

*CATEGORIZATION OF NATURAL MOVEMENTS BY
PIGEONS: VISUAL CONCEPT DISCRIMINATION AND
BIOLOGICAL MOTION*

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In three experiments, pigeons were exposed to a discriminated autoshaping procedure in which categories of moving stimuli, presented on videotape, were differentially associated with reinforcement. All stimuli depicted pigeons making defined responses. In Experiment 1, one category consisted of several different scenes of pecking and the other consisted of scenes of walking, flying, head movements, or standing still. Four of the 4 birds for which pecking scenes were positive stimuli discriminated successfully, whereas only 1 of the 4 for which pecking was the negative category did so. In the pecking-positive group, there were differences between the pecking rates in the presence of the four negative actions, and these differences were consistent across subjects. In Experiment 2, only the categories of walking and pecking were used; some but not all birds learned this discrimination, whichever category was positive, and these birds showed some transfer to new stimuli in which the same movements were represented only by a small number of point lights (Johansson's "biological motion" displays). In Experiment 3, discriminations between pecking and walking movement categories using point-light displays were trained. Four of the 8 birds discriminated successfully, but transfer to fully detailed displays could not be demonstrated. Pseudoconcept control groups, in which scenes from the same categories of motion were used in both the positive and negative stimulus sets, were used in Experiments 1 and 3. None of the 8 pigeons trained under these conditions showed discriminative responding. The results suggest that pigeons can respond differentially to moving stimuli on the basis of movement cues alone.

Key words: concept discrimination, biological motion, motion features, natural categories, video images, key peck, pigeons

Movement is one of the most important dimensions in the visual perception of natural objects. Most of the objects that have adaptive value for an organism, whether as food, prey, enemies, or social partners, will normally be seen in motion. Birds behave as if they readily and accurately perceive moving objects in a visually changing environment. Furthermore, the adaptive response to an object will usually depend on the way in which it is moving: For example, a predator moving away demands a different response than a predator approaching, and a conspecific emitting a threat re-

sponse demands a different response than one emitting sexual solicitation.

Even when still, natural stimuli are inherently generic (cf. Skinner, 1935) or categorical (Herrnstein, 1990), in the sense that it is very unlikely that any two instances of the stimulus will be identical, or that all instances will contain any one necessary or sufficient feature. Stimuli in motion pose this problem in an extreme form, for they are not even the same from moment to moment. As Dittrich and Lea (1993) argued, accurate response to moving stimuli is thus a demanding exercise in category or concept discrimination (cf. Lea, 1984). Yet experiments with human observers, like everyday experience, show that movement powerfully facilitates visual object recognition; in the limiting case, movement alone can make it possible to identify who a person is and what he or she is doing (e.g., Bassili, 1978; Dittrich, 1991, 1993; Johansson, 1973).

Following the pioneering work of Herrnstein and Loveland (1964), numerous experiments have used operant techniques to demonstrate discrimination between categories of

The research reported in this paper was supported by Grant GR/H31844 from the UK Science and Engineering Research Council.

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natural objects in nonhuman subjects; for a recent review of this literature see Watanabe, Lea, and Dittrich (1993). Virtually all of these experiments have used still stimuli, typically color slides projected either onto a pecking key or onto a larger screen. In principle, it is easy enough to extend this method to use moving images from a movie projector, videotape recorder, or some other kind of video display. Some evidence suggests that birds may not respond to moving video displays (e.g., Ryan & Lea, 1994, Experiment 3), and that they do not transfer learned discriminations between objects to their video depictions (Patterson-Kane, Nicol, Foster, & Temple, 1997). But a growing body of evidence suggests that birds do respond appropriately to moving video or computer displays under some circumstances. Evans and Marler (1991), Evans, Macedonia, and Marler (1993), Keeling and Hurnik (1993), and McQuoid and Galef (1993) have all shown that such stimuli can elicit social responses in chickens. Dittrich and Lea (1993) showed that pigeons could be trained to discriminate moving from still video clips of other pigeons, and that this discrimination generalized to other objects that moved in quite different ways.

The present experiments aimed to extend those of Dittrich and Lea (1993). The discrimination demonstrated in that experiment, between moving and still stimuli, is a very coarse one. We argued above that it is important biologically for animals to discriminate between different types of movement of the same object, and the first two experiments investigated whether such discrimination could be demonstrated using video stimuli. Because moving stimuli are inherently categorical, a successful demonstration of discrimination between movement types would raise the question of what cues are involved in the discrimination, a fundamental question in all concept discriminations. In the case of moving stimuli, there are two broad possibilities. Movements of a particular class might present unique views or features of an object, or the movement as such might be discriminated. The latter possibility can be investigated using the point-light stimuli introduced by Johansson (1973). Still pictures of such stimuli are unrecognizable as objects, but when seen in movement they are easily

recognized by human observers. Therefore discrimination of these stimuli must depend on motion cues alone. When the lights are attached to a person, humans can make a range of discriminations from such displays, including the gender of the person (Kozlowski & Cutting, 1977; Runeson & Frykholm, 1983), the identity of a friend (Cutting & Kozlowski, 1977), the nature of the action (Dittrich, 1993; Johansson, 1973), the weight of an object being lifted (Runeson & Frykholm, 1981), and the emotion being expressed, either by a face (Bassili, 1978; Dittrich, 1991), or by the whole body in a dance (Dittrich, Troscianko, Lea, & Morgan, 1996). In contrast, there is almost no information about discrimination of such displays by other animal species. Blake (1993) trained cats to discriminate computer-generated point-light animations, some of which simulated biological motion while others were scrambled. However, by the standards of experiments on concept discrimination, Blake's experiment was limited: Only a single motion stimulus was used, in both training and testing, and there was no attempt to test transfer from the point-light stimulus to or from fully detailed motion stimuli.

It is thus of interest to see whether point-light stimuli could be discriminated by any nonhumans, and also whether such subjects show transfer of discrimination between fully detailed movement scenes and point-light scenes. There is a particular interest in investigating such stimuli with birds, because the organization of the pigeon's retina and visual pathways is different from that in mammals: On the one hand, pigeons have a binocular frontal visual system for discriminating near objects, which are typically static, and a monocular lateral system that is specialized in detecting distant moving objects (Güntürkün, Miceli, & Watanabe, 1993), a separation of function not seen in mammals; on the other hand, there is as yet no evidence that birds share the separation of processing between static and moving stimuli seen in primates, for which motion is processed via the magnocellular pathway and static form information is processed by the parvocellular pathway (Livingstone & Hubel, 1988; Mishkin, Ungerleider, & Macko, 1983). If pigeons' response to moving visual stimuli is not what we would expect from our experience with mammalian

vision, that might therefore have implications for the underlying neurophysiology.

Our experiments used natural stimuli. The disadvantage of such stimuli is that they cannot necessarily be characterized simply, unlike, for example, the artificial movement stimuli used by Emmerton (1986). On the other hand, the stimuli we used were related in a direct way to stimuli that it is adaptive for the birds to discriminate: They were all images of pigeons. Because movements of conspecifics are likely to be biologically important, we expect that pigeons' visual and brain systems have evolved to make their discrimination efficient.

Most of pigeons' natural movements are sustained for only a few seconds, so we wanted to make the stimulus durations correspondingly brief. In the present experiments, therefore, we used the same discriminated autoshaping procedure as Dittrich and Lea (1993), which involves trials of limited duration. Acquisition training was followed immediately by testing in extinction, because Dittrich and Lea found that when birds were trained under movement-negative conditions, using the same procedures as in the present paper, discrimination could not be seen during acquisition but did become evident during extinction, particularly when discrimination ratios rather than percentages of trials with a correct response were used to assess performance. Initial training was of limited duration (15 sessions with 80 trials in each), on the grounds that discriminations requiring very lengthy training are unlikely to be biologically important; Dittrich and Lea found that the discrimination between moving and still scenes reached asymptotic levels within 10 sessions of this length.

EXPERIMENT 1

The first experiment aimed to demonstrate a discrimination between categories of movement, using fully detailed video scenes and many different instances of each type of movement. One of the movement types involved was pecking. Keeling and Hurnik (1993) demonstrated that feeding in chickens was facilitated in the presence of combined audio-video displays of other chickens feeding, so pecking may have a special status as a stimulus. For example, it might be hard

for pigeons to inhibit pecking in the presence of an image of another pigeon pecking, and this would generate a feature-positive effect of the kind observed by Dittrich and Lea (1993) using moving and still stimuli. Accordingly, one stimulus class consisted only of images of pigeons pecking, and the other consisted of images of a variety of other movements. In an attempt to reduce the false-positive rate, which tended to be high in Dittrich and Lea's experiments, their procedure was varied in one respect: The number of pecks required to produce immediate reward was increased from three to eight.

METHOD

Subjects

The subjects were 12 experimentally naive pigeons of retired racing stock. They were maintained at or above 85% of their free-feeding weights on an 11:13 hr light/dark cycle, with half-hour simulated dawn and dusk periods. The birds were held in individual cages for between 1 and 3 hr before and after testing sessions. Otherwise they were housed in an indoor aviary. Water and grit were continually available except in the test apparatus.

Apparatus

Two identical one-key operant chambers (69 cm by 49 cm by 39 cm) were used. Each consisted of a plywood box whose front wall was an aluminum panel (69 cm by 39 cm). The general arrangement of the apparatus was the same as that used by Dittrich and Lea (1993). Stimuli were presented on a video monitor screen (52 cm by 39 cm) situated 170 cm in front of the experimental chambers. The pigeons could view this screen through the transparent Perspex response key (6.5 cm by 6.5 cm) positioned on the front wall of the operant chamber, 104 cm above the floor. A shutter, operated by a rotary solenoid, could be used to prevent the bird from viewing the screen. The panel also contained an aperture (7 cm by 7.5 cm), positioned 15 cm below the pecking key, giving access to a solenoid-operated food hopper containing a food grain mixture. The availability of this food was signaled by a 1.0-W white light in the hopper aperture that was operated when the hopper was presented. General illumination was given by a 3.5-W yel-

low-lensed houselight situated 12 cm above the pecking key. Masking noise was provided by a ventilation fan and by white noise relayed via a 35- Ω loudspeaker mounted on the back of the intelligence panel. Both chambers and the video monitor were housed in a darkened testing room. All other equipment was outside this room. For most of the experiment, a PC-compatible microcomputer (Viglen 4DX266), programmed in Turbo Pascal, controlled and recorded all experimental events and responses (an Apple II[®] microcomputer programmed in UCSD Pascal was used for pretraining and the first five sessions of acquisition). Stimuli were generated from a videotape, which played continuously throughout the session. The stimulus sequence on the videotape was synchronized to the experimental contingencies by tones recorded onto the audio channel of the tape; these were decoded electronically and were not passed to the video monitor, which was not fitted with loudspeakers. In order that the pigeons' behavior could be regularly monitored, a videocamera, fitted with a wide-angle lens, was placed outside each chamber; a view to the interior was provided by a window (10 cm by 10 cm) in the rear wall.

Stimulus Materials

Video scenes of pigeons moving naturally in an open environment (a public park) were recorded in color with a Panasonic MS2 videocamera in S-VHS format and edited on a Panasonic edit suite to VHS PAL format. The edited tape consisted of 40 scenes involving pecking movements and 40 scenes involving nonpecking movements. The latter consisted of 10 scenes each of walking, flying near the ground, standing still, and standing with head movements only. All scenes lasted for 6 s and consisted of continuous videotape (no still images or edited scenes were used). In each scene the individual bird emitting the appropriate movement remained within view throughout, and was either positioned near the center of the screen or moved across the center. The scenes included images of three sizes: large (about 16 cm by 30 cm as displayed in the experiment), medium (about 9 cm by 18 cm), or small (about 4 cm by 8 cm); 1 cm on the screen equaled approximately 0.34° of visual angle from the pigeon's viewing position. Whole-body movements result-

ed in movement of the pigeon's image across the screen at average speeds ranging from 3 cm per second to 6 cm per second, although screen speeds of up to 30 cm per second were attained briefly. Speeds across the screen depended on the pigeon's direction of movement relative to the camera and frequently varied within trials, so that it would be misleading to give figures for mean movement speeds; however, in general, the highest screen speeds were associated with walking (rather than flying, because scenes in which birds flew laterally across the screen did not last long enough to be used) and the lowest with standing still and head movements. In the pecking scenes, pecking was at rates of about 1.25 pecks per second. As far as possible, bird-image size and background type (grass or path) were balanced across the movement types; no scenes with a background of sky or distant objects were included. The 80 scenes were mixed in a quasi-random order, constrained so that no more than three pecking or nonpecking scenes were shown in succession. Two tapes with identical scenes but in a different order were alternated across sessions.

Procedure

In the first few sessions all pigeons were trained by standard procedures to find food in the hopper while the tray light was illuminated, with the duration of food presentation gradually reduced to 4 s. They were then trained by an autoshaping procedure to peck the key when the shutter opened to reveal a bright screen behind it. The key-peck requirement was gradually increased to eight pecks (fixed-ratio [FR] 8).

For discrimination training, the discriminative autoshaping procedure described by Dittrich and Lea (1993) was used. This procedure involved both operant and respondent contingencies. In the present experiment, sessions consisted of 80 trials separated by intertrial intervals varying in duration from 12 to 32 s, with a mean of 22 s; during intertrial intervals, the shutter was closed. Trials lasted for a maximum of 6 s. During each trial, the shutter opened to reveal a stimulus on the video screen. When positive stimuli were presented, the trial was terminated either by the end of the 6-s duration or when the subject completed an FR 8 response re-

quirement. All positive trials ended with the presentation of food. Negative trials lasted for 6 s regardless of any pecking, and no food was presented when they ended. Fifteen sessions of this acquisition procedure were given. *Correct* responses were defined as completing the required FR schedule within the 6-s stimulus period for a positive stimulus, and making fewer than that number of pecks within 6 s for a negative stimulus. (Because food occurred at the end of a positive trial regardless of responding, no pattern of responding is strictly incorrect. The terms *correct* and *incorrect* are merely used for convenience.)

The 12 pigeons were arbitrarily allocated to the following three groups, with 4 birds in each:

Pecking-positive. Scenes of birds pecking were the positive stimuli and the nonpecking images were the negative stimuli.

Pecking-negative. Scenes of movements other than pecking were the positive stimuli and the pecking movements were the negative stimuli.

Pseudocategory. Twenty randomly chosen scenes of pecking and 20 nonpecking scenes were arbitrarily classified as positive stimuli, and the remaining scenes were classified as negative stimuli. This last condition was included to control for unexpected biases towards particular features or individual stimuli, and also to control for the possibility that the birds could learn the sequences of positive and negative trials on the videotapes.

Following the 15 sessions of acquisition, a single session of extinction was given; during this session neither respondent nor operant contingencies were in force, and all trials lasted for 6 s. A single-session generalization test was then carried out, which involved distorted versions of the scenes used in acquisition. Because the results were inconclusive, this part of the experiment is not presented in the present paper. After the generalization test, acquisition conditions were reinstated for two sessions, and a further session of extinction then followed.

RESULTS AND DISCUSSION

On initial exposure to the acquisition conditions, all birds tended to peck on all trials, and discrimination developed through a reduction in responding on negative trials. Fig-

ure 1 shows the proportions of trials with a correct response for each bird during each session of the acquisition period and during the subsequent extinction and reacquisition sessions.

From the top panel of Figure 1 it can be seen that all 4 birds in the pecking-positive group developed reasonable discrimination during the 15 sessions of initial acquisition: For each bird, performance was better than the chance level (50% correct) in every one of the last five sessions, with no obvious trend to further improvement. In the pecking-negative group (middle panel of Figure 1), Bird 07 developed excellent discrimination during acquisition and sustained it during extinction, but the others showed no evidence of discrimination at any stage. Dittrich and Lea (1993) found that birds in a movement-negative group showed clearer evidence of discrimination during extinction when discrimination ratios rather than percentage correct measures were used; however, in the present experiment, discrimination ratios essentially mirrored percentages correct, so they are not presented separately. It seems likely that the difference between the two measures in the experiment of Dittrich and Lea resulted from the strong feature-positive effect seen in that experiment. In the pseudocategory group (bottom panel of Figure 1), no bird developed reliable discriminative responding by any measure.

As has been noted, in all groups almost all errors were false positives (response criterion met on a trial with a negative stimulus) rather than misses (response criterion not met on a trial with a positive stimulus). In the first session of acquisition, the difference was not marked, with a median false positive rate of 60% and a median miss rate of 45%. By the fifth session of acquisition, however, the median rates were 95% (false positive) and 5% (misses), and by the end of acquisition, when error rates had fallen because discriminative responding had been established in some birds, the median rates were still very different, at 85% (false positives) and 2% (misses). That is, pigeons that did not respond discriminatively failed to withhold pecks to negative stimuli. Increasing the response requirement from the FR 3 used by Dittrich and Lea (1993) did not seem to have reduced this tendency.

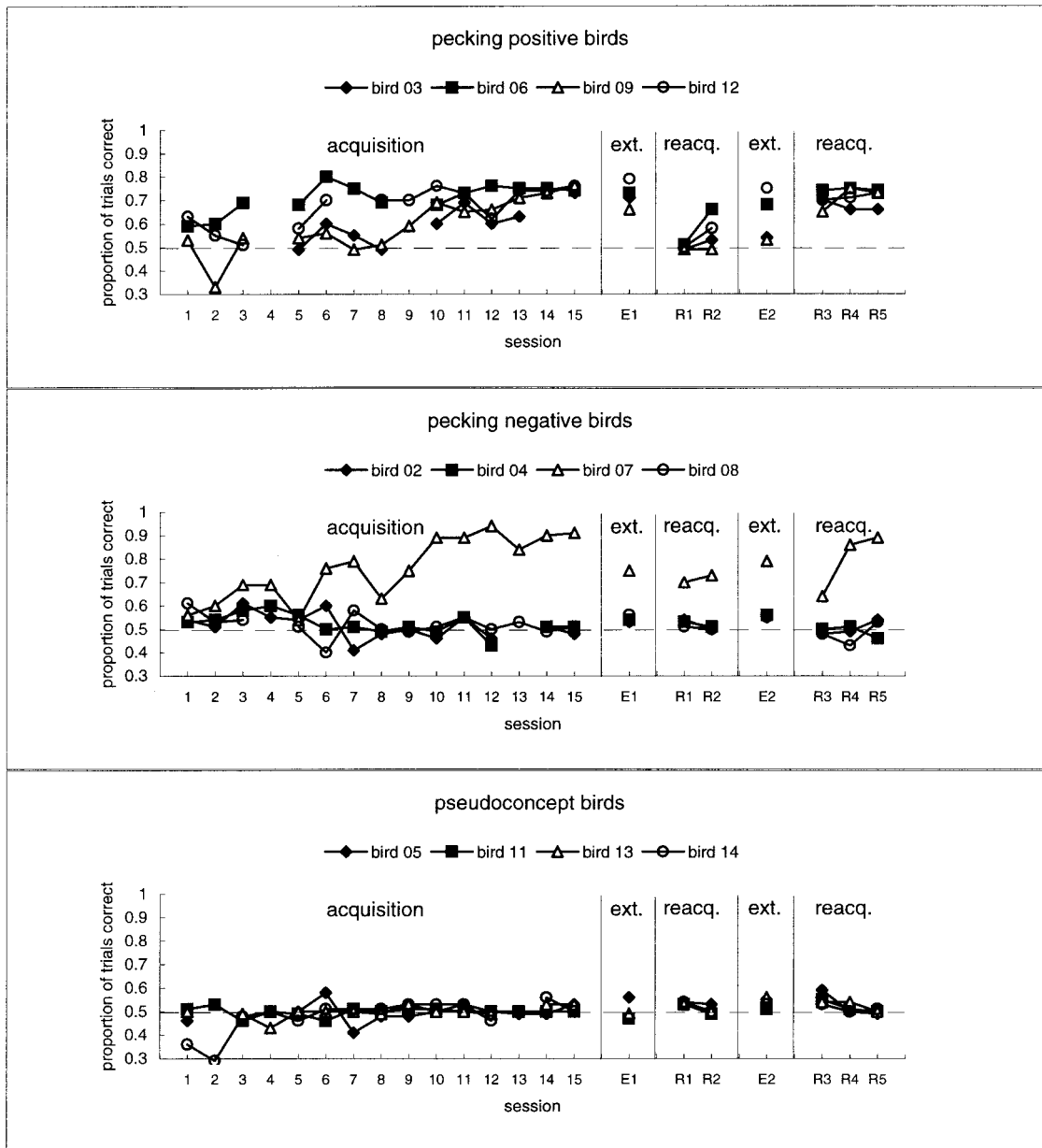


Fig. 1. Experiment 1: Percentages of trials with a correct response during acquisition, extinction (E), and reacquisition (R) sessions of a pecking versus other behavior movement scenes discrimination, under discriminated autoshaping conditions. Transfer test sessions occurred between Sessions E1 and R1. Absent data points correspond to sessions in which data were lost because of computer errors, but these do not obscure the general trends.

For the pecking-positive group, the negative stimuli included scenes of four different kinds of movement, and errors were not distributed evenly between them. Figure 2 shows the proportion of trials with a correct response to each movement type for each bird

in this group during the last five sessions of initial acquisition. All birds withheld pecks best to the head movement stimuli, next best to the standing and walking stimuli (standing was better for all birds, but not by much), and were very poor at withholding pecks to the

discrimination by category pecking positive birds

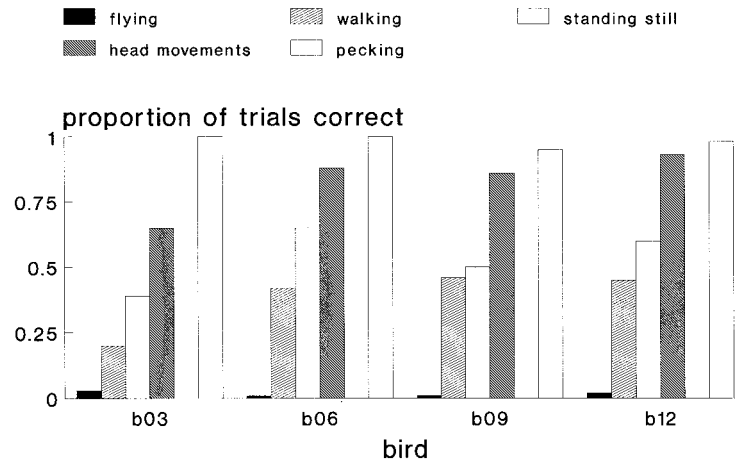


Fig. 2. Experiment 1: Mean percentages of trials with a correct response during the last five sessions of acquisition of the discrimination, in 4 birds for which pecking scenes were positive stimuli and four other kinds of movement scenes were negative stimuli. Data are shown separately for each kind of scene.

flying stimuli. The appropriate metric and significance test for agreement between different individuals in ranking the same set of objects is the *W* coefficient of concordance (Kendall, 1962, chap. 6). An identical order of the levels of discrimination of the four negative movement types for all 4 birds gives a *W* value of 1.00, and this level of agreement is statistically significant ($p < .01$; Siegel, 1966, Table R). The observed ordering of the discriminability of the four types of negative stimuli from pecking seems to rule out the possibility that simple similarity between the body orientations taken up by the birds in the different scenes was responsible for errors. To the experimenters' eyes, it was birds performing head movement that looked most similar to birds performing pecking, yet head movement was the category best discriminated from pecking; on the other hand, flying, which involved major changes in the outline body shape of the pigeon, was least well discriminated.

The difference between the pecking-positive group and the pseudocategory group shows that the birds were not learning the stimuli by rote (absolute discrimination: Vaughan & Greene, 1984), but were helped by the similarities between the different stim-

uli within each category. Absolute discrimination would make the pseudocategory group's task as easy as that of the other two groups. The consistent differences in behavior towards the four categories of negative stimuli within the pecking-positive group is further evidence that responding was affected by the relationships among stimuli.

There are at least two possible explanations for the difference between the pecking-positive and pecking-negative groups. There might be social facilitation of pecking by the tape image, making it difficult for a pigeon to withhold pecks in the presence of an image of another pigeon pecking. This would be consistent with Keeling and Hurnik's (1993) demonstration of social facilitation of feeding in chickens from video scenes. Alternatively, the difficulty for the pecking-negative group may arise from the category structures used: For the pecking-positive group, there was a single class of positive images and several negatives, whereas for the pecking-negative group, there were several classes of positive images and a single negative. Perhaps the latter arrangement makes a discrimination task harder to learn. It is not possible to distinguish between these two explanations

from the present results, and they are explored in more detail in Experiment 2, below.

Experiment 1 thus demonstrated that pigeons can discriminate categories of conspecific movement on the basis of video displays, at least in some conditions. But the discrimination was not as straightforward as might have been expected from the ease with which pigeons discriminate categories of static stimuli or from the biological importance of moving stimuli.

EXPERIMENT 2

In Experiment 1, not all birds learned to discriminate movement categories. In particular, only 1 of the 4 birds was successful in the condition in which images of pecking birds were negative and four other types of movement were positive. One aim of Experiment 2 was to gain further evidence for discrimination of movement categories and to investigate some possible reasons for the asymmetry between pecking-positive and pecking-negative groups found in Experiment 1. The procedure was therefore similar to that of the previous experiment, except that the stimulus categories used during acquisition were simplified. As before, one stimulus category consisted of pecking scenes. The second category contained scenes of only one movement type, instead of the four used in Experiment 1. The chosen movement type was walking, which had been moderately well discriminated from pecking by the pecking-positive birds in Experiment 1 (see Figure 2). For one group of birds, pecking was the positive category and walking the negative category; a second group had the reverse of these contingencies. If the difficulty of the pecking-negative discrimination in Experiment 1 arose from social facilitation of pecking, it would be expected to be repeated in this experiment, but if it arose from having a single movement type in the negative category and several movement types in the positive category, it should disappear.

Another aim of Experiment 2 was to investigate the generalization of motion-category discrimination to the point-light representations of biological motion introduced by Johansson (1973), and thus to test whether the discrimination was based on movement cues alone. Trials using point-light stimuli were

therefore introduced in a transfer stage after acquisition.

In Experiment 1, as in the experiment of Dittrich and Lea (1993), the majority of errors made were false positives. The increased response requirement (FR 8 compared with the FR 3 used by Dittrich and Lea) did not succeed in controlling this tendency, and in the present experiment we therefore reverted to an FR 3 requirement. Dittrich and Lea found that discrimination that was concealed by this high false positive rate could be revealed by test sessions under extinction conditions. Although this effect was not replicated in Experiment 1, such extinction tests were included in the present experiment before proceeding to generalization tests.

METHOD

Subjects and Apparatus

The subjects were 8 pigeons of retired racing stock, chosen at random from the 12 birds used by Dittrich, Gilbert, Green, McGregor, and Grewcock (1993) in an experiment involving the discrimination of still color slides of insects, using the same test chambers as the present experiments. One of the pigeons originally chosen failed to show reliable key pecking when it was reintroduced into the chambers, so it was replaced with a different bird with the same history. The pigeons were maintained under the same conditions as in Experiment 1. They were divided into two groups of 4.

The same apparatus was used as in Experiment 1, with the PC-compatible computer being used for all experimental control and data collection.

Stimulus Materials

Acquisition and extinction. New scenes of moving pigeons were recorded in the same way as those used for Experiment 1. There were 40 scenes of pigeons walking and 40 scenes of pigeons pecking. All the scenes were recorded in the department's rooftop aviary, so the birds were seen against a generally gray, built-environment background. The image sizes of the birds were approximately those used for the medium size category in Experiment 1. For one group of 4 birds (the pecking-positive group), the scenes involving pecking were designated as positive;

for the other group (the walking-positive group) the scenes involving walking were designated as positive. As far as possible, no scene involved both walking and pecking, but in case of ambiguity, the presence of pecking was taken as definitive, and the stimulus was placed in the pecking category. To distinguish them from the point-light stimuli used in generalization tests, the acquisition stimuli are referred to below as "full-detail" stimuli.

Generalization tests. Two additional tapes were used in generalization tests. One included 60 of the stimuli used in training plus 20 point-light movement scenes of pigeons, 10 of pigeons walking and 10 of pigeons pecking; the other included 40 of the stimuli used in training plus 40 point-light movement scenes (20 of walking and 20 of pecking). The bird sizes and movement speeds used in the point-light stimuli were made as similar as possible to those in the acquisition stimuli. The point-light stimuli were obtained by placing seven self-adhesive ultraviolet fluorescent spots on a pigeon and videotaping the appropriate behavior categories under ultraviolet light. Adjustment of the brightness and contrast of the image during the tape-editing process ensured that only the point-lights were visible in the final tape. One spot was placed centrally on the top of the head, one on the center of the breast, one on the tail, and one on each shoulder and foot. All point-light stimuli were filmed from a single bird, using the same spot placements. To the human eye, the resulting stimuli were uninterpretable when static but were immediately recognizable as a pigeon when moving, and it was easy to identify whether the pigeon was walking or pecking.

Additional materials were used in a preliminary series of generalization tests, but these were inconclusive and are not discussed in the present paper.

Procedure

Conventional magazine training and auto-shaping were used to reestablish key pecking. For 4 of the birds, a single session of each was sufficient. The remaining birds required from 2 to 16 sessions of pretraining. The birds that were slower to pretrain were assigned equally between the two experimental groups.

For all birds, acquisition training consisted

of 15 sessions of the discriminated autoshaping procedure used in Experiment 1, with the difference that three instead of eight key pecks were required for immediate reinforcement on positive trials.

The following series of test sessions was then given:

Extinction in the presence of the acquisition stimuli (two sessions).

Generalization tests (five sessions). These were directed at questions not relevant to the present paper and gave inconclusive results, so are not discussed further here.

Retraining under acquisition conditions (three sessions).

Generalization test including 20 point-light movement scenes (two sessions).

Generalization test using the acquisition stimuli from Experiment 1 in monochrome form (one session); this test was also inconclusive and is not discussed here.

Retraining under acquisition conditions (two sessions).

Generalization test including 40 point-light movement scenes (three sessions).

In extinction conditions, no reinforcement was presented, and pecks during trials were ineffective (so all trials lasted for 6 s). In generalization tests, the discriminated autoshaping procedure was used, with both operant and respondent contingencies in effect during both training and test trials. Thus reinforcement was given on point-light as well as full-detail trials involving pecking stimuli for birds from the pecking-positive group and on point-light as well as full-detail trials involving walking stimuli for birds from the walking-positive group. In reacquisition sessions, the contingencies in effect were the same as during acquisition.

Correct responses were defined in the same way as in Experiment 1 (note, however, that the number of responses required to register either a hit or a false positive was reduced from eight to three). On generalization trials, responses were designated as correct if they corresponded to the contingencies (e.g., if a pecking-positive bird completed the FR schedule on a trial with a point-light scene of a pigeon pecking, or if a walking-positive bird did not complete the FR in such a trial).

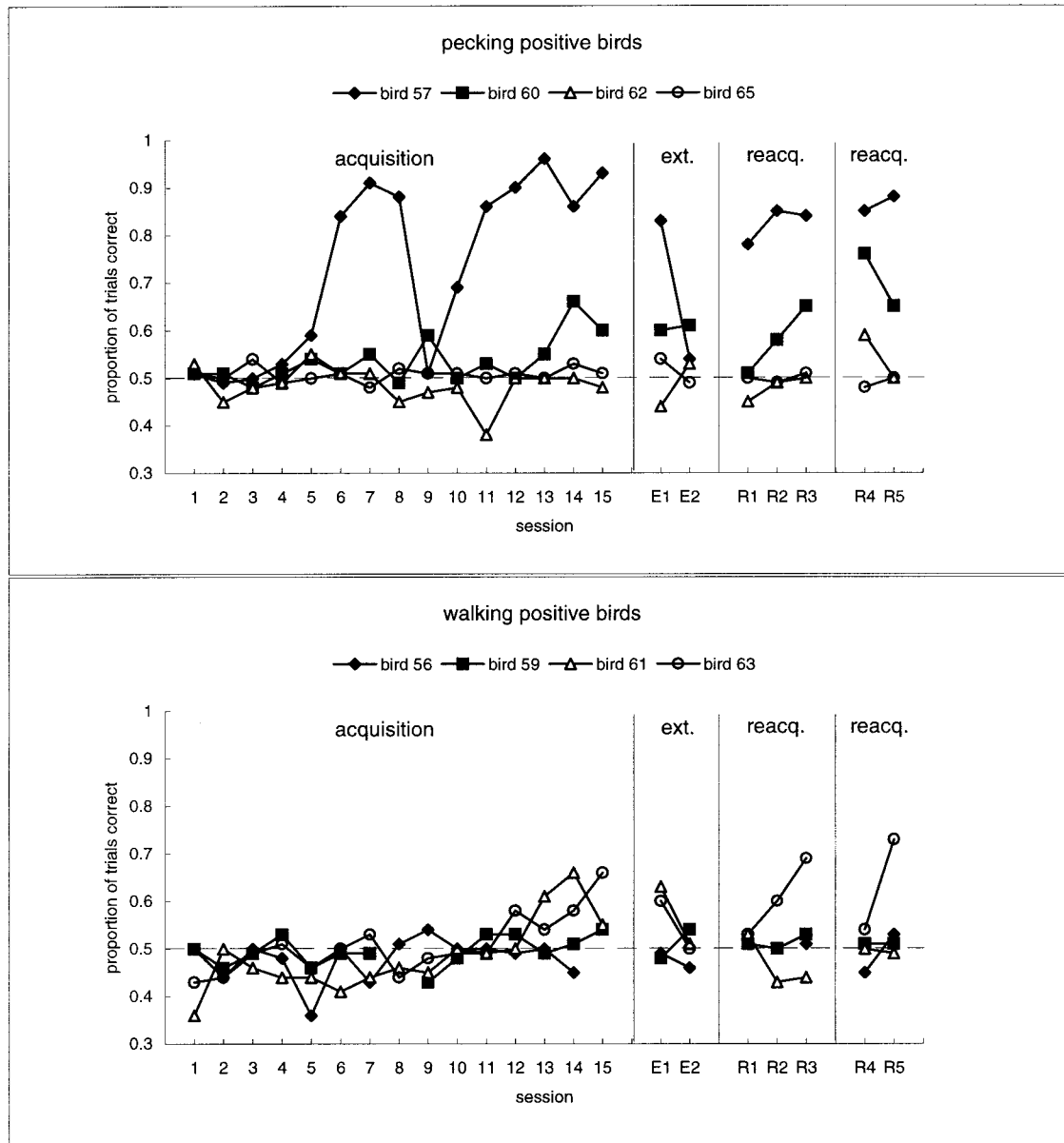


Fig. 3. Experiment 2: Percentages of trials with a correct response during acquisition, extinction (E), and reacquisition (R) of a pecking versus walking movement scenes discrimination, using full-detail stimuli under discriminated autoshaping conditions. Transfer test sessions occurred between Sessions E2 and R1 and between Sessions R3 and R4.

RESULTS AND DISCUSSION

Acquisition

Figure 3 shows the proportions of trials with a correct response for each bird during all acquisition, extinction, and reacquisition sessions. It can be seen that, as in Experiment

1, for most birds acquisition was slow and incomplete. In the pecking-positive group, Bird 57 quickly developed good discrimination, Bird 60 was showing weak discrimination by the end of the 15 acquisition sessions (proportions of trials correct on the last three sessions were .55, .66, and .60), and the other 2

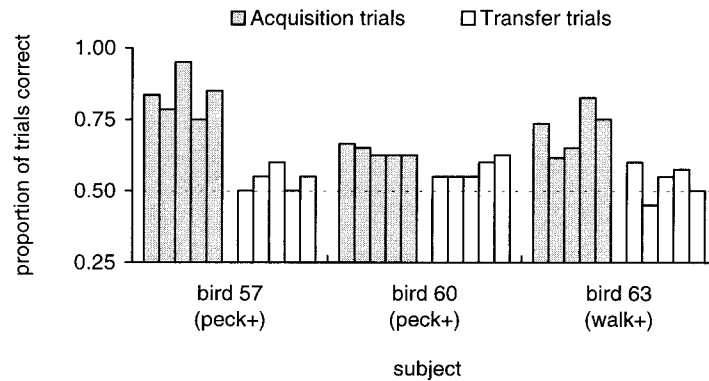


Fig. 4. Experiment 2: Percentages of trials with a correct response during five test sessions involving point-light stimuli, for 3 birds that showed sustained discrimination during acquisition and extinction with full-detail stimuli. Data are shown separately for the trials with acquisition (full-detail) stimuli and transfer test (point-light) stimuli. Each bar represents data from a single session. For Birds 57 and 60, pecking scenes were positive stimuli; for Bird 63, walking scenes were positive stimuli.

birds showed no signs of discrimination at all. In the walking-positive group, 2 of the 4 birds (Birds 61 and 63) showed gradual improvement and had achieved a sustained but weak discrimination by the end of acquisition, and Bird 59 showed marginal discrimination.

False positives again formed the majority of errors, but not initially, and not as overwhelmingly as in Experiment 1: The median false positive and miss rates in the first session of acquisition were 46% and 64%, in the fifth session of acquisition they were 65% and 38%, and in the final session of acquisition they were 69% and 18%. Thus, the tendency to peck on all trials was not as strong in Experiment 1, despite the reduced response requirement in the present experiment. The results give little support to the hypothesis that discriminations requiring birds to withhold pecks in the presence of pecking scenes are especially difficult for pigeons to acquire, because acquisition in the walking-positive group was no slower than in the pecking-positive group (although performance in the walking-positive group was slightly below chance in the earliest sessions). Rather, the results support the hypothesis that movement categories, at least as represented on videotape, are relatively difficult for pigeons to discriminate. The particular difficulty for the pecking-negative group in Experiment 1 may, therefore, have arisen from the multiple categories that were used as positive stimuli in that experiment, although that interpretation

would require further tests before it could be adopted with confidence.

Test Sessions

Results from the extinction and reacquisition sessions prior to the introduction of point-light stimuli are included in Figure 3. As in Experiment 1, extinction sessions were introduced before transfer tests in the hope that they would reveal more pronounced discrimination, as such sessions did in the experiment of Dittrich and Lea (1993). In fact, however, extinction rapidly abolished discrimination: In the second extinction session, the only bird to show substantially higher than chance discrimination (61% of trials correct) was Bird 60 from the pecking-positive group; no other bird scored higher than 54%. As in Experiment 1, examining performance in terms of discrimination ratios did not reveal any different result. The three sessions of reexposure to the acquisition conditions that followed the unsuccessful test trials successfully reinstated the original discrimination for 3 birds, Birds 57 and 60 from the pecking-positive group and Bird 63 from the walking-positive group. Results from the generalization tests using point-light stimuli are therefore reported for these 3 birds only.

Figure 4 shows the performance of these 3 birds in the transfer sessions involving point-light stimuli, separating the trials with point-light (transfer) stimuli from those with full-detail (training) stimuli. It can be seen that

performance with the training stimuli remained consistently above 50% correct, but performance on transfer trials was substantially worse than on trials with the original stimuli. However, it was above 50% in the majority of sessions for each bird. The appropriate test to investigate whether a proportion of a small number of cases in a single sample differs significantly from 50% is the binomial test (Siegel, 1966, chap. 4). However, the number of transfer sessions was too small for the trend to reach conventional significance levels for any bird individually, whatever the birds' behavior. Accordingly, the significance levels from individual binomial tests were pooled across birds by the method of Jones and Fiske (1953). This procedure resulted in a significant χ^2_6 value of 13.45 ($p < .05$). The null hypothesis that all birds had equal numbers of sessions with transfer performance above and below 50% can therefore be rejected. The results thus imply that there was transfer to at least some of the moving dot stimuli from fully detailed scenes of the same motion types. Because autoshaping contingencies were in effect during transfer trials, the sequence of five transfer sessions would in principle allow the birds to learn a new discrimination between the two categories of point-light stimuli, but Figure 4 shows no general pattern of increasing discrimination between transfer categories across sessions.

EXPERIMENT 3

The transfer trials from Experiment 2 gave some evidence that the discrimination of two movement categories would generalize to point-light representations of the same movements. The transfer seen in Experiment 2 was weak, however, so in Experiment 3 we investigated whether pigeons could be trained to discriminate such stimuli. We also tested for transfer to full-detail videos of the same movement categories, which was the inverse of the transfer test carried out in Experiment 2.

In the previous two experiments, not all birds showed successful discrimination, leaving open the possibility that there were methodological problems with the discriminated autoshaping procedure or sharp individual differences among birds in the way they respond to it. In order to evaluate these possibilities, the birds in the present experiment

were first exposed to a simple discrimination using the same procedure. In this preliminary discrimination, the positive stimuli for all birds consisted of white dots on a black background so as to provide a basis for positive transfer to the point-light stimuli to be used in acquisition for the main experiment. The extinction tests in Experiments 1 and 2 were not successful in revealing discrimination, but they were repeated in the present experiment for the sake of comparability of the procedures undergone before the transfer tests.

METHOD

Subjects and Apparatus

The subjects were 12 pigeons of retired racing stock. They were maintained under the same conditions as in Experiments 1 and 2. The same apparatus was used as in Experiments 1 and 2, with the PC-compatible computer being used for all experimental control and data collection.

Stimulus Materials

Two tapes were used in training. The first was used for the preliminary discrimination, in which negative scenes showed a dark screen and positive scenes showed visual noise (i.e., white dots in random motion against a dark background). The visual noise stimuli were obtained by recording the output produced by a video player with no tape present. The second tape was used in acquisition of the point-light discrimination. It included the point-light scenes used in generalization tests from Experiment 2; there were 10 scenes of pigeons walking and 10 scenes of pigeons pecking, with four copies of each scene on the tape. In generalization tests, the tapes used in the generalization tests in Experiment 2 were used.

Procedure

Conventional magazine training and autoshaping were used to establish key pecking. The birds first experienced at least three sessions of discriminative autoshaping using the random motion versus blank screen tape; contingencies were exactly as in Experiment 2. Random motion stimuli were positive for all birds. Training for each bird was continued until it had had at least three sessions and had reached a criterion of two sessions

with performance above 75% correct or one above 80%; training was accidentally continued for two additional sessions for 2 birds. Following this, all birds experienced discriminative autoshaping using the point-light stimuli, with the same training procedures. The birds were divided arbitrarily into three groups of 4. For one group (pecking-positive), pecking scenes were followed by food and walking scenes were not. For a second group (walking-positive), the opposite contingencies applied. For the final group (the pseudoconcept group), a randomly chosen half of the pecking scenes and half of the walking scenes were consistently followed by food and the remainder were not.

In the light of the results of Experiments 1 and 2, the following criteria were set on the number of acquisition sessions to be given in the discrimination between categories of point-light motion: (a) Training was abandoned for any bird that responded on every trial for three successive sessions. This rule was introduced because experience showed that such birds never developed discriminative responding. It affected 2 birds in the pseudoconcept group, causing them to be given only nine and eight sessions of training. (b) Training was stopped after the 10th session for any bird that had, at that stage, performed at or above 60% correct for at least three sessions. This rule was set to avoid overtraining the birds on the acquisition stimuli in case that should inhibit transfer to new stimuli. (c) As in Experiments 1 and 2, no bird was trained for more than 15 sessions, for the reasons outlined in the introduction.

Following the training sessions, extinction conditions were introduced. These were maintained for one to three sessions, depending on the maintenance of key pecking. No further training or testing was carried out with the pseudoconcept birds. For the pecking-positive and walking-positive groups, extinction was followed by sufficient sessions of reacquisition to restore peck rates to acquisition levels: Up to three sessions were required. After reacquisition, four transfer sessions were conducted: The first and third involved 40 trials with the training stimuli and 40 trials with full-detail scenes of the pigeons performing the same two actions, and the second and fourth transfer sessions involved 20 trials with training stimuli and 60 with the

full-detail scenes. By the fourth of these sessions, key pecking had fallen to low rates, so four sessions were given under acquisition conditions but with positive stimuli only in order to reestablish pecking; a further two transfer sessions, one with 40 transfer stimuli and one with 60, then followed. Contingencies effective during the extinction, transfer, and reacquisition sessions paralleled those used in Experiment 2.

RESULTS AND DISCUSSION

Preliminary Discrimination

Performance on the visual noise versus blank screen discrimination is shown in Figure 5. All birds quickly showed discrimination; between two and seven sessions were required to reach the 80% correct level. Thus the discriminated autoshaping procedure can yield quick acquisition of discrimination if the stimulus differences are simple and obvious, so that if discrimination is acquired slowly and incompletely, as it was in Experiments 1 and 2, it must be because the stimuli are hard for the birds to discriminate.

Acquisition and Extinction of Discrimination of Point-Light Stimulus Classes

Figure 5 also shows performance during all acquisition and extinction sessions with the point-light movement category stimuli (except for the reacquisition sessions between the two sets of transfer sessions, when only positive stimuli were used). Discrimination was clear for only 4 birds, Birds 87 and 91 in the pecking-positive group and Birds 88 and 90 in the walking-positive group. Comparison of Figure 5 with Figure 3 shows that those birds that did learn the task showed better discrimination than the successful birds of Experiment 2. The bottom panel of Figure 5 shows that, as in Experiment 1, no bird in the pseudoconcept group showed any sign of discrimination. As in the previous experiments, nondiscriminative performance generally took the form of rapid responding on almost every trial, with an increasing tendency to do this as acquisition sessions continued: The median false positive and miss rates in the first acquisition session were 75% and 23%, by the fifth session they were 94% and 6%, and in the final session of acquisition they were 88% and 5%.

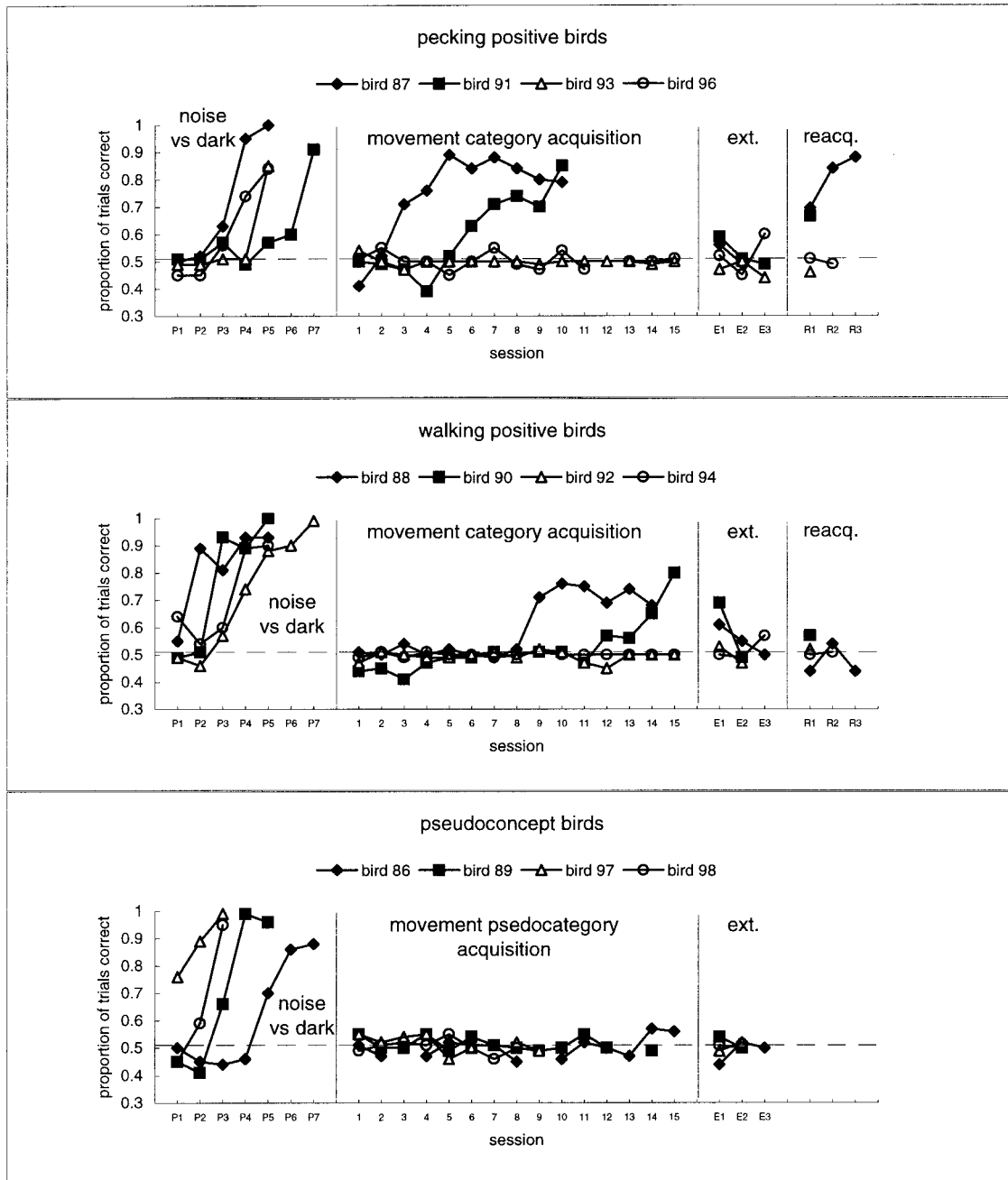


Fig. 5. Experiment 3: Percentages of trials with a correct response during acquisition of a visual noise versus blank dark screen discrimination (P), and during acquisition, extinction (E), and reacquisition (R) sessions of a pecking versus walking movement scenes discrimination, under discriminated autoshaping conditions using point-light stimuli. Note that different birds experienced different numbers of acquisition sessions before extinction. Transfer tests occurred between the extinction and reacquisition sessions.

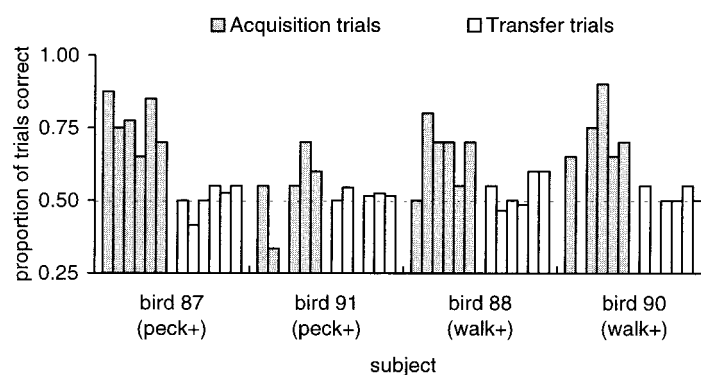


Fig. 6. Experiment 3: Percentages of trials with a correct response during six test sessions involving full-detail stimuli, for 4 birds that showed sustained discrimination during acquisition with point-light stimuli. Data are shown separately for the trials with acquisition (point-light) stimuli and transfer test (full-detail) stimuli. Each bar represents data from a single session. For Birds 88 and 90, pecking scenes were positive stimuli; for Birds 87 and 91, walking scenes were positive stimuli.

As in Experiments 1 and 2, there was no evidence of improvement of discrimination during extinction; in fact the performance of most birds deteriorated and in some cases was not restored by the reacquisition sessions that followed extinction. The same results were obtained if performance was examined in terms of discrimination ratios instead of percentages correct. However, during transfer sessions, discrimination of acquisition stimuli was evident for all 4 birds that had shown it during the original training.

Tests of Transfer to Full-Detail Stimuli

Figure 6 shows performance in the generalization sessions, broken down into acquisition and transfer stimuli, for the 4 birds that showed discrimination during initial training. There was little evidence for transfer from the point-light to the full-detail stimuli. Discrimination of the training stimuli was sustained, but no bird showed consistently better than 50% correct responding to the transfer stimuli. The significance of transfer was tested using pooled significances from binomial tests, as in Experiment 2, and this procedure yielded a χ^2_8 value of 9.83, falling well short of significance ($p > .20$). In addition, the birds were much less likely to peck the transfer stimuli (whichever category they belonged to) than the training stimuli: Across the six transfer sessions, the mean probabilities of reaching the response criterion to a training stimulus were 62%, 50%, 73%, and 74% for Birds 87, 91, 88, and 90, respectively,

and the corresponding probabilities for the transfer stimuli were 10%, 15%, 35%, and 4%.

The results of this experiment are consistent with those of Experiments 1 and 2. Once again, discrimination of movement categories was shown by some but not all birds, implying that such discriminations are possible but, at least with the present training procedure, difficult for pigeons. The fact that all birds acquired the preliminary discrimination rapidly shows that the difficulty lies with the stimuli, not the training procedure. However, the fact that 4 of the birds showed substantial discrimination in the present experiment shows that pigeons are capable of discriminating categories on the basis of point-light stimuli, and thus on the basis of movement cues alone. The proportion of birds succeeding in the discrimination was slightly lower than in Experiments 1 and 2 (4 of 8 compared to 10 of 16, one of them highly marginal, for the other experiments combined), but comparable. The fact that 4 of the 8 birds that were exposed to true concept discriminations did discriminate successfully, but none of the 4 birds that were exposed to pseudoconcept discriminations did so, suggests that the similarities between the stimuli within the categories were important. No transfer to full-detail stimuli could be demonstrated, but that may be partly because of the generally low rates of responding to such stimuli during the transfer sessions.

GENERAL DISCUSSION

Six conclusions can be drawn from these experiments. First, pigeons are capable of responding discriminatively to categories of movement from scenes presented on videotapes. It was argued in the discussion of Experiment 1 that the observed discrimination could not be traced to absolute discrimination or rote learning, but must be based on the relationships between the stimuli presented. Taking the three experiments together, this argument can be strengthened: 14 of the 24 birds trained with true concept discriminations showed some evidence of discrimination, whereas none of the 8 birds trained with pseudoconcepts did so. The results thus add to those of Dittrich and Lea (1993), who showed that pigeons could discriminate still from moving scenes on videotapes, and to those of Keeling and Hurnik (1993), who showed that video scenes could elicit unconditioned responses in chickens.

Second, the discriminations as trained were relatively difficult, by the standards of category discriminations. Across the three experiments, 10 of 24 birds trained on movement category discriminations were showing no discrimination by the end of 15 sessions of training under discriminated autoshaping conditions. With the simple visual noise versus blank screen stimuli used for the preliminary discrimination of Experiment 3, all 12 birds rapidly achieved high levels of discrimination, none requiring more than seven sessions to reach an exacting criterion.

Third, discrimination was not improved by testing under extinction conditions, or by expressing performance in terms of discrimination ratios. This is a difference from the results of Dittrich and Lea (1993), and we suggest that the improvement under extinction reported in that paper may have been associated with the strong feature-positive effect seen in their experiment.

Fourth, pecking was not selectively elicited by video scenes of pigeons pecking. Eight of the 12 birds that were trained with pecking scenes as positive stimuli showed discrimination, whereas 5 of the 12 birds that were trained with pecking scenes as negative stimuli (and therefore had to withhold pecks in their presence) reached comparable levels of performance. The difference between these

proportions does not approach significance, and in any case it is inflated by the results of Experiment 1, in which pecking-positive and pecking-negative conditions differed in an additional factor (the number of negative actions).

Fifth, birds, like humans, are capable of discriminating between categories of scenes when the stimuli in them are represented only by moving dots in the biological motion or point-light procedure pioneered by Johansson (1973).

Finally, there is some evidence that the discrimination of fully detailed movement stimuli generalizes to point-light scenes. We were not able to demonstrate transfer in the reverse direction.

Although the stimuli were difficult to discriminate (some possible reasons for this are discussed below), the experiments clearly show that pigeons can discriminate movement categories from video displays. This result is consistent with the data obtained by Emmerton (1986), and opens up for investigation the question of what aspects of moving stimuli exercise control over pigeons' behavior. This crucial question cannot be completely answered from the present data, but what we can say is that among the stimuli that do achieve control are aspects of movement per se, not just the static body positions the bird takes up in the course of executing a particular movement. This conclusion follows from the fact that there was some transfer to the moving dot scenes in Experiment 2 and from the demonstration in Experiment 3 that moving dot scenes can be discriminated. As far as we know, this is the first case in which transfer from full images to point-light displays has been demonstrated with nonhuman animals of any taxon, and the first demonstration that birds can discriminate point-light displays at all.

Why were the movement categorization tasks relatively difficult for the pigeons to learn? The ease with which the pigeons learned the preliminary discrimination in Experiment 3 shows that the difficulty lay with the stimuli, not with the experimental procedure. However, the critical problem may not have been the fact that the stimuli involved movement, but the fact that they were presented as video recordings. Using chickens as subjects, Patterson-Kane *et al.* (1997)

have shown that easy discriminations (between live conspecifics) can become difficult when the original stimuli are replaced with their video images. Some possible reasons for such a difference are discussed by Ryan and Lea (1994); for example, the screen refresh rate may be below the pigeon's flicker-fusion frequency, which is known to be higher than that for humans (Hendricks, 1966). Furthermore, D'Eath and Dawkins (1996) reported that laying hens were unable to discriminate conspecifics on the basis of video images. They related this finding to the impoverished nature of the video films and emphasized three main aspects: lack of detail and distortion in the video image (especially when viewed close up), lack of depth cues, and the inappropriate and nonreactive behavior of the bird in the video image. In contrast, still video images have been used successfully in concept discriminations (e.g., Cook, Cavoto, & Cavoto, 1996; Pearce, 1989). Thus, there may be a specific problem with the representation of movement using conventional video techniques. However, it should be noted that the preliminary discrimination in Experiment 3, which all 12 birds learned rapidly, involved moving images in one stimulus category. Furthermore, the results of Experiments 2 and 3 suggest that problems due to the use of video recordings are unlikely to be the whole story. The Johansson (1973) moving dot stimuli are very impoverished stimuli indeed, yet there was some sign of transfer to them from fully detailed scenes in Experiment 2, and in Experiment 3, 4 birds learned to discriminate them; furthermore, the performance of these birds was rather better than that of birds that successfully discriminated fully detailed stimuli. This makes it unlikely that there is insufficient information in fully detailed video scenes to allow pigeons to discriminate them efficiently.

Why, then, might moving stimulus categories be more difficult for pigeons to discriminate than the static stimulus categories that have been used in many successful investigations of avian concept discrimination? The problems might lie within any of three domains: the essential nature of movement stimuli, the manner in which pigeons process visual information, or the anatomical and physiological organization of the pigeon's visual system.

We are not in a position to draw conclusions at the neurophysiological level, although we should note that it cannot be taken for granted that static and moving stimuli are processed by the same brain structures, or that any differentiation between them is the same in birds as it is in mammals. With regard to the nature of movement stimuli and their processing, the key point is that movement stimuli inherently involve visual complexity in the temporal as well as in the spatial domain, and this fact has a number of implications. First, in moving stimuli, no feature is repeated exactly from moment to moment, let alone from trial to trial. Accurate discrimination must therefore depend on simultaneous control by multiple stimulus features, and it is known that this is difficult to achieve in pigeons compared with humans (e.g., Blough, 1985; Fersen & Lea, 1990; Lea, Lohmann, & Ryan, 1993); in the language of human cognition, pigeons would be described as having limited attentional resources (cf. Eriksen & Hoffman, 1972; Treisman, Kahneman, & Burkell, 1983).

Second, in order to identify the nature of any movement, it is necessary to integrate information from successive views of the stimuli, which may well occur at different locations within the visible area. In humans, limitations of attentional resources are known to be strongly modulated by the spatial organization of the display (Treisman, 1988).

Third, with moving stimuli, parts of the object will frequently be hidden in the course of the movement. Sekuler, Lee, and Shettleworth (1996) have shown that pigeons do not readily generalize between occluded figures and the complete object.

Fourth, in the present study, the same stimulus birds and backgrounds were used for different movements. The stimulus birds moved; the backgrounds did not. Greene (1983) has shown that pigeons' behavior tends to come under control of what to the human eye are ground rather than figure cues, and we would expect this tendency to be accentuated if, for the reasons outlined above, the moving parts of the stimulus posed problems for the birds.

All these trends would make discrimination of movement categories relatively difficult. To a greater or lesser extent, they should be difficulties for the human observer also, but for humans, moving stimuli seem to be power-

fully salient relative to static ones, and as a result the inherent difficulties of recognizing them are overcome. Our experiments suggest that this relative salience of moving stimuli may not exist, or may not be as strong, for pigeons, at least under the viewing conditions we used. If the nature of the difficulty can be pinpointed through further experiments, it should become possible to determine whether it results from the distinctive neural architecture of the avian visual system.

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Received August 20, 1997
Final acceptance June 26, 1998