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Use of Spatial Dimensions in Pattern Discrimination and Similarity Judgments by Pigeons

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Two experiments examined the role of spatial dimensions in pattern discrimination and judgment of similarity by pigeons. In Experiment 1, pigeons were given a symbolic matching-to-sample task in which they first learned to discriminate between two patterns (A and B) that differed in the spatial layout of an arrow inside a circle divided into four quadrants. The first training stimulus contained an arrow inside the Top Left quadrant and the tip of the arrow was pointing toward 90 degrees. The second training stimulus contained an arrow inside the Bottom Left quadrant and the arrow was pointed downwards at 180 degrees. Fourteen new patterns, consisting of all the remaining combinations of arrow orientations and arrow locations (quadrants), were then presented and their categorization by the pigeons was examined. The results showed that the two dimensions pertaining to the position of the arrow (Top/Bottom and Left/Right halves of the circle) and their interactions were more salient than the two dimensions pertaining to its orientation (Horizontal / Vertical arrows and two arrow ends). Experiment 2 showed that the position of a pattern component was encoded and used in similarity judgments even when the A and B differed along nonspatial dimensions (a rectangle vs a circle). When pigeons encountered new visual patterns and judged their similarity to old ones, they privileged the position of the pattern components over shape in their judgments.

The purpose of this study was to investigate the role of spatial dimensions (orientation and position) of individual simple components of a pattern and to integrate their importance within the broader perspective of object perception and recognition by pigeons. Historically, it was thought that pigeons were merely "feature detectors": They seemed to recognize an image by its physical components regardless of how they were arranged in space. Pigeons seemed incapable of learning a discrimination between two patterns based on the spatial layout of the components of the pattern (for example, a discrimination between drawings of two-dimensional oak leaves that had the same features but organized differently; Cerella, 1979). Moreover, once they had learned a discrimination between two patterns, such as a two-dimension (2-D) drawing of the cartoon character Charlie Brown and other Peanuts characters, then recognition of the positive stimulus seemed undisturbed when the components were scrambled (Cerella, 1980). More recent research, however, has begun to reveal the role of spatial organization in pattern learning and recognition, and the notion that pigeons are merely feature detectors has been rejected. For instance, Landry and Plowright (2002) demon-

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strated that pigeons can learn a discrimination between two patterns (2-D) that contain the same features arranged differently, though the process is arduous (about 4000 trials).

In three-dimensional objects or drawings, the spatial organization of components is thought to be important. It is explicitly incorporated within Biederman's structural theory of recognition: Geons (geometrical ions) are extracted from the image and matched with the appropriately organized mental representation (Biederman, 1987). Evidence for the role of spatial organization in pattern recognition includes one study in which recognition of a three-dimensional (3-D) image was impaired when its components were scrambled (Wasserman, Kirkpatrick-Steger, Van Hamme, & Biederman, 1993). Other studies have also supported the claim that pigeons are capable of using spatial information to discriminate among different scrambled images of the same object parts, showing that spatial information plays a role in object recognition (Kirkpatrick-Steger, Wasserman, & Biederman, 1996, 1998; Wasserman, Young, & Nolan, 2000). In most of the research where pattern components were scrambled, however, the components were repositioned but not reoriented and so the effect of scrambling may have been heretofore underestimated. Moreover, the relative salience of position versus orientation has not been evaluated. In this paper, when images were scrambled, the spatial dimensions of position and orientation of pattern components were independently manipulated simultaneously. In this way, we could examine the relative importance of these two dimensions: What is worse for the perceiver, that some elements of a pattern have been reoriented or that they have been displaced?

The research reported here differs from research on rotation invariant recognition (as in studies of mental rotation; Delius & Hollard 1995; Hamm, Matheson, & Honig, 1997; Hollard & Delius, 1982; Lohmann, Delius, Hollard, & Friesel, 1988) or from human between-object recognition (Humphreys & Riddoch, 1994) in that the focus is on the internal organization of the pattern. When orientation is manipulated, it is not the pattern itself but the elements within that are rotated along a vertical axis.

Experiment 1

In this first study, position and orientation were pitted against each other via a discrimination task in order to determine which of the two, if either, is predominant. The method used was a symbolic matching-to-sample task with two original stimuli (A, B) (see Figure 1). Those stimuli differed along four spatial dimensions: 1) Two dimensions pertaining to the position of an arrow inside a circle (Left vs Right side of the circle; Top vs Bottom half of the circle) and 2) Two dimensions pertaining to the orientation of the arrow (the arrow consisted of a Horizontal vs a Vertical line; arrow tip pointing toward one end vs the other). The four quadrants will be hereafter referred to as TL (Top, Left), TR (Top, Right), BL (Bottom, Left), BR (Bottom, Right). Once the discrimination between A and B was learned, new test stimuli were presented to see how they were categorized by the pigeons. The 14

test stimuli were the remaining combinations of the (2x2x2x2) spatial dimensions.

If the orientation dimensions are predominant in the recognition processes of the birds, we predict that the classification of the new stimuli will be made according to whether the arrows are oriented in the same ways as A (TL-90°) or B (BL-180°): At least the three stimuli with the arrows pointing at 90° (TR-90°, BL-90° and BR-90°) should be categorized as A; and those with the arrow pointing at 180° (TL-180°, TR-180°, and BR-180°) should be categorized as B. Alternatively, if the position dimensions are predominant, then at least the stimuli with the arrow in the top-left quadrant (TL-270°, TL-180° and TL-0°) should be categorized as A; and those with the arrow in the bottom-left quadrant (BL-270°, BL-0° and BL-90°) should be categorized as B. In the case that both position and orientation are equally important, some of the new stimuli that contain attributes from both original stimuli should not be significantly categorized as either similar to A or B. The birds' classification of TL-180° and BL-90° should be particularly informative: TL-180° contains an arrow in the same orientation as B but is placed in the same quadrant as in A. Similarly, BL-90° contains an arrow in the same quadrant as in B but contains an arrow in the same orientation as in A.

Method

Subjects. Five White King pigeons from the Palmetto Plant in South Carolina were maintained at $85 \pm 2\%$ of their free-feeding body weights. Three pigeons had previously served in unrelated studies (timing and food competition) and the other two were naive. Prior to this experiment, the birds were taught to peck operant keys using a combination of hand shaping and autoshaping. The birds were kept in individual cages with unlimited access to water and grit.

Apparatus. Two operant chambers (32 cm x 32 cm x 30 cm) were used. On the side wall of each chamber were three operant keys: a clear plastic centre key (5 cm in diameter) covered with white paper on the back which served as a projection screen for the slides; two opaque white plastic side keys (2 cm in diameter), one on each side of the centre key (4 cm away), illuminated by a red or a green light. Each side key was 12 cm above a feeder opening into which were dispensed 20 mg BioServ food pellets. The operant chambers were controlled by a 386SX IBM compatible computer via an Interface and MED-PC software (Tatham & Zurn, 1989).

Two projectors (Elmo Omnigraphic 301 AF) with an Elmo zoom lens 1:3.5 f=100-150 mm and a Kodak slide carousel with 80 slots were used (only 40 slots were used to allow for an intertrial interval between each slide). The lens stood at 30 cm from the centre key outside the sound-attenuating boxes that enclosed the operant chambers. To focus the stimuli on the centre key, the lens had to be held four to five cm in front of the projector by a retort stand. A fan and a white noise generator inside the sound-attenuating box helped to mask the outside noise.

Stimuli and Experimental Design. The stimuli each consisted of a circle (4 cm in diameter) with a 1-mm thick black circumference divided into four quadrants by two 1-mm thick black lines; a black arrow (1.7 cm long X 0.5 cm thick) was positioned in one of the quadrants (see Figure 1). Four spatial dimensions were manipulated. The first two dimensions pertained to the position of the arrow: 1) Left vs. Right side of the circle divided by a vertical median line and 2) Top vs. Bottom half of the circle divided by a horizontal median line. The second two dimensions pertained to the orientation of the arrow itself: 1) The arrow consisted of either a Vertical vs. a Horizontal line, or 2) The tip of the arrow could be at either end of the line so the arrow pointed at 0 vs. 180 or 90 vs. 270 degrees. For discrimination training, the two original stimuli (see Figure 1) were: 1) A horizontal arrow inside the top left quadrant pointing at 90 degrees (A); 2) a vertical

arrow inside the bottom left quadrant pointing at 180 degrees (B). The fourteen remaining combinations of the four spatial dimensions (2 top/bottom X 2 left/right X 2 horizontal/vertical X 2 arrow ends) were used as tests.

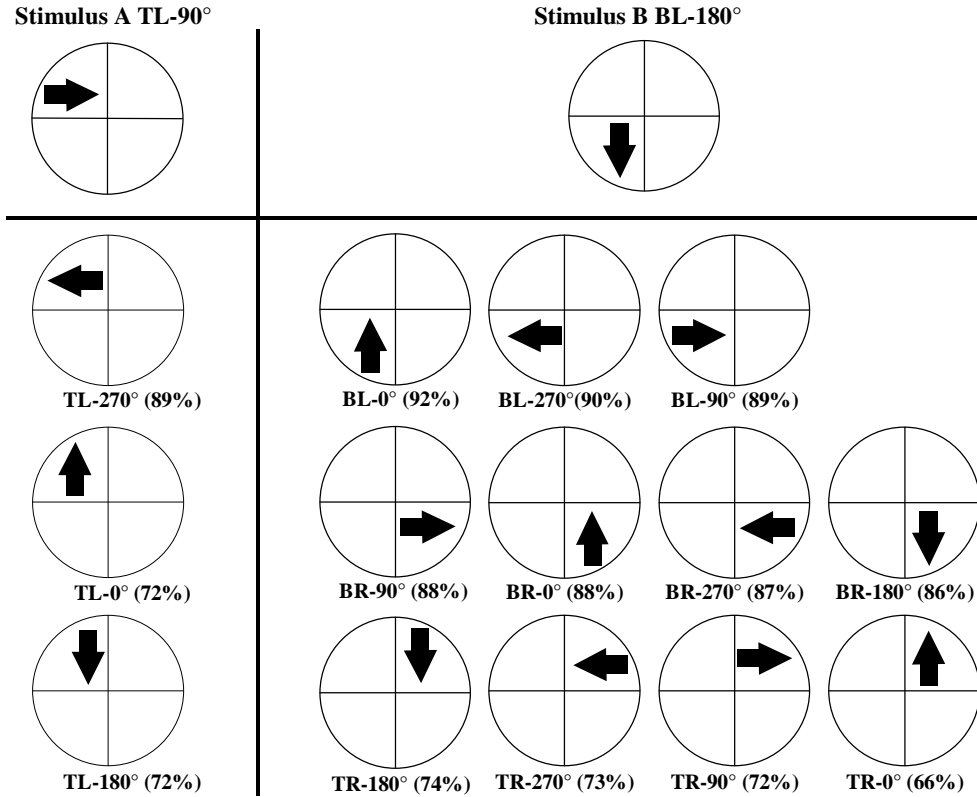


Figure 1. Categorization of the test stimuli as A and B by the pigeons in Experiment 1. The average choice proportion is given in parentheses below each test pattern. None of the fourteen test stimuli were uncategorized. Legend: T= top, B= bottom L=left, R=right, and degrees of orientation on a 360° plane.

Procedure. A symbolic matching-to-sample procedure was used in which the birds had to associate the stimuli with two colours. A or B were quasi-randomly projected on the centre key (four different slide orders) with the constraint that the same stimulus would not be used more than three times in a row. The birds had to peck it eight times to turn on the two coloured side keys. The centre key would remain illuminated so the image would remain visible during the choice. For two of the five birds, the red-right key was associated with A (i.e., A was presented, the pigeon received food if and only if it pecked the red-right key), and the green-left key was associated with B. To counterbalance the colours, the red-right key was affiliated with B and the green-left key with A for the other three birds. When a bird pecked the correct key, it was reinforced with two pellets of food. If it pecked the incorrect key, a correction procedure was undertaken: the feeder light under the incorrect key would turn on, showing the bird the absence of food. Then, the side keys would turn off and the pigeon had to peck the centre key again to be allowed another choice. If after five correction trials, the birds had still not chosen the correct key, only the correct side key would turn on and the bird had to peck it to receive food. The centre key was then turned off. A new trial began after a 4-s intertrial interval. The correction trials were not cumulated. When the bird achieved 80% success for three consecutive days, no more correction trials were given. A session was composed of 120 trials (60 A and 60 B - three rotations of the carousel) and only one session a day was given at approximately the same time each day, five days a week.

Test sessions began when the birds reached the criterion of 80% correct choices for three consecutive days in sessions with no correction trials. In a test session, 21 test stimuli (7 different test stimuli X 3 rotations of the carousels) were randomly intermingled with 99 rewarded A and B (It took two days to see all 14 test stimuli three times). For the test stimuli, the birds' responses were not reinforced – no food was delivered following the choice. Thirty test sessions were needed so each bird saw each of the 14 stimuli, 45 times (10 different slide orders). During testing, pigeons had to maintain a 70% minimum success criterion in the A/B trials. If they did not reach that criterion, training sessions were given until the criterion of 80% was attained for two days and then testing was resumed.

When the pigeon responded to the test stimuli by pecking one key or the other, it informed us on the similarity (or dissimilarity) it perceived between the test stimulus and A or B, thus reporting which spatial dimension of the stimuli was used to perform the discrimination.

Results

The 80% discrimination criterion was obtained in approximately 40 sessions (mean = 39.60, range: 22 to 62).

Figure 1 shows the pigeons' symbolic association between the 14 test stimuli and the two original stimuli. Because the data were frequencies with replication within individuals, a replicated goodness-of-fit test (G Statistic) was used (Sokal & Rohlf, 1981). Two G values are reported in Table 1 for each test stimulus and they are compared to chi-square values in the tests of significance: (1) G_p (P for pooled), which compares group choice proportions to a chance level of 50:50 and (2) G_H (H for heterogeneity), which tests for individual variation. A significant G_H means that the individual choice proportion differed significantly from that of the group. An alpha value of 0.05 was used in all the statistical tests reported in this article.

All the stimuli were categorised: all choice proportions were significantly different from 50%. Eleven test stimuli were treated by the birds as similar to the B and three as similar to the A. The three test stimuli that had the arrow in the same quadrant as A were categorized as A and all the rest were categorized as B.

The eleven test stimuli associated with B were not treated equally (see Figure 1): the test stimuli that had the arrow in the same quadrant (Bottom Left) as B were strongly categorized (?89%). The test stimuli that had the arrow in the bottom-right half of the circle (between 88%-86%) were almost as well categorized. Least well categorized as B were the test stimuli that had the arrow in the top right quadrant (?74%). A test x Pigeon analysis of variance showed a significant difference among the 11 test stimuli chosen as B, $F(10, 40) = 8.18$. This analysis shows that the position of the arrow within B was encoded. It casts doubt on an alternative interpretation that the pigeons learned a simple rule (i.e., peck one key if the top left quadrant is dark; otherwise, peck the other key).

In regards to the two particular test stimuli (BL-90° and TL-180°) which contained the arrow orientation of one training stimulus and the arrow position of the other, position prevailed over orientation: BL-90° which had the same arrow orientation as A but was placed in the same quadrant as B was categorized as an B; TL-180° which had the same arrow orientation as B but was placed in the same quadrant as A was categorized as an A.

Thirteen G_H were statistically significant, showing that there was heterogeneity among the pigeons. The heterogeneity reflected individual differences in the

magnitude of the choice frequencies but not in the direction. In other words, if a group choice proportion showed that the pigeons categorized a

Table 1

The test statistics (G_P), for the comparison of the choice proportions (given in Figure 2) to chance (50:50) and the G_H test for individual differences for each of the 14 test stimuli in Experiment 1.

Test Stimuli	G_P (df=1)	G_H (df=4)
BL-0	186.47***	8.33 ns
BL-90	159.14***	15.50**
BL-270	172.33***	18.76***
TL-0	45.09***	40.69***
TL-180	45.09***	45.28***
TL-270	163.44***	19.72 ***
TR-0	25.48***	25.99***
TR-90	45.09***	21.05***
TR-180	55.09***	36.00***
TR-270	50.95***	27.99***
BR-0	135.21***	19.18***
BR-90	150.83***	27.98***
BR-180	135.21***	29.07***
BR-270	142.86***	12.04*

*** $p < 0.001$ ** $p < 0.01$ * $p < 0.05$ ns = non significant

stimulus as A, the pigeons all did so to a greater or lesser degree.

The discrimination weight of the spatial dimensions was investigated via a standard multiple linear regression between the proportion of choices symbolically linked to A as the dependent variable and the four spatial dimensions that could be used to make the original discrimination as independent variables (the 2 position dimensions and their interaction and the 2 orientation dimensions and their interaction). A multiple regression analysis allows for finding the best predictors of the dependent variable. The analysis was performed using Statistica software (Statistica, 1993). The regression R was significantly different from zero $F(6, 63) = 40.51$, $MSE = 193.96$. The values of the dimensions related to position (Left/Right and Top/Bottom) were significantly different from zero: 1) Left/Right, $t(63) = 6.66$, Std. err. b = 1.71; Top/Bottom, $t(63) = 12.25$, Std. err. b = 1.74; interaction, $t(63) = 7.72$, Std. err. b = 1.74. The dimensions related to orientation were not significantly different from zero; Vertical/Horizontal, $t(63) = -0.83$, Std. err. b = 1.74; arrow end, $t(63) = -0.00011$, Std. err. b = 1.74; interaction, $t(63) = 0.72$, Std. err. b = 1.71. In other words, the position dimensions, but not the orientation dimensions, were the best predictors of the symbolic choices of the pigeons. All together 57% of the variability in choice was predicted by incorporating the two position terms and their interaction in the regression equation.

Discussion

This experiment examined similarity judgments between original and new patterns which all consisted of an arrow positioned inside a circle. The results

showed that pigeons relied on the variables pertaining to the position of the arrow (in this case, the Left and the Right side of a median line and the Top and the Bottom part of a divided circle) to categorize new stimuli. The orientation of the arrow, however, was virtually irrelevant. In a general theory of object recognition by components (RBC), Biederman (1987) proposed that the role of relations is specified when the separate geons (or 3-D components) are matched to the representation of the image in memory which contains the proper (or encoded) spatial relationships. With such a structural description, recognition would be disrupted when the components are scrambled since the original spatial relations would no longer characterize the object (Wasserman, et al., 1993).

In our study, simple 2-D patterns were used and scrambled, and the results stress that relocating a component during scrambling is far more disruptive than reorienting a component. The fact that the pigeons chose the three test stimuli that were in the top left quadrant as similar to A suggested that the combination of top-bottom and left-right was a more precise evaluation of the spatial organization than just the relative positions alone. Why the three test stimuli in the top-left quadrant were categorized as A and everything else was treated as B remains unclear. Perhaps the top left quadrant is the first to be processed as the pigeon visually scans the stimulus. Another interpretation is that the learning in this experiment consisted only of absolute spatial location of the arrow in the A (e.g., if a certain area of the key is darkened then peck red, if not peck green). Our data, however, do not support this “absolute location hypothesis”: the eleven stimuli which were categorized as B were not all treated equivalently. The learning in this experiment was not confined to whether the top-left quadrant was darkened or not: The spatial location of the arrow in the B must have been extracted.

For the two stimuli (BL-90° and TL-180°) of particular interest, the results were unequivocal: They were both categorized as an instance of the training stimulus in which the arrow was located in the same quadrant and not as an instance of the training stimulus in which the arrow was oriented in the same way. BL-90° was categorized as a B and TL-180° was categorized as an A.

These results further demonstrate that pigeons are able to learn a discrimination task which includes spatial elements, contrary to Cerella's (1979) claim. They emphasize the importance of the spatial constituents of the components of an object and the fact that pigeons can encode and use them in a discrimination task as proposed by Wasserman et al. (1993) for 3-D objects. The use of spatial dimensions by the pigeons in this experiment, however, might well stem from the training discrimination (A vs. B) which forced attention to spatial organization: The training discrimination could only be solved by attending to the orientation and/or the position of the arrow. Our pigeons used position predominantly, but perhaps if the training discrimination could have been solved in another way, then neither spatial dimension (position or orientation) would have been used. If so, our results would have limited generalization. The following experiment was designed to test this possibility.

Experiment 2

In Experiment 2, one group of pigeons (the Position-Shape group) was trained to discriminate between a rectangle in the top portion of a circular outline, and a filled circle in the bottom portion. This discrimination could in principle be solved without encoding the spatial position of the rectangle and circle. In the past, discriminations solely based on shape have been known to be relatively easy. For example, pigeons learned to distinguish between a triangle and another geometric shape (star, circle, diamond) in about 2000 trials (Cerella, 1980). Also, in another experiment, pigeons learned to discriminate among drawings of a chair, a flashlight, a desk lamp and an airplane in about 1500 trials (Wasserman, Gagliardi, Cook, Kirkpatrick-Steger, Astley, & Biederman, 1996). In comparison, Lohmann, Delius, Hollard and Friesel (1988) showed that a spatial discrimination (orientation in that case) was lengthier to learn than a discrimination between arbitrary shapes. Moreover, in our first experiment, pigeons took almost 5000 trials to learn to discriminate between the two training stimuli.

In the second group in Experiment 2 (the Position-Orientation group), pigeons were trained to discriminate between two rectangles with a different orientation and position, much as in Experiment 1. We expected a difference between the two groups in the use of spatial dimensions in similarity judgments. An alternative scenario is suggested by the work of Kirkpatrick-Steger, Wasserman and Biederman (2000). Their procedure included relative location information and different three-dimensional object drawings in a Go/No-Go task. Pigeons were trained to respond to one stimulus and to refrain from responding to 15 others that contained either the same shape but in a different layout or the same layout but with a different accompanying shape. Then, similarity judgement was assessed by the response rate to each of the 15 negative stimuli. Their results indicated that pecking behaviour was controlled by both attributes (the different shapes and their layout), but they stressed that the location might have had a stronger stimulus control than the shapes themselves. So, perhaps in both groups of the present experiment, similarity judgments will be based on the position of the components within the patterns and not on their shapes. The method used in this experiment differed from the one used by Kirkpatrick-Steger, et al. (2000) in that we used simple 2-D drawings in a symbolic matching to sample task with two training stimuli (A, B) both of which led to reinforcement, so we had two positive stimuli instead of one positive and several negative stimuli. More important, attention to the spatial layout of the stimulus components was not required to solve the training discrimination as it was in the Go/No-Go procedure. If the birds in this experiment encoded spatial position and used it in similarity judgments anyway, it would reflect their own bias more so than experimental demands.

In the Position-Orientation group, if position is more salient than orientation, as it was in Experiment 1, we expected that the pigeons would associate Test B with A and Test A with B. If orientation is more salient, we would expect the opposite: that they would associate Test B with B and Test A with A. The same logic applies for the Position-Shape group: If the position is more salient than the shape, we expected that they would associate Test B with A and Test A with B. If the shape is more salient, we would expect the reverse: that they would associate Test A with A and Test B with B. For this reason, Test A was particularly

informative since it was identical for both groups.

Method

Subjects. Eight White King pigeons from the Palmetto Plant in South Carolina were used. They were maintained at $85 \pm 2\%$ of free-feeding body weights. Five pigeons had previously served in studies on mirror image and similarity judgment and the other three were naive. After 40

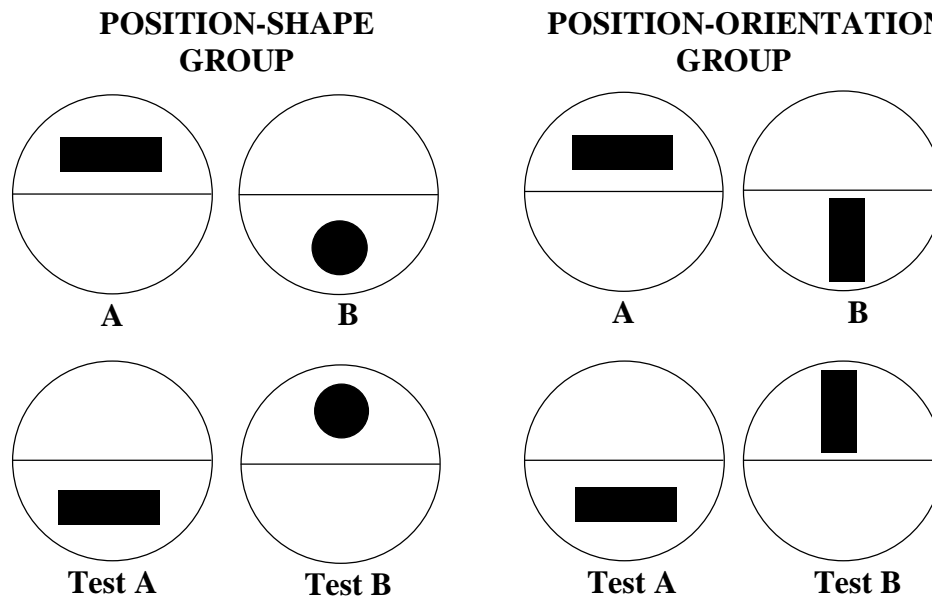


Figure 2. Original and test stimuli (Experiment 2)

sessions of training, one bird in each group still showed choice behaviour no different from chance and so three birds per group were tested. Within each group there were two birds with prior experience and one naive bird.

Stimuli and Experimental Design. The stimuli (see Figure 2) each consisted of a black circle (4 cm in diameter) with a 1 mm thick circumference divided into two halves by a 1-mm thick black line; a black rectangle (1.5 cm X 0.5 cm) was positioned in one half of the circle. In the discrimination training, two groups were formed: (1) A Position-Orientation group: the two dimensions that were manipulated (and deliberately confounded) were position and orientation. For this group, the first original stimulus (A), was a horizontal rectangle in the top half portion of the circle and the second original stimulus (B) was a vertical rectangle in the bottom half. (2). A Position-Shape group: the two dimensions that were manipulated (and deliberately confounded) were the position and the shape. For this group the first original stimulus (A) was a horizontal rectangle in the upper half of the circle (identical to A in the spatial group). The second original stimulus (B) was a filled circle (1 cm of diameter) in the bottom half of the stimulus.

The test stimuli (Test) consisted of the remaining combinations of the dimensions. For the Position-Shape group, Test A was a rectangle in the bottom half (the rectangle had now the same position as the circle in the original stimuli) and Test B was a filled circle, in the top half of the stimulus (the circle had now the same position as the rectangle in the original stimulus). For the Position-Orientation group, the horizontal rectangle was placed in the bottom half (Test A) and the vertical rectangle was placed in the top half (Test B).

Test Trials. When the birds reached the criterion of 80% correct choices for three con-

secutive days in sessions with no correction trials, the test sessions began. In a test session, 18 unrewarded test stimuli (6 different tests stimuli X 3 rotations of the carousels) were randomly intermingled with 102 A and B. Five sessions of tests were needed so each bird saw each of the two stimuli forty-five times. When the pigeon responded to the test stimuli by pecking one key or the other, it informed us on the similarity it perceived with A or B, telling us which dimensions of the stimuli were used to perform the discrimination.

Other aspects of the procedure were as described in Experiment 1.

Results

The 80% success criterion was achieved in approximately 25 sessions (mean = 25.33; range: 18 to 29) in the Position-Orientation group and in 25 sessions (range 18 to 33) in the Position-Shape group.

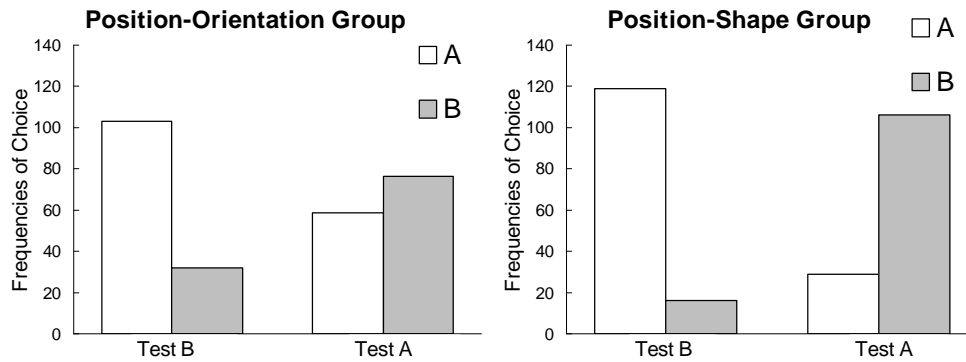


Figure 3. Frequencies of choices in the categorisation of Test A and Test B in relation to A and B (Experiment 2)

Figure 3 presents the choice frequencies for Test A and Test B in relation to A and B for the two groups. In associating the tests with either A or B, we could infer the dimensions on which they based their similarity judgment, that is, in the Position-Shape group, if the pigeons associated Test A with A, they might have used the shape dimensions, if they associated Test A with B, they used the position dimension. The same goes for Test B: if they associated Test B with A they used the position dimension and finally, if they associated Test B with B, they used the shape dimension. In the Position-Orientation group, if the pigeons associated Test A with A, we infer that they used the orientation dimension to judge the similarity, if they associated Test A with B, they used the position dimension. If they associated Test B with A, they used the position dimension and finally, if they associated Test B with B, they used the orientation dimensions. As shown in Figure 3, pigeons in both groups judged that Test A was similar to B and that Test B was similar to A, indicating that the position of the components bore more weight than either its orientation or its shape. Because the data were frequencies with replication within individuals, a replicated goodness-of-fit test (G Statistic) was used (Sokal & Rohlf,

1981) as in Experiment 1. G_p (p for pooled) compares group choice proportion to a chance level 50:50. For the Position-Orientation group (the analysis compares the number of trials the pigeon chose position vs. the number of trials it chose orientation—see paragraph above) $G_p = 29.12$, $df = 1$: the choice frequencies reflecting the use of position were significantly above chance. For the Position-Shape group (the analysis compares the number of trials pigeons chose position vs the number of trials they chose shape) $G_p = 131.00$, $df = 1$: here again, the choice frequencies reflecting the use of position were significantly above chance

The G_H (H for heterogeneity) tests for individual variation provided the following information. A significant G_H means that the individual choice proportion differed significantly from that of the group. The data are not homogeneous for either group. In the Position-Orientation group, $G_H = 46.91$, $df = 2$, two birds showed a choice behavior that indicated that position might be used more than the orientation, but one bird displayed random choice behavior for the position and orientation variables. That bird categorized both test stimuli as similar to B. As an explanation, we suggest that since it had almost a perfect score on A and B symbolic choices, it might have learned that both Tests were nonrewarding and thus, did not categorize them. This might have been prevented by giving the pigeons an intermittent reinforcement schedule instead of a continuous reinforcement schedule. In the Position-Shape group $G_H = 7.32$, $df = 2$, the difference among pigeons is one of magnitude and not of direction of choice.

Given that the test stimuli were presented more than once, we examined the first trial separately from the others, and tested for significant changes in behaviour over time. The first trial performance for each bird in each group were are as follows. In the Position-Orientation group, two birds chose the position dimension when presented with Test A the first time and one bird chose orientation. When presented the first time with Test B, two birds chose orientation and one chose position. As for the Position-Shape group when presented with Test A the first time, two birds chose shape one chose position. When presented the first time with Test B, all the birds chose position. An analysis between sessions showed no change (for the Position-Orientation group, $F < 1$ for Test A and $F(4, 8) = 1.06$ for Test B. For the Position-Shape group, $F < 1$ for Test A and $F < 1$ for Test B.

Discussion

In this experiment, one group replicated the results of Experiment 1 in using position instead of orientation in the categorization of the new stimuli. The second group had the choice of selecting the position or the shape of the components of the stimuli. In this group, the position was also used over the geometric shape. Hence, a spatial discrimination during training is not a prerequisite for the use of spatial information in a subsequent judgment of similarity between new and old stimuli. This outcome stresses the importance of the spatial dimensions, and especially of the position information of the components in the process of image discrimination. This is in accordance with the suggestion made by Kirkpatrick-Steger, et al. (2000) to the effect that position might have a stronger stimulus control than shape. It seems counterintuitive, however, that shape was not even used in the discrimination

between a rectangle and a circle (Position-Shape group), especially given that shape can be encoded and used (e.g., Lohmann, et al. 1988). Our results do not necessarily show that shape was not encoded at all, but only that position was used preferentially: shape information seems to have been superfluous in this task.

Although we expected that the training discrimination would take longer for the Spatial-Orientation group than for the Spatial-Shape group, it took approximately the same time for both groups. The two training discrimination tasks seemed to be both of comparable difficulty, and the reason is likely that both groups used the same information, spatial position, to resolve the discrimination.

General Discussion

Results from both experiments showed that in discrimination and similarity judgment tasks, pigeons used information about the position of the components instead of their orientation to resolve a discrimination task. Moreover, position was used even when the task included a non-spatial dimension (the Position-Shape group of Experiment 2 for which the position information was pitted against shape). In these similarity assessment tasks, the birds had to initially encode some properties of the stimuli to be able to perform the initial discrimination. Then, upon presentation of new stimuli, which presented different spatial organization of the same features, they retrieve and use the information regarding the position of the components to evaluate the similarity between the new stimuli and the initial stimuli.

Studying how pigeons assess similarities and differences in classifying stimuli may improve our understanding of the processes underlying form recognition. First, our results leave little doubt that pigeons do not rely solely on physical features to recognize an object as was proposed by Cerella (1980, 1986). If it had been so, they would not have been able to make the initial discrimination of Experiment 1 and the initial discrimination of the group position-orientation of Experiment 2. So far, theories in pattern recognition have not pinpointed the importance of the relative role of position of components in the internal spatial arrangement of simple images. Rilling, LaClaire and Warner (1993), proposed a hierarchical theory for object recognition which subsumes some of the research in comparative visual analysis with pigeons and humans. Their mostly bottom-up theory proposes that recognition is initiated with edge extraction as suggested by both Biederman's theory (1987) and Marr's computational approach to human vision (1982). Then, orientation of the features is assessed by specialized brain cells (Hubel & Wiesel, 1959). Furthermore, features are extracted and weighted. This is where our results seem to belong to theory: The stimuli used in our studies (the arrow, the rectangle, the filled circle inside divided outlined circles) were simple primitive components as envisaged by Marr (1982). For instance he suggested that the primal sketch consists of edges, bars, blobs, and terminations and that those components had the perceptual attributes of orientation, contrast, length-width, and position. In our study, some of the attributes of the components of the 2-D pattern namely, the position, the orientation and the shape were contrasted to identify their relative weights. The fact that the birds weighted the position as more important than either orientation or shape in this particular task might imply that those

“primitive components” not only specify the early perceptual attributes of position and orientation but somehow, position may be more salient than orientation.

In 3-D objects or images, the position can be assessed not only globally (an object in the scene; Humphreys & Riddoch, 1994), but also locally; the components or geons might be assessed in relation to the others (Kirkpatrick-Steger, et al., 1996, 2000; Kirkpatrick-Steger & Wasserman, 1996; Wasserman, et al., 1993). Biederman (1987) suggested that despite the subjective componential interpretation given to the arrangement of image features as simple volumes, it is the image features themselves, in specified relationships, that mediate perception. Is it so or are spatial dimensions rated and used at different levels of object processing? Their relative influence in the sequence of the entire object evaluation needs further investigation.

Although we envisaged the collection of components as a pattern, our research still begs the question of object unity: Do pigeons see an image as a whole or do they see it as an assemblage of components? Gestalt principles have been widely employed with humans to delimit components from objects. Proximity and similarity have been proposed as early mechanisms of object detection by pigeon (Cook, 1993). However, Ushitani, Fujita and Yamanaka (2001) suggested that pigeons do not complete occluded portions even though the two elements move in concert. They also suggest that some alternative way of identifying objects may have evolved in pigeons. To answer this sort of question, the method used here might be useful: A symbolic matching to sample with original and new stimuli has the advantage of giving the choice of dimensions to be extracted from the stimulus to the pigeon. In most visual discrimination tasks, pigeons are trained to respond to some dimensions of the stimuli or to refrain from responding to others. The present study illustrates a more animal-centred approach to visual processing.

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