ($F_{2,8}=1.93$, $P=0.20$ in box 1, $F_{2,8}=2.39$, $P=0.15$ in box 2), so there was no evidence of a feature-positive effect in either box separately. Nor did the pattern of mean ρ values suggest such an effect in either box; rather, the wolf-negative birds in one box had relatively high starting levels of ρ . Since no such effect was predicted, and no explanation of it is obvious, it is probably best attributed to some uncontrolled factor such as clearer visibility of the stimuli in that box allowing faster learning in the early sessions.

This experiment therefore demonstrated that “intentional” and “non-intentional” stimuli of the kind used by Dittrich and Lea (1994) could be discriminated by pigeons. However, given that there was no feature-positive effect either overall or in either box separately, the experiment gave no evidence that “intention” was a salient distinctive feature for the birds.

Experiment 2

In the second experiment, the number of wolves in the intentional motion stimuli was increased in an attempt to make the difference of movement pattern more salient. Studies using still-picture stimuli imply that the number of exemplars in each stimulus influences the task difficulty of same–different concept discrimination in pigeons (e.g. Young et al. 1997). In particular, when the number of exemplars in each stimulus was small, birds performed poorly. The task used in experiment 1 could also be considered as a kind of same–different concept discrimination, between wolf and sheep movements. Therefore, the influence of a change in the number of stimulus elements on pigeons' performance was investigated in experiment 2. The parameters of the wolf element, namely speed and angular variation, were the same as in experiment 1. Therefore, the stimuli simulated movements of a group of predators attacking a prey animal in the natural environment.

The aim of the experiment was to investigate (1) whether the discrimination shown in experiment 1 would transfer to these modified stimuli; (2) whether increasing the number of wolf dots would improve the discrimination shown by either or both groups of birds; and (3) whether a feature-positive effect would emerge under these new conditions.

Methods

Subjects and apparatus

The twelve pigeons used in experiment 1 were used after a habituation session to new stimuli, and they were divided into the same two groups as before. The apparatus was identical to that of experiment 1.

Stimuli and procedure

Following experiment 1, a habituation session was given to avoid the risk of pigeons failing to respond if a session began with new stimuli. The habituation session consisted of 80 trials. In the first 20 trials, the stimuli used in experiment 1 were used. Then, new intentional stimuli were used for the rest of the intentional trials (non-intentional stimuli continued unchanged). After the habituation session, the procedure used was the same as in experiment 1 except that the new intentional motion stimuli were used throughout. The new intentional stimuli consisted of three wolf elements and one sheep element.

It was determined in advance that testing of individual birds would cease if the criterion of a ρ value of 0.80 in two consecutive sessions was reached, but that otherwise testing would cease if either or both groups showed a distinct change in performance from levels reached in experiment 1. As in experiment 1, unless the criterion was

reached, the number of training sessions was to be divisible by 3 to allow analysis of early, middle, and late training periods.

Results and discussion

No bird reached the criterion of $\rho=0.80$ in two consecutive sessions. After nine sessions, the wolf-negative group were showing an apparent fall in discrimination performance, so training of all birds was terminated. The group averages of the ρ value in the last three sessions of experiment 1 and all the sessions of experiment 2 are indicated in Fig. 3. A three-way mixed model ANOVA was carried out, with a within-subject factor of four session blocks, and between-subject factors of group and box. Sessions in experiment 2 were segmented into three blocks of three and the last three trials of the first experiment were also taken into account. There are no significant differences by session block ($F_{3,24}=0.23$, $P=0.875$) or groups ($F_{1,8}=0.74$, $P=0.414$) but there is a significant effect of the interaction between session block and group ($F_{3,24}=7.34$, $P<0.001$). In both wolf-positive and wolf-negative groups, no pigeon showed improvement of its performance in experiment 2 compared with that in experiment 1, and indeed there was little change in performance between the final three sessions in experiment 1 and the first three sessions in experiment 2. However, the significant interaction between session block and group implies that there was a feature-positive effect, in that performance in the wolf-negative group decreased towards chance levels: this is typical of performance in feature-negative groups (Jenkins and Sainsbury 1970; Dittrich and Lea 1993). This is also confirmed by the t -tests conducted on the performances of both wolf-positive and wolf-negative groups on session 9; the performance of the wolf-positive group (mean=0.61) is significantly above chance level ($t_5=9.53$, $P<0.001$) but the performance of the wolf-negative group

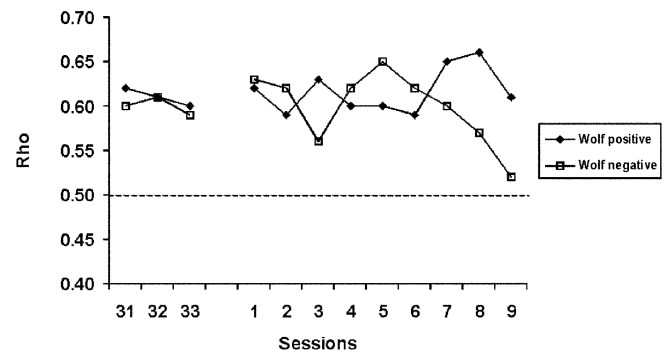


Fig. 3 Group mean results from experiment 2. The *horizontal axis* indicates the sessions and the *vertical axis* indicates mean of the ρ discrimination index. The first three sessions (31, 32, and 33) are the last three sessions in experiment 1 and are followed by all sessions of experiment 2. The wolf-positive group maintained their discrimination performance, whereas the wolf-negative group showed a decrement in their performance by session 9 of experiment 2

(mean=0.52) is not significantly above chance ($t_5=0.81$, $P=0.457$). Moreover, there was a significant difference in performance between wolf-positive and wolf-negative groups on session 9 ($t_{10}=2.78$, $P=0.019$).

The gradual loss of performance in the feature-negative group is consistent with the “simultaneous discrimination” hypothesis about the origins of the feature-positive effect advanced by Jenkins and Sainsbury (1970), according to which the feature-negative birds correctly learn to discriminate the common and distinctive features but respond to the common features and therefore to both stimuli. It must be supposed that the feature of multiple goal-directed motion in experiment 2 had enough in common with the tracking movement of the single wolf in experiment 1 to support initial transfer, but as the birds learned to differentiate the stimuli on the basis that some were “goal-directed” and some were “random”, consistent responding to “random” began, causing loss of apparent discrimination.

In summary, therefore,

1. The discrimination shown in experiment 1 did transfer to the modified stimuli used in experiment 2;
2. Increasing the number of wolf dots did not improve the discrimination shown by either group of birds;
3. It did, however, reveal a feature-positive effect, in that discrimination was maintained in the wolf-positive group but lost in the wolf-negative group.

It can be concluded that, for pigeons, a convergent motion of several dots is similar to a tracking motion of a single dot, but it does not simply constitute an amplified version of the same stimulus, and indeed convergence constitutes a distinctive, salient feature whereas tracking does not.

General discussion

Perception of intention in pigeons

Our initial evidence that pigeons are able to discriminate between “intentional” and “random” motion should not be taken as direct evidence that pigeons can perceive intentions in the sense of perceiving the psychological state of others or potential predators. However, our findings indicate that future research about the perceptual characteristics of potential prey may well reveal cognitive mechanisms directly corresponding to characteristic predator behaviours such as “intentional” motion paths. Though previous studies (e.g. Emmerton 1986; Dittrich et al. 1998; Bischof et al. 1999) have found that pigeons are able to discriminate reliably between different complex motion stimuli of moving dots, the results of both experiments 1 and 2 demonstrated that it is difficult to train them to discriminate between stimuli that do and do not contain either one or three wolf elements among four moving dots with any substantial level of accuracy. However, some discrimination is possible. In experiment 1, pigeons in both wolf-positive and wolf-negative groups did improve their performances as the sessions proceeded. This im-

plies that they learned some discrimination. The reason why pigeons’ performance was poor will be discussed below.

In experiment 2, pigeons did not show any improvement compared with the first experiment, regardless of in which condition they were trained. On the contrary, the wolf-negative group showed a decline, leading to a group difference by session 9, with only the wolf-positive group maintaining performance above chance level. Though the main effect of group in the ANOVA was not significant, the significant session×group interaction and *t*-tests show the two groups had different levels of performance.

The results of experiment 1 showed no feature-positive effect, suggesting that the presence of a single wolf element did not constitute a feature for the pigeons. The interaction seen in experiment 2, however, indicates some feature-positive effect. This in turn suggests that instead of a stalking or “intentional” movement of one element towards another it is the goal-oriented movements of multiple elements towards one goal that seems to constitute a discriminatory feature for the birds. Such an interpretation seems to be supported by recent findings on the discrimination of Glass patterns by pigeons (Kelly et al. 2001), which similarly imply that a converging pattern of moving dots is discriminable. In the radial Glass pattern stimuli used by Kelly et al., 20–100 dots moved convergently with different levels of coherence, and pigeons could discriminate the Glass pattern from random dot movement at around 75% correct when the proportion of coherently moving dots was 80%, with the remaining 20% of dots moving randomly. In experiment 2 of our study, the percentage of wolf dots in the intentional stimuli was 75%, whereas there was no coherent motion in the non-intentional stimuli.

Therefore, though the stimuli in this experiment were discriminated by pigeons, there was little evidence that they did so on the basis of a category of “intentional movement”. The evidence from experiment 1 was that they learned to discriminate two different movement patterns, but not that they saw them as “random alone” versus “random plus intention”. From experiment 2, however, there was some evidence that the feature of multiple goal-directed motion paths was salient and distinctive. Furthermore, there was good transfer from the performance in experiment 1 to experiment 2. This implies that the pigeons’ perception of moving dots in this study was not the same as that of human participants (Dittrich and Lea 1994) and that birds do not perceive intention in moving dots, at least under the conditions of the present experiment. The fact that there was some feature-positive effect in experiment 2 suggests that the multiple goal-directed motion paths as used in that experiment increase the intensity of “intentional” elements, so that they became salient features. We would therefore predict that if inexperienced birds were trained in a convergence-positive task, they would probably show more rapid acquisition than the birds in experiment 1. The absence of improvement in the wolf-negative group in experiment 2 may simply reflect negative transfer from the previous task.

Why did pigeons have difficulty in discriminating between the different movement patterns in this study?

Though discrimination was shown in experiment 1 of this study, it was not as obvious as that found in some previous studies on movement pattern recognition (Emmerton 1986; Bischof et al. 1999). It is important to examine why pigeons had difficulty in discriminating between different motion stimuli in this study. There are two major issues with regards to the experimental stimuli used in this study: one is the use of a computer monitor as a stimulus generator and the other is the particular task.

The first issue is fully discussed by D'Eath (1998) and Lea and Dittrich (1999). The problems of a computer monitor as a stimulus generator for birds are its limited resolution, its colour range (omitting ultraviolet), and its flicker rates. In particular, the flicker rates could disturb pigeons' perception of the stimuli. However, this source of disturbance should be reduced by using white dots moving on the black background. In any case, much higher rates of discrimination have been achieved using moving dot stimuli in highly similar apparatus (e.g. Dittrich et al. 1998), so it seems very unlikely that either the apparatus as such or the general nature of the stimuli was the source of the pigeons' difficulty with the task.

The second problem, the particular task used, can be considered in the light of studies on same–different concepts. The task in this study can be viewed as a kind of same–different categorisation of movement, with the movement of the wolf being different from that of sheep. Wright et al. (1983) trained pigeons to discriminate between pairs of slides of real objects that were the same as or different from one another. Pigeons given nearly 20,000 trials showed an average of 80% correct responses to familiar pictures but they showed only 62% correct when tested for transfer to unfamiliar pictures. This result implies that pigeons have difficulty in learning a same–different concept from such stimuli. However, Young et al. (1997) demonstrated that the difficulty of such a task depended strongly on the number of items used in the stimuli. Their stimuli were visual displays comprising from 2 to 16 computer icons either the same as or different from one another. Using stimuli involving a greater number of items, especially when the number is greater than eight, made it easier for pigeons to form a same–different concept. The implication is that the number of moving dots in this study may not have been great enough to allow pigeons to discriminate easily between the different movement patterns.

There is one other possible source of difficulty for the pigeons in this experiment: the stimuli used on each trial were always novel. This is discussed below.

Randomly generated stimuli and their future application

A major difference of the present study from most previous motion studies of birds, except for Bischof et al. (1999), was the way in which the stimuli were generated.

In most previous studies, especially those using video, sets of movement stimuli were prepared in advance and were repeatedly presented throughout the experimental sessions (e.g., Siegel 1970, 1971; Emmerton 1986; Dittrich et al. 1998). However, it is very rare that animals and objects reproduce exactly the same movements repeatedly in the natural environment. Therefore, the movements used in experimental situations should also be more diverse to secure the validity of the movement stimuli.

Concept discrimination studies using still pictures indicate that the more exemplars pigeons encounter in training, the better generalisation to novel exemplars is found. For instance, the experiment by Herrnstein and Loveland (1964), in which they trained pigeons to discriminate stimuli containing humans from those not containing humans, used over 1,200 different still-picture stimuli during the training sessions, and pigeons were exposed to the same stimuli very few times. In generalisation tests, pigeons discriminated between novel human and non-human stimuli very well, though the characteristics of human were very diverse in the stimuli. This example suggests that birds could also form a better concept of movements if it was acquired through a greater number of different stimuli. In the present experiment, the stimulus used on each trial was unique. Generalisation to rather different stimuli, between experiments 1 and 2, did indeed indicate very little decrement in the present study (see Fig. 3). Therefore, the stimulus-production method used in this study, in which diverse patterns of movements are produced according to construct rules rather than a limited set of fixed stimuli being used repeatedly, should become the method of choice when categories of movement stimuli are to be discriminated and there is any concern with conceptualisation. The technique of producing different stimuli for each trial simulates movements in the natural environment, in which it is rare for exactly the same movements to be reproduced.

However, it is possible that although using a newly generated stimulus on each trial gives better transfer to new members of the category once discrimination has been learned, it also makes it more difficult for pigeons to learn the initial discrimination, since it prevents the birds from using a rote learning or absolute discrimination strategy, which can be highly effective (Vaughan and Greene 1984). It is also possible, for example, that the early stages of acquisition of concept discriminations involve making a simple discrimination based on an adventitious distinctive stimulus feature, and when the stimuli are generated afresh on each trial, this cannot happen.

Comparative issues

From this study, it appears that

1. It is difficult, though not impossible, to train pigeons to discriminate between stimuli containing a wolf movement and three sheep movements and stimuli consisting of four sheep movements.

2. There is no evidence that a stalking wolf movement is seen as a distinctive feature by pigeons.
3. Multiple goal-directed motion paths, on the other hand, may be a distinctive feature for the birds.

At least the first two of these results constitute differences from human performance in similar tasks (Dittrich and Lea 1993). The first difference is purely quantitative and could well be due to methodological inadequacies, for it is always much easier to be sure that stimuli and procedures are appropriate for human subjects than it is for animals. The second difference, however, appears to be qualitative, and it adds to a small group of results that suggest that the visual cognition of pigeons, and perhaps birds in general, may be different in kind from that of humans. Another example is the absence of a mental rotation effect in pigeons (Delius and Hollard 1995), though this seems to depend on the stimulus properties (Hamm et al. 1997). As knowledge of birds' visual cognition expands, the identification of the basis for such differences will become an increasingly important task.

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