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Discrimination of Simple Patterns by the Honeybee Apis mellifera

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DISCRIMINATION OF SIMPLE PATTERNS BY THE HONEYBEE *APIS MELLIFERA*

A Thesis
Presented to
The Faculty of the Department of Biology
The College of William and Mary in Virginia

In Partial Fulfillment
Of the Requirements for the Degree of
Master of Arts

by
Mary Agnes Linehan Wiseman
1977

APPROVAL SHEET

This thesis is submitted in partial fulfillment of
the requirements for the degree of

Master of Arts

Mary Agnes Linehan Wiseman
Mary Agnes Linehan Wiseman

Approved, July 1977

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Gustav W. Hall

DEDICATION

To my parents.

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ACKNOWLEDGMENTS

I wish to express my great appreciation to Dr. Norman Fashing for his expert guidance, valuable criticism, and patience during the course of this work. I am grateful to Dr. G.R. Brooks and Dr. G.W. Hall for their careful reading of the manuscript. I especially wish to acknowledge the invaluable support the friendship of all my committee members afforded me both before and during this investigation.

Special thanks are due my husband, Larry, for his constant support and encouragement, without which I could never have completed this work.

I also wish to thank all of my friends for their thoughtfulness and support.

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ABSTRACT

Experiments on visual acuity in the honeybee performed by Hertz (in 1929) led to the conclusion that honeybees cannot distinguish between simple patterns such as triangles, squares, circles and rectangles, because the patterns have approximately equal "brokenness" (contour density). She found they could, however, readily distinguish any of these from a figure which was slightly more complex such as a cross, a "Y", a hollowed-out square or four closely spaced bars. She also found they could not distinguish between any of these more complex figures.

The present study reinvestigated the conclusions of Hertz by using similar test patterns but a different experimental design. Hertz trained bees to horizontally placed test patterns at feeding stations, whereas the present study employed an apparatus in which the bees were trained to a pattern centrally placed in a vertical position over the hive entrance. The bees were thus forced to fly through a hole in the center of the pattern to go in and out of the hive. Advantages of the latter method are the added dimensions of up and down and left and right, as well as greater motivation of the bees to learn a pattern (the urge to enter the hive being greater than that to feed at a particular station). Bees were trained to a particular pattern (standard), and then a series of preference tests were conducted between the standard and all other patterns.

In further tests with the same simple patterns, bees were given a choice between the horizontal and vertical components of a pattern. Because bees tend to fly back and forth across the front of a pattern in the horizontal direction, the horizontal pattern should more closely resemble the training pattern in contour density.

Results demonstrate conclusively that bees <u>can</u> distinguish between simple patterns. In addition, bees given a choice between the horizontal and vertical elements of a pattern more often choose the horizontal component.

DISCRIMINATION OF SIMPLE PATTERNS BY THE HONEYBEE *APIS MELLIFERA*

INTRODUCTION

Vision plays an important role in the life of the honeybee (Apis mellifera). While foraging for food, a bee uses visual cues in making a choice between species of flowers, and when returning from foraging, she orients partly by recognizing landmarks in the vicinity of the hive (von Frisch, 1967). The visual acuity of the honeybee as it relates to light intensity and the size and motion of an object has been described (Hecht and Wolf, 1929; Wolf, 1933; Wolf and Zerrahn-Wolf, 1934). Another aspect of visual acuity, the ability of bees to discriminate between different shapes, was first tested by Karl von Frisch (1915; as cited in von Frisch, 1950). His results led him to conclude that bees cannot distinguish between simple geometric figures, probably because they do not encounter them in nature. Hertz (1929) continued the work of von Frisch, and using the eight simple shapes of Figure 1, found that bees could distinguish any figure in the top row from any figure in the bottom row. However, she was unsuccessful in training bees to discriminate between any two figures from the same row. The factor she believed to be most important in pattern discrimination is the degree of "brokenness" (contour density) of the shape. Since figures within the same row have approximately equal amounts of broken area, Hertz felt that they are too similar for discrimination by the honeybee.

Mazokhin-Porshnyakov (1969) states that insects respond more to the totality of characteristics of a pattern than to individual parameters such as size, shape, and degree of brokenness. Postulating that Hertz could not train bees to recognize all eight shapes because the patterns were too large relative to the size of the bee, he redesigned some of the shapes into composites (Fig. 2). The bees were able to discriminate between them, but the question remains whether composite shapes can still be considered simple geometric figures.

Anderson (1972) was at first unable to train bees to distinguish between a square and a triangle. However, after training bees to figures along a continuum of decreasing contour density, he found they could distinguish between these two simple patterns. He stated that the innate preference of bees for broken patterns (Wolf and Zerrahn-Wolf, 1936) makes it impossible to train them to simple figures unless they are forced to focus their attention on other parameters.

Although most early work on pattern recognition was performed with the patterns in a horizontal position, Wehner (1967) has shown that vertically oriented figures are more useful in testing form perception. Using this type of design, he was able to demonstrate that bees can distinguish between two identical patterns inclined at different angles. These results indicate that the orientation of a shape must be important in pattern recognition, since the figures had equal contour density. Vertical pattern testing has also revealed that the lower median part of the visual field is most important for pattern recognition (Wehner, 1972). Results of tests by Anderson (1977) on the scanning of patterns by bees support this conclusion. Use of vertically placed patterns allows for testing of the relative importance of vertical and horizontal components of a shape in recognition. Using high-speed cinematography, Anderson (1977) has shown that the majority of runs made across the front of a pattern by bees are in the horizontal direction.

Another interesting aspect of pattern recognition in bees involves their innate preference for certain shapes. Although foraging bees overwhelmingly prefer broken patterns to solid ones, it has been demonstrated that bees flying homeward prefer solid figures (Jacobs-Jessen, 1959, as cited in von Frisch, 1967). This might be explained by the fact that foraging bees are seeking flowers, and thus would prefer broken contours. Homing bees, on the other hand, are seeking the hive entrance, which is more likely to be a smooth contour.

The following study was undertaken to determine conclusively whether or not bees are able to distinguish between simple patterns. Hertz (1929) stated they cannot, but Mazokhin-Porshnyakov (1969) stated they can. It is debatable, however, whether or not the composite patterns used by Mazokhin-Porshnyakov are simple patterns. Also, both Hertz and Mazokhin-Porshnyakov trained bees to a feeding station, and since foraging bees prefer broken patterns, this might interfere with the learning process. In addition, they trained bees to patterns placed in a horizontal plane, thus perhaps unintentionally eliminating cues which have since been found to be important in pattern recognition. My experimental design utilized vertically oriented patterns and also takes into account the homing bees' preference for simple shapes. For testing, I used the same shapes used by Hertz, with the exception that they were larger. In addition to testing the ability of bees to discriminate between simple patterns, I tested the relative importance of the horizontal and vertical elements of a shape in pattern recognition.

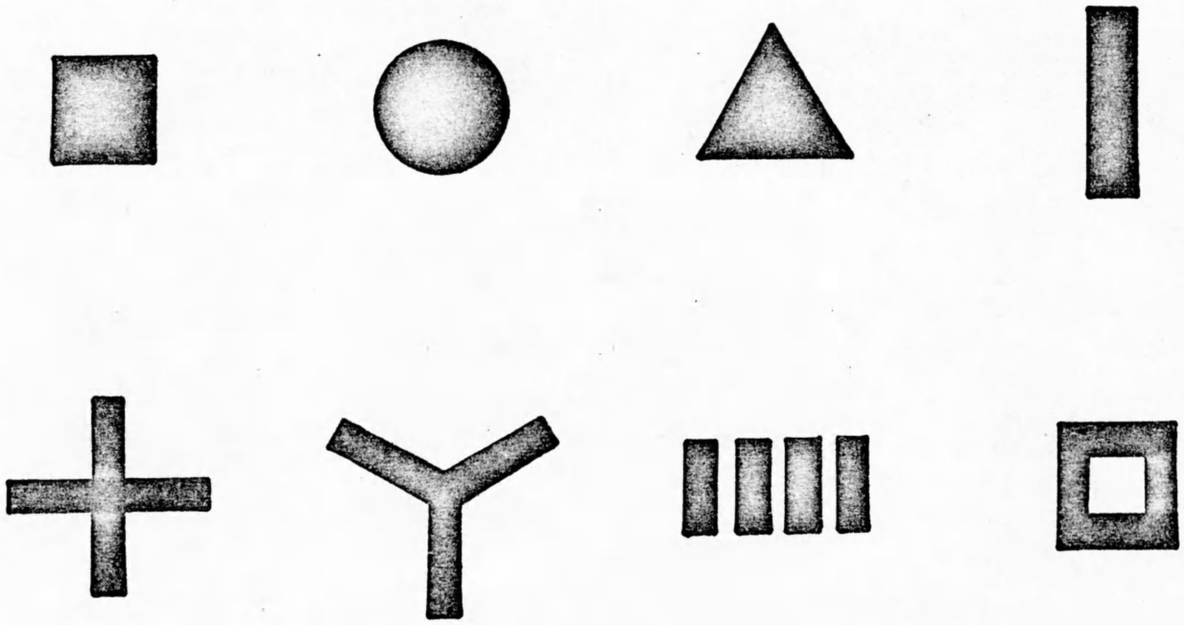


FIGURE 1: Simple shapes as tested by Hertz (1929).

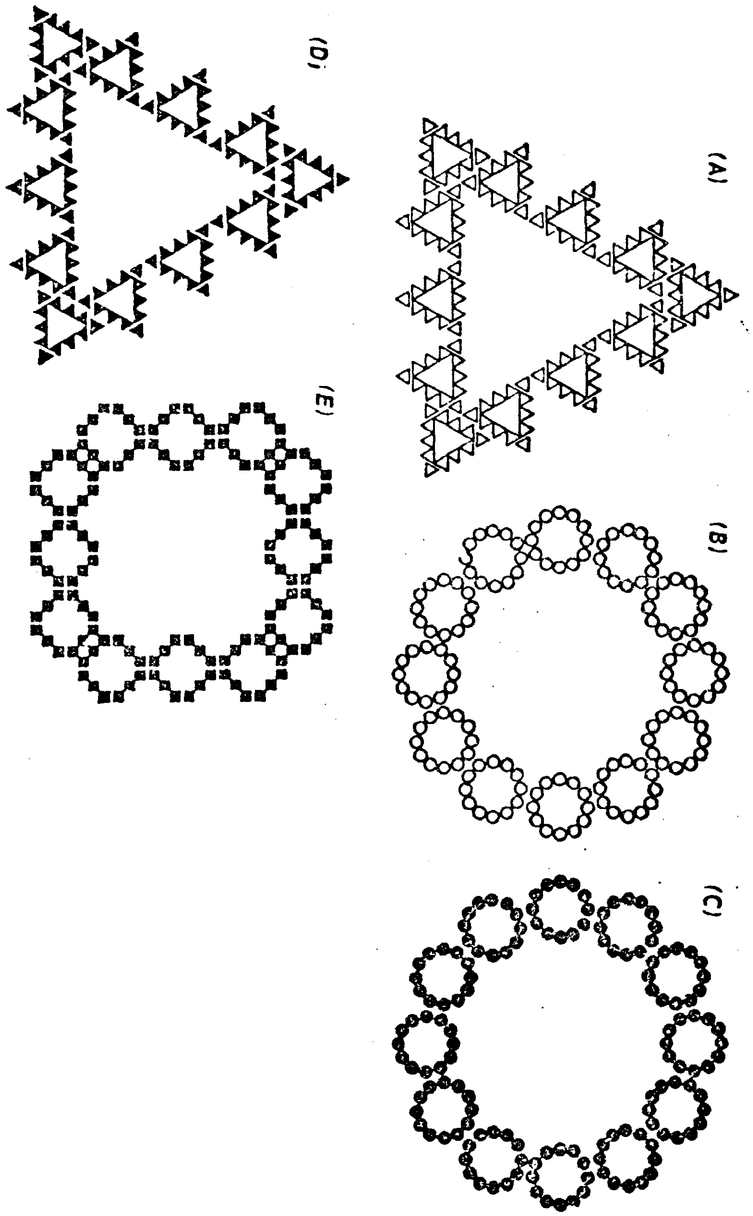


FIGURE 2: Composite figures "a-e" used by Mazokhin-Porshnyakov (1969).

MATERIALS AND METHODS

Testing of honeybees occurred during the summers of 1974, 1975 and 1976. Hives were located on the grounds of the Laboratory of Endocrinology and Population Biology at the College of William and Mary using the pattern recognition apparatus pictured in Figures 3, 4, and 5. Two units were constructed so that one hive could be trained to a pattern while the other hive was being tested. Both units were painted flat white.

The hive rested on a table behind the large backboard, and was connected to the board by a screen funnel. A 4 cm hole in the center of the backboard led into the screen funnel and served as the hive entrance. The bees had to fly through the hole and thus through the center of the backboard to get into and out of the hive. The top and side boards forced the bees to make a fairly direct approach to the hive entrance, and therefore to the training pattern, standardizing their perception of the pattern to a large extent. The sides and roof of the apparatus also prevented shadows from obscuring the patterns. For testing, two 4 cm holes leading into false entrances were constructed equidistant from the center. The false entrances led into detachable funnels on the back of the apparatus. The funnels converged to the center of the apparatus and led into a removable collecting cage. Circular boards, 43 cm in diameter with a 4 cm hole in the center, to which patterns could be attached, fitted over the three entrances on the front of the backboard, thus allowing for simple changing of patterns during testing.

Forty-three cm diameter circles were cut from stiff white construction paper and utilized as a background on which to glue the patterns. These circles in turn could be attached to the circular boards with double-sided tape. The patterns could thus easily be attached and removed from the board as often as necessary during testing. The patterns used during the initial stages of this study were the eight originally employed by Hertz (1929), having approximately equal black area, and of the dimensions shown in Figure 6. Later tests utilized these same figures or parts of them. In the center of each pattern was a hole 4 cm in diameter to allow the passage of the bees.

The shape to which the bees were to be trained was hung over the hive entrance and not disturbed for at least one week. During this time, the bees trained themselves using their innate behavior to learn landmarks around the hive entrance. To begin each test, the training pattern was removed from the front of the hive and a piece of white paper taped securely over the entrance to allow only those bees returning from foraging to be tested. The bees knew where the true entrance was, and unless it was plugged, would not choose either test pattern. After covering the true hive entrance, test patterns were hung over each false entrance. In retesting Hertz's work, the training pattern was also the standard against which the other seven patterns were tested. One test pattern was therefore a duplicate of the training pattern (never physically exposed to bees before), while the other pattern was any of the other seven of Hertz's shapes. Once the patterns were hung over the false entrances, the bees could be counted as they flew up the funnels into the collecting cage on the back side of the apparatus. The choices of the first fifty bees to enter the collecting cage were recorded.

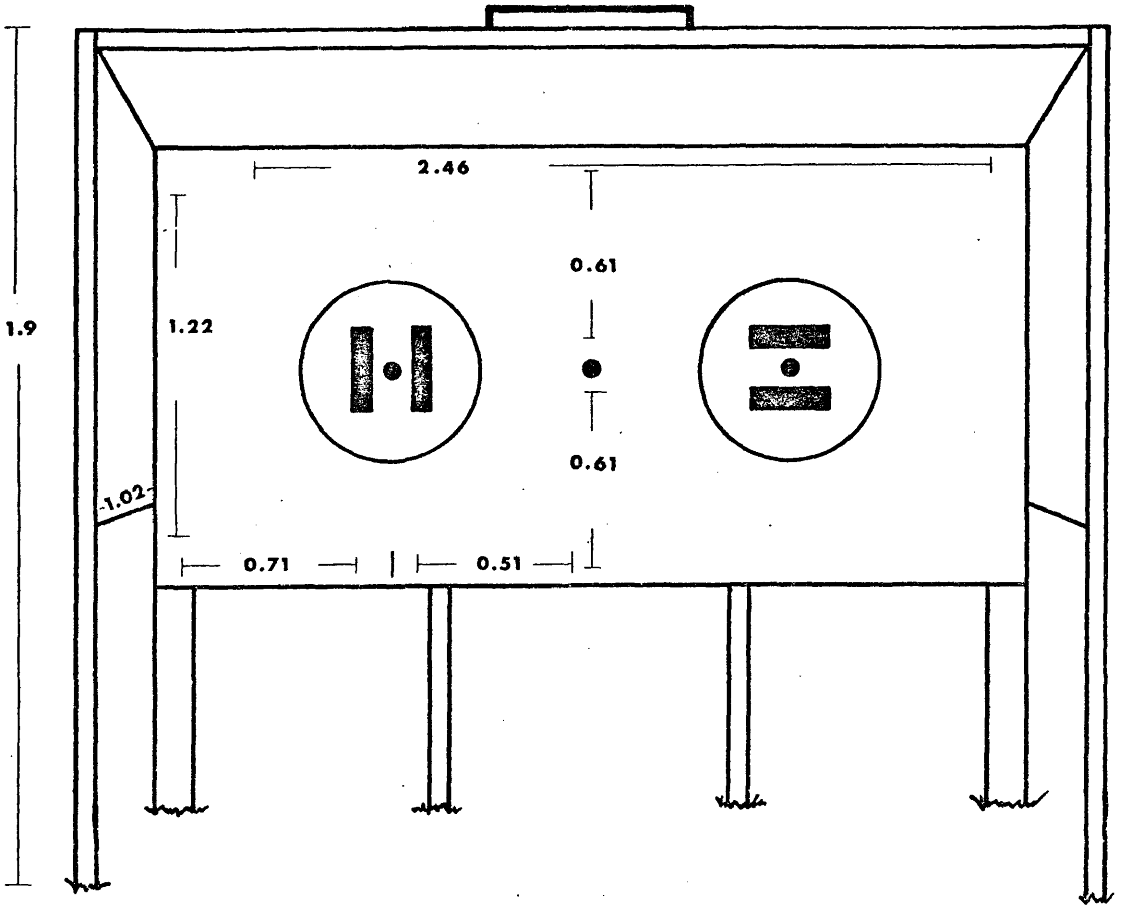
Preference of the bees for a particular side of the apparatus was observed during the initial testing, and in order to eliminate the effects of this bias, the following procedure was used. After recording the choices of the first fifty bees, the test patterns were each removed, and the training pattern replaced over the hive entrance. The funnels were checked to make sure no bees remained. The training pattern was then removed again, the hive entrance covered, and the same two patterns replaced over the false entrances, but this time on opposite sides to compensate for side bias. The choices of fifty more bees were then recorded. When the number of bees going to each pattern in this instance was added to the respective number for the tally of the first fifty bees, a percentage of bees choosing each pattern was obtained. The test patterns were again removed and the training pattern replaced over the hive entrance.

The remaining six figures were each tested against the standard in this fashion, thus obtaining one observation of 100 bees for each of the seven test patterns against the standard. The sequence was then repeated using the same series of test patterns until the standard was tested against each of the seven patterns at least five times. Since each pattern was used as a training pattern and served as a standard against which the other seven patterns were tested, 56 tests were performed in testing Hertz's shapes.

The results of the experiments were submitted to a statistical analysis. A Mann-Whitney U-test (Sokal and Rholf, 1969) was performed to test for differences between a training pattern and each of the other patterns it had been matched against.

As stated earlier, bees were trained to a particular pattern and this pattern (standard) tested against the other seven patterns. Therefore for any one training pattern, seven independent tests were conducted (e.g., square vs. triangle, square vs. circle, square vs. rectangle, etc.). With this in mind, it is also interesting to look at the following problem: in reference to a common training pattern, are certain shapes perceived as more similar to the training pattern than others? For this analysis, the data were grouped based on a common test pattern (standard), thus forming eight groups, each with seven sets of data. Since the data were collected as percentages, an arc sine transformation was first performed (Sokal and Rohlf, 1969), and an analysis of variance then run on each group. An a posteriori test (Student-Newman-Keuls test) was used to point out differences between patterns within a group.

FRONT



BACK

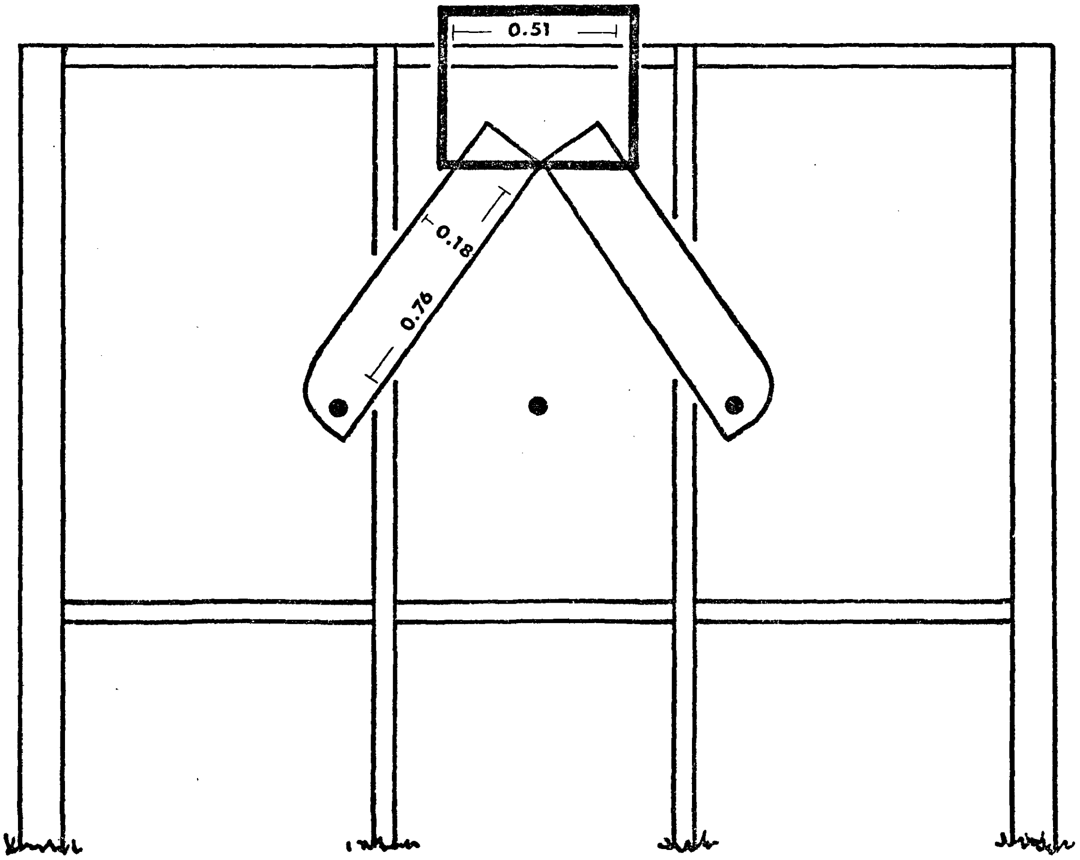


FIGURE 4: (above) Photograph of front of testing apparatus.

FIGURE 5: (right) Photograph of collecting cage and funnels at back of apparatus.

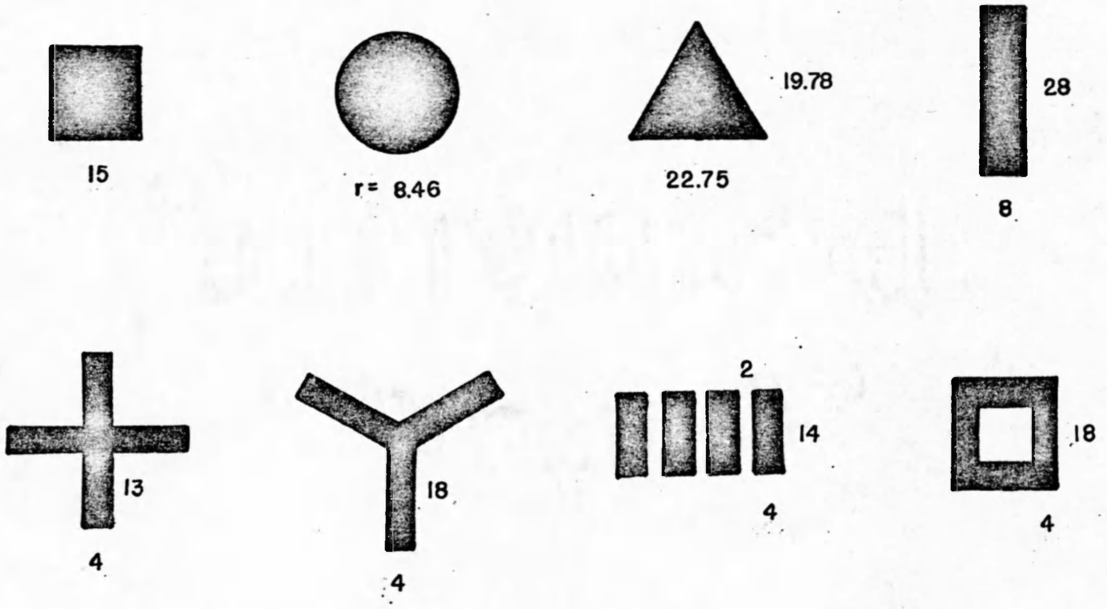


FIGURE 6: Patterns' dimensions in centimeters.

RESULTS

Figures 7-22 illustrate the results of testing Hertz's patterns. In each figure, the pattern at the left is the standard against which the other patterns were tested. In every test, more than fifty percent of the bees chose the figure to which they had been trained. Also, in every case, the standard was significantly different from the test pattern at a probability of less than .01 (Mann-Whitney U-test). It can therefore be concluded that bees can and do distinguish between all eight simple patterns.

Although the bees were able to discriminate between standard and test patterns in every case, it was noted that within each group of seven test patterns certain test figures were visited with unequal frequency by the bees. An ANOVA demonstrated that there was a significant difference between patterns in each group of 7 patterns (Tables 1-8). A posteriori testing (Student-Newman-Kuels Test) showed statistically those test patterns between which there were no differences to the bees (Tables 1-8). The bees did not distinguish between the circle and the square in five out of six tests in which neither served as the standard (in which the triangle, open square, Y, cross, and four bars were standards).

In four out of six tests (bar, square, cross, and Y as standards), the circle and the triangle were regarded as the same. The hollow square and the four parallel bars were perceived to be equivalent in all six tests in which neither was the training pattern. Four tests out of six (bar, square, triangle, and hollow square as standards) demonstrated that the bees did not discriminate between the cross and the four parallel bars when they had been trained to another pattern.

The bees tended to differentiate more between solid shapes than broken ones. In each of the four tests where a solid figure was the standard, at least three of the broken patterns were perceived as equivalent by the bees. When the bees were trained to the four broken patterns, three or more solid patterns were treated equally in only two tests. In the other two tests, no more than two of the solid shapes were considered equivalent. It should be noted that a sample size of five or six might be too small to point out subtle differences.

Separate test revealed the relative importance of horizontal and vertical components of pattern recognition. Figure 23 shows the results of testing bees which were trained to a solid square. The left shape, the vertical components of the hollow square, was the standard. More bees chose the horizontal bars than the vertical ones, and when given a choice between the hollow square and the vertical bars, more chose the hollow square. Figure 24 illustrates the results of a test where bees were trained to a solid square and given a choice between a vertical and a horizontal rectangle. The horizontal rectangle was preferred. When trained to the hollow square and offered the horizontal and vertical components of the shape as the only choices, as in Figure 25, a significant number of bees chose the horizontal bars. The cross was the training pattern in Figure 26. When tested with the horizontal and vertical bar, more than fifty percent of the bees chose the horizontal bar in each of the six test runs. From the above tests, it can be concluded that a significant number of bees find the horizontally oriented figure more closely resembles the training pattern.

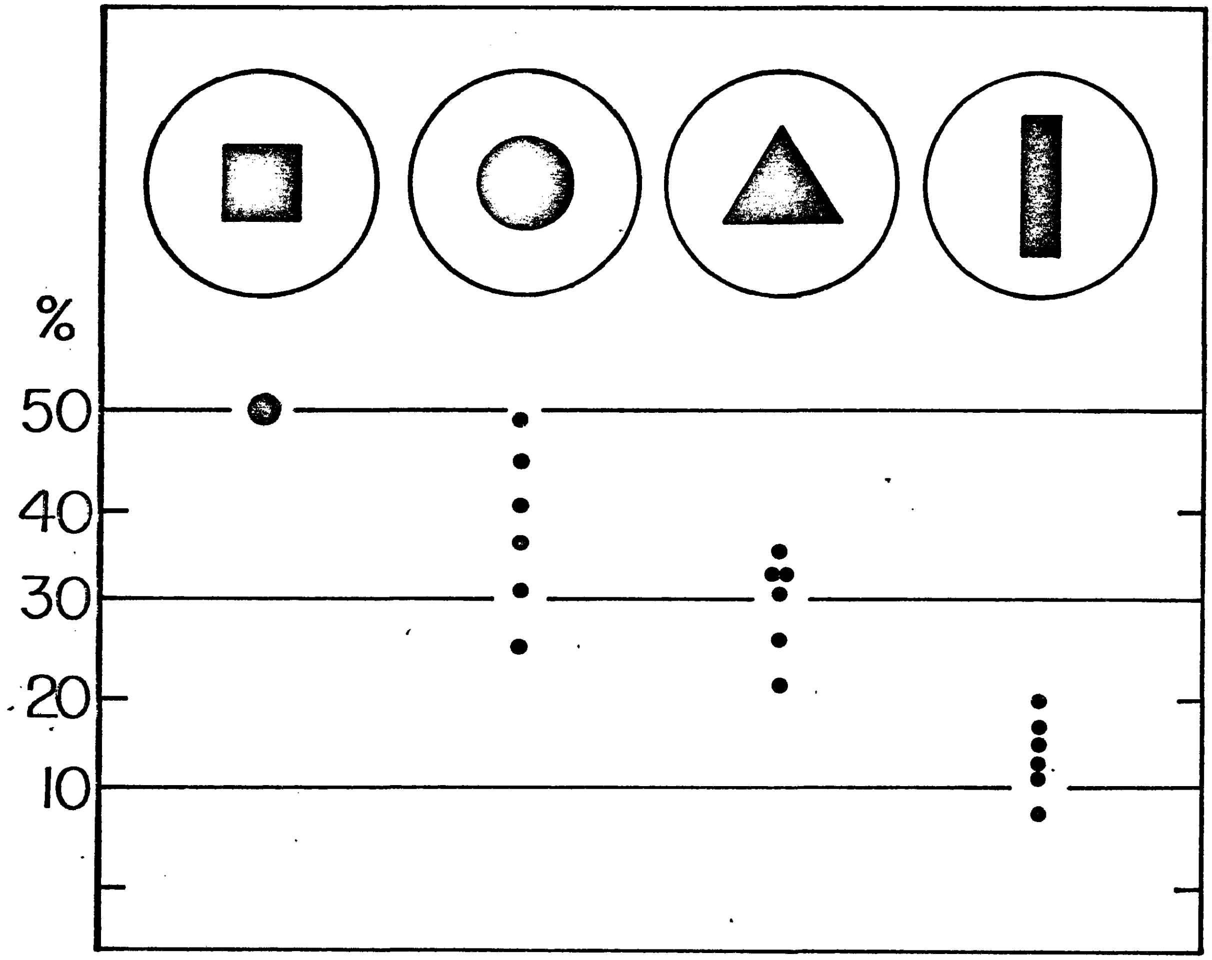


FIGURE 7: Bees were trained to the square which served as the standard against which the three solid shapes were tested. Note that less than fifty percent of the bees chose the test pattern in each case. Each point represents the percent choice of 100 bees.

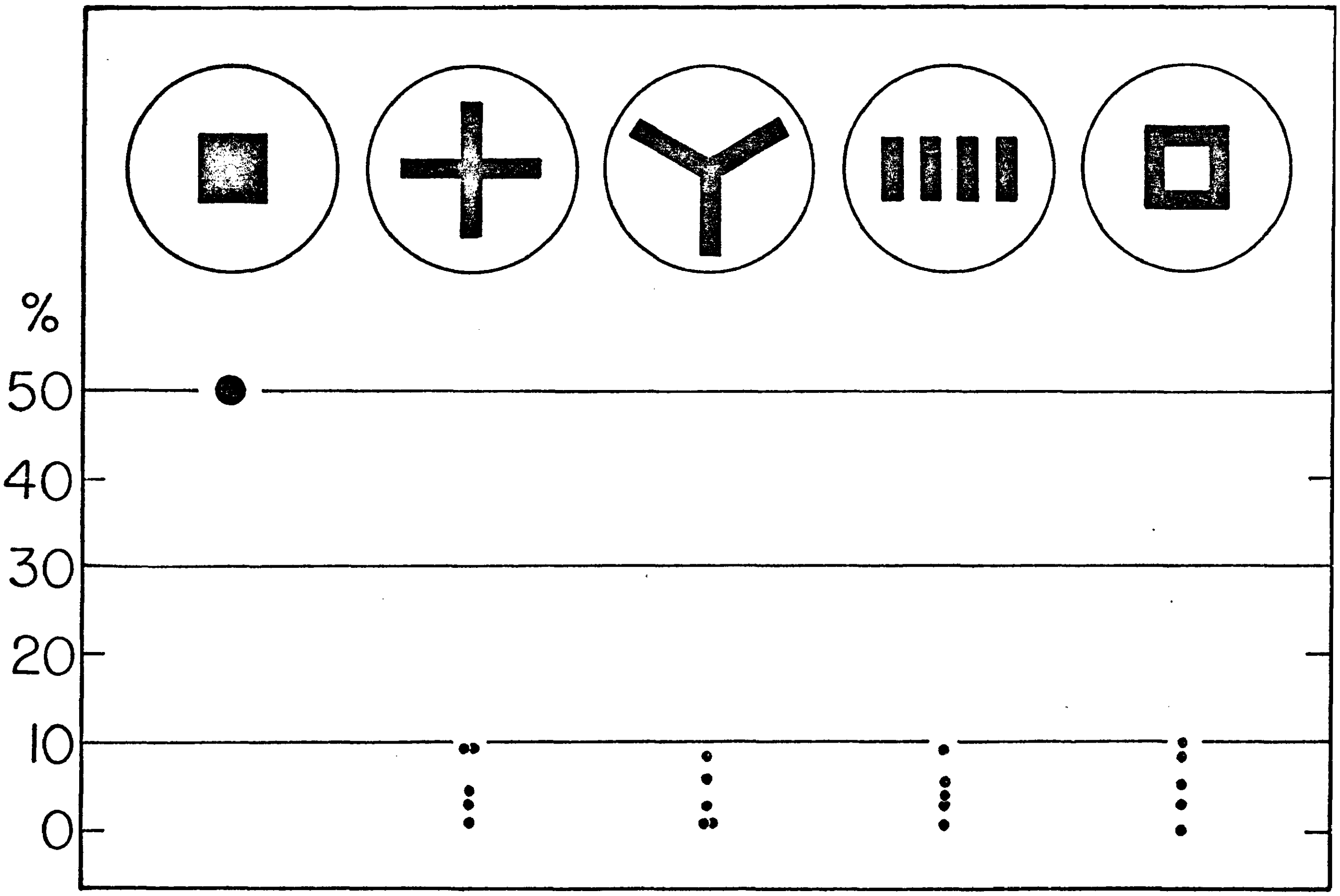


FIGURE 8: Results of testing bees trained to the square, using the square as the standard. Each point represents the percent choice of 100 bees.

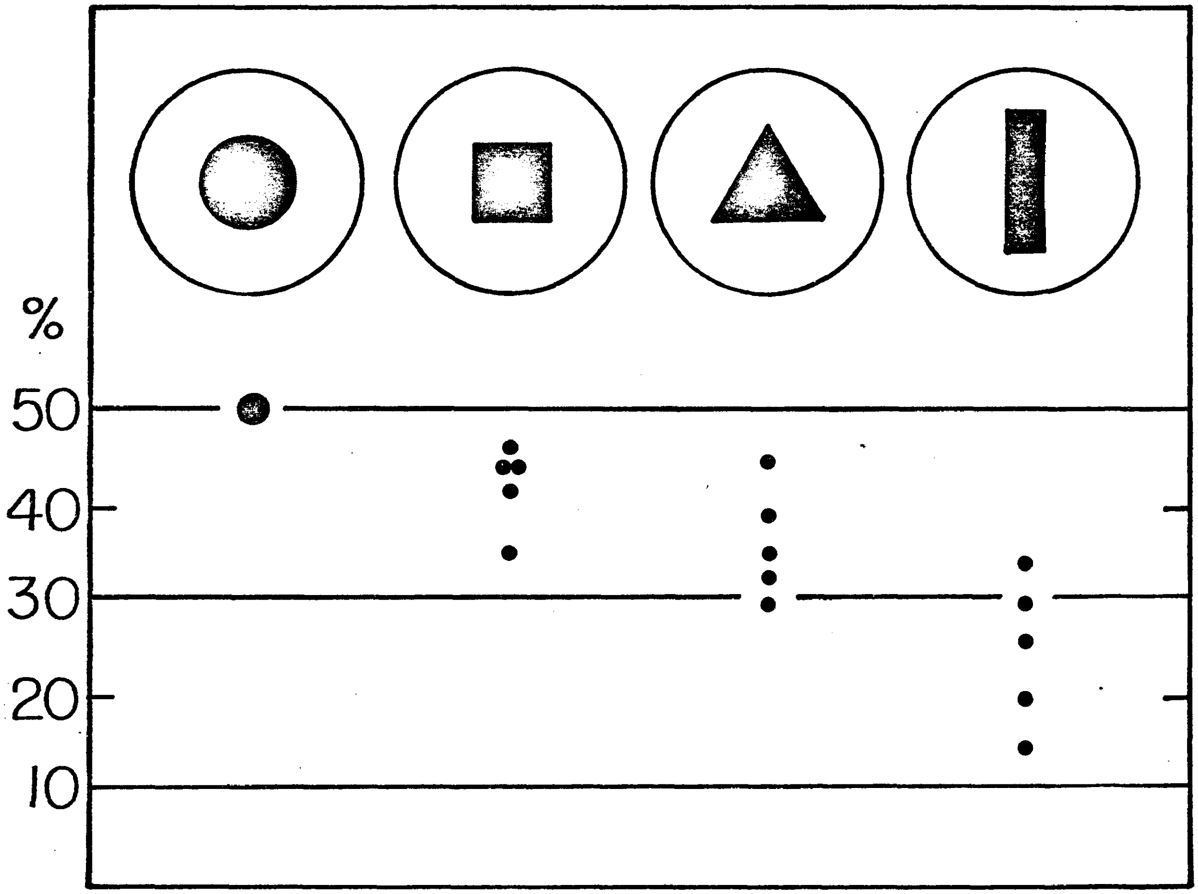


FIGURE 9: Results of testing bees trained to the circle, using the circle as the standard. Each point represents the percent choice of 100 bees.

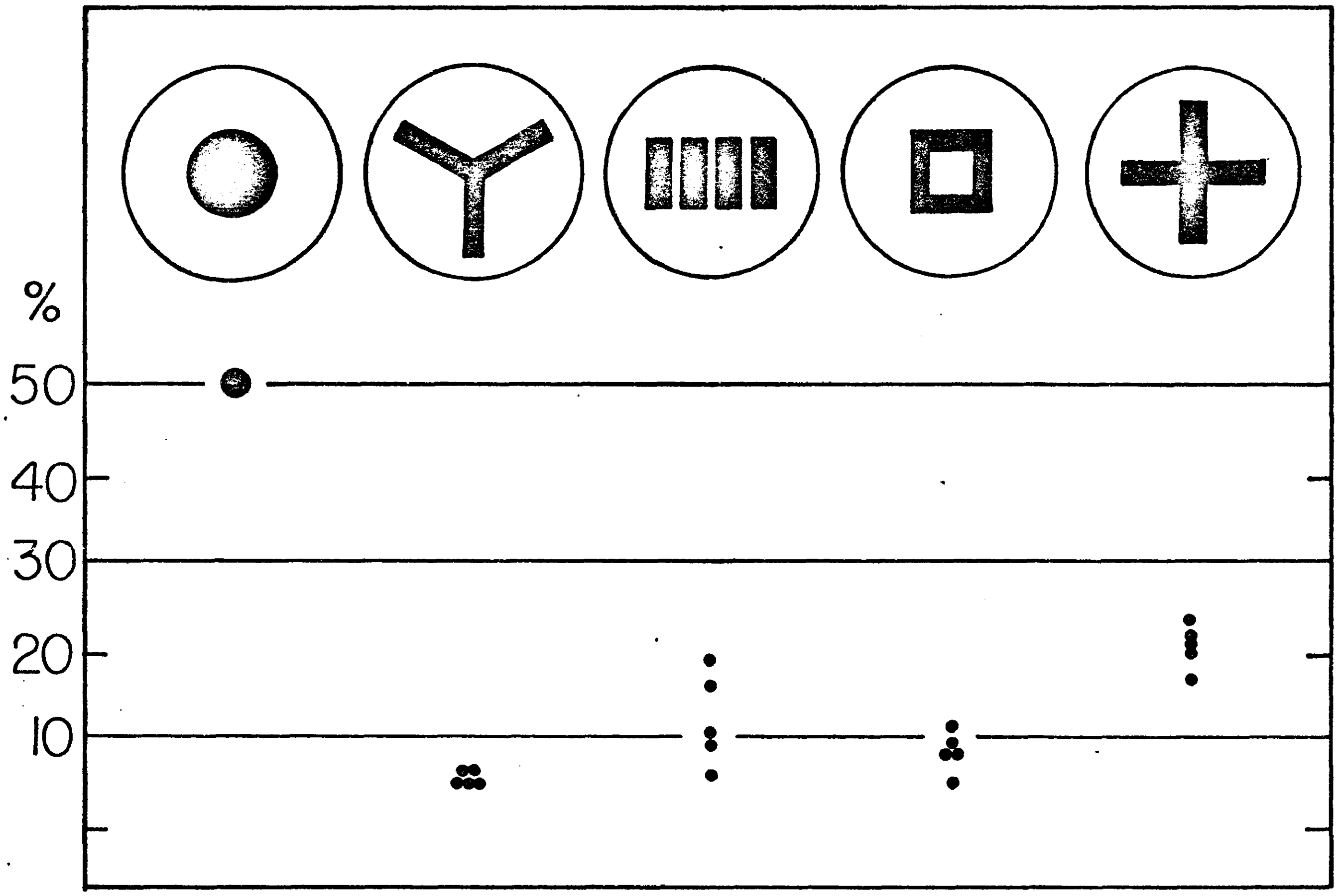


FIGURE 10: Results of testing bees trained to the circle, using the circle as the standard. Each point represents the percent choice of 100 bees.

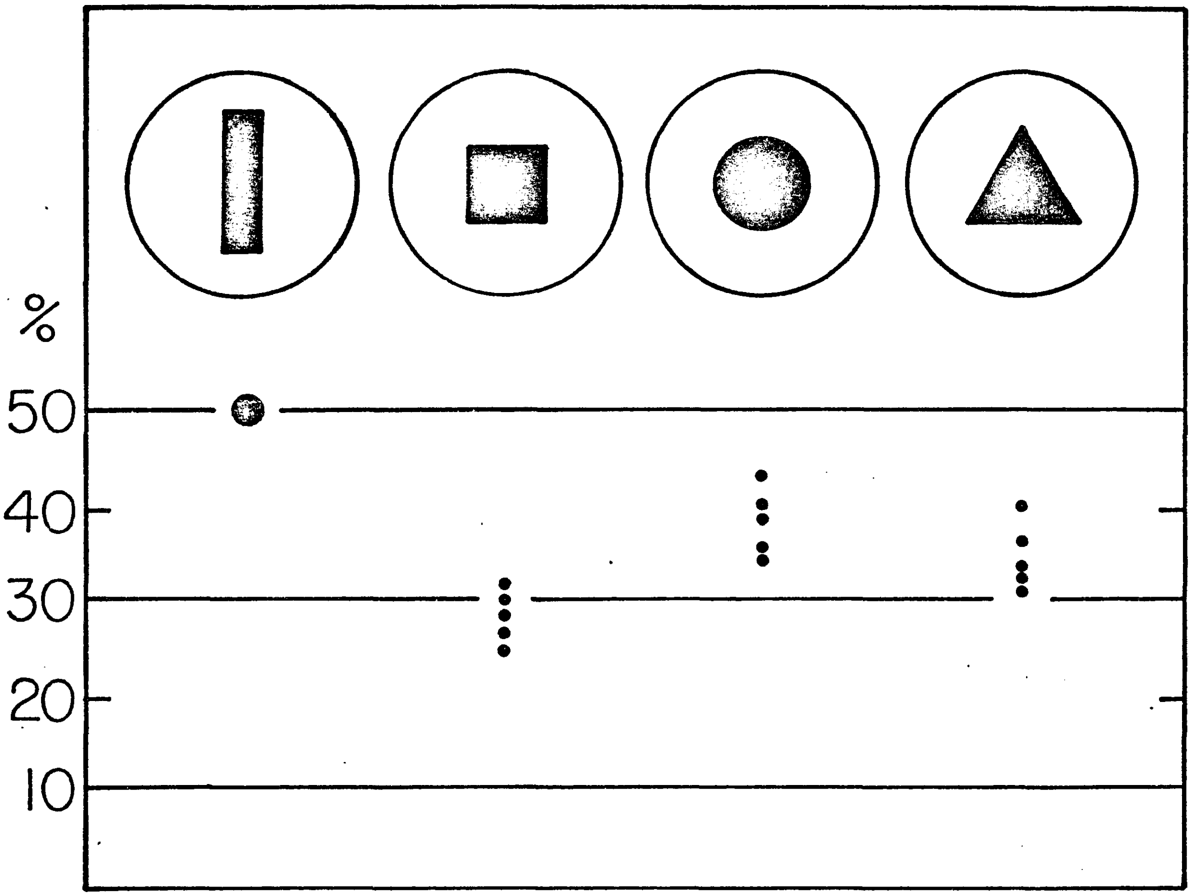


FIGURE 11: Results of testing bees trained to the bar, using the bar as the standard. Each point represents the percent choice of 100 bees.

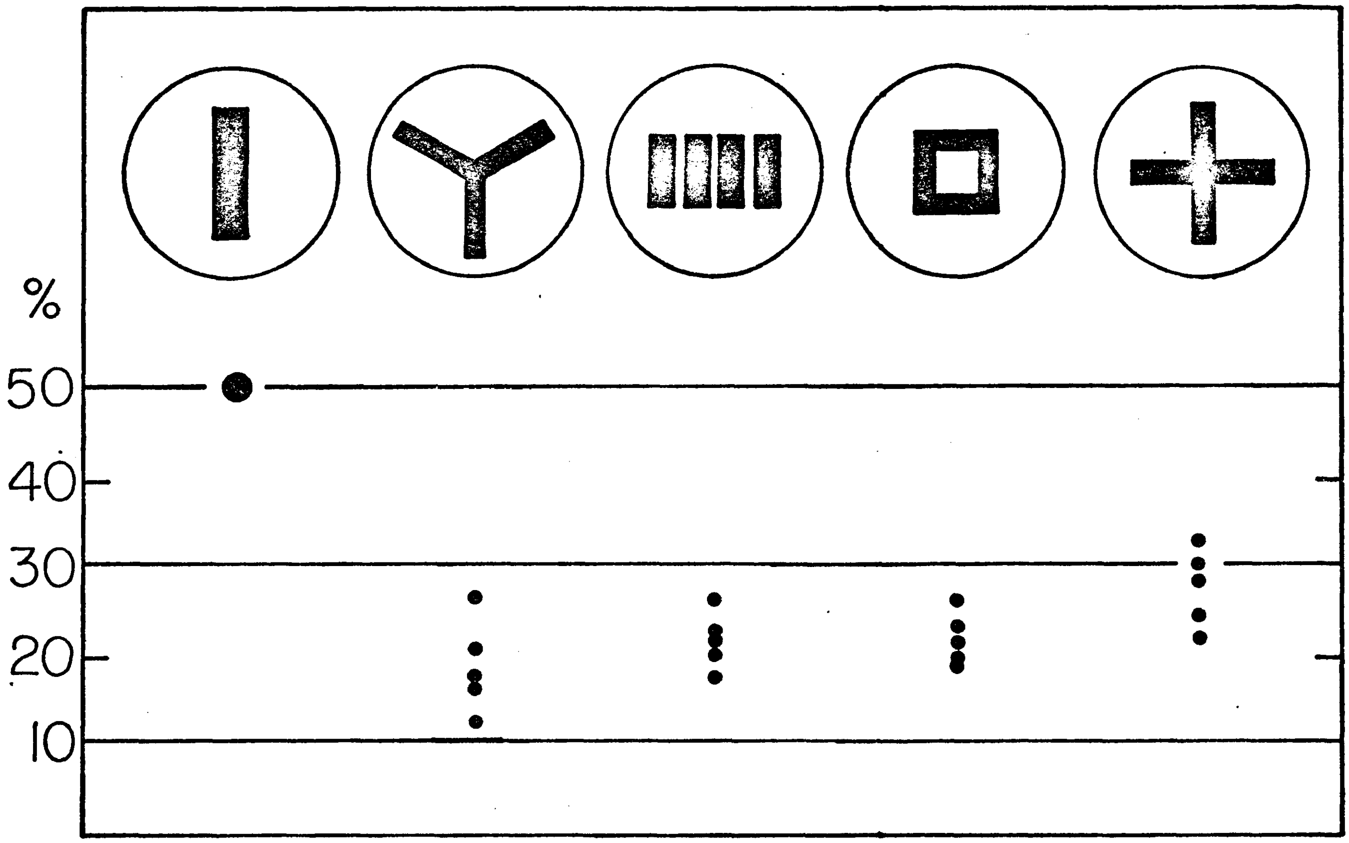


FIGURE 12: Results of testing bees trained to the bar, using the bar as the standard. Each point represents the percent choice of 100 bees.

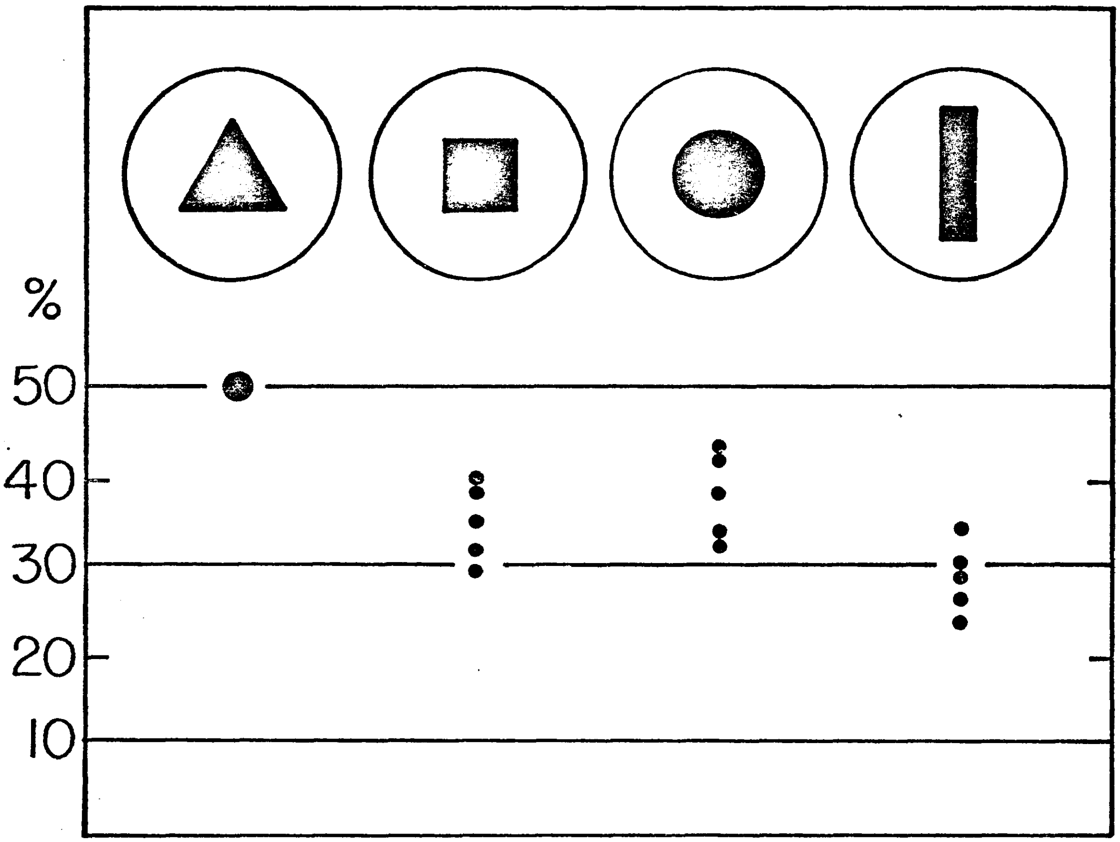


FIGURE 13: Results of testing bees trained to the triangle, using the triangle as the standard. Each point represents the percent choice of 100 bees.

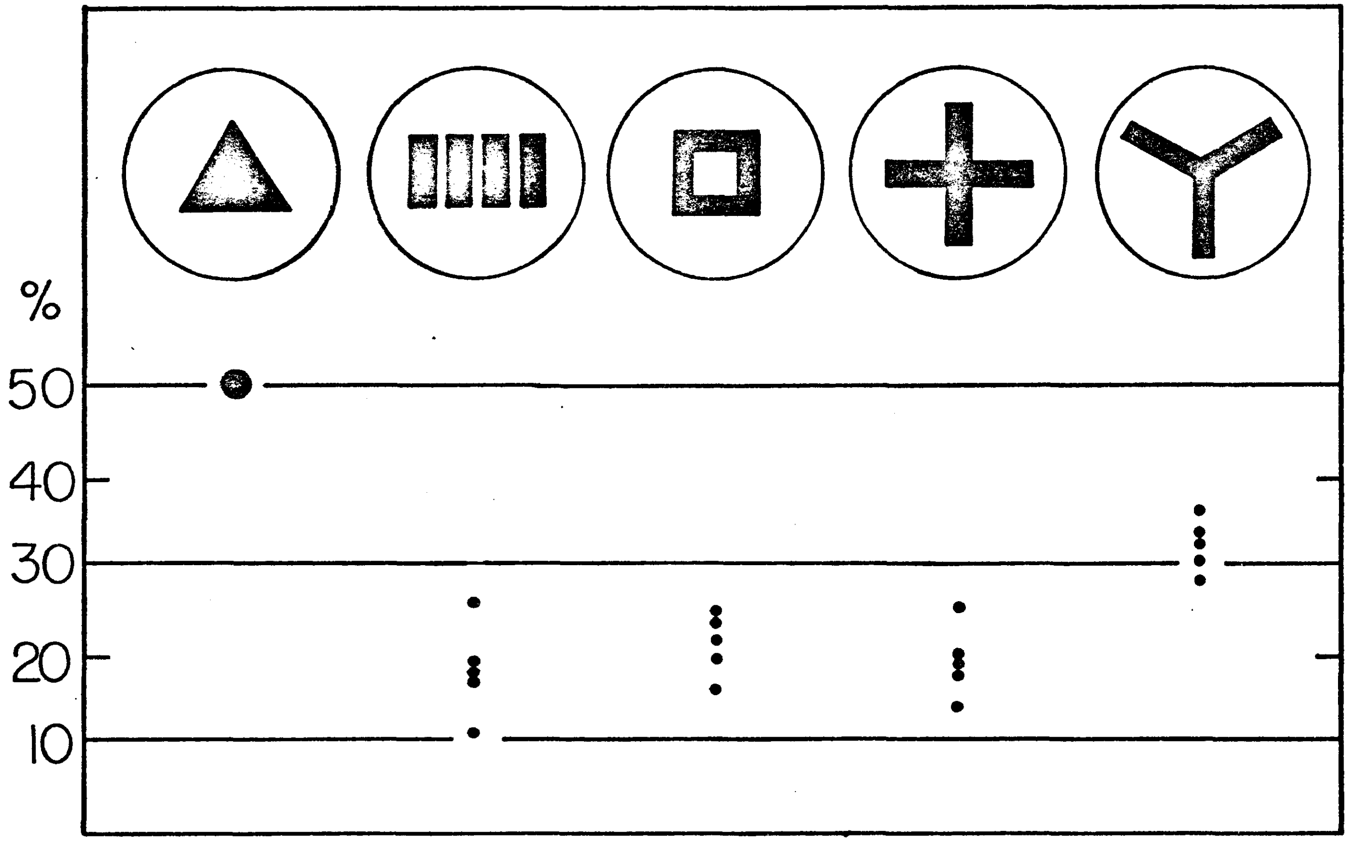


FIGURE 14: Results of testing bees trained to the triangle, using the triangle as the standard. Each point represents the percent choice of 100 bees.

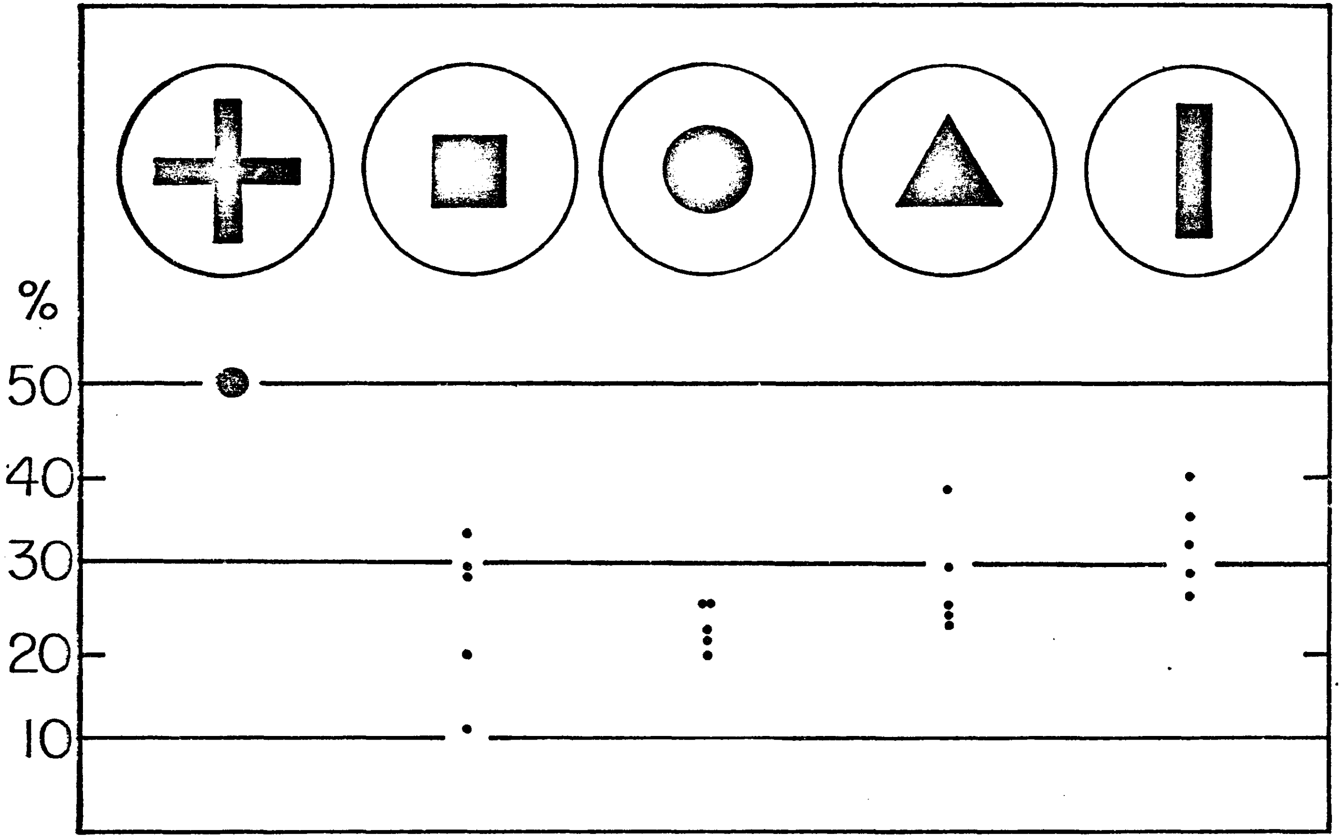


FIGURE 15: Results of testing bees trained to the cross, using the cross as the standard. Each point represents the percent choice of 100 bees.

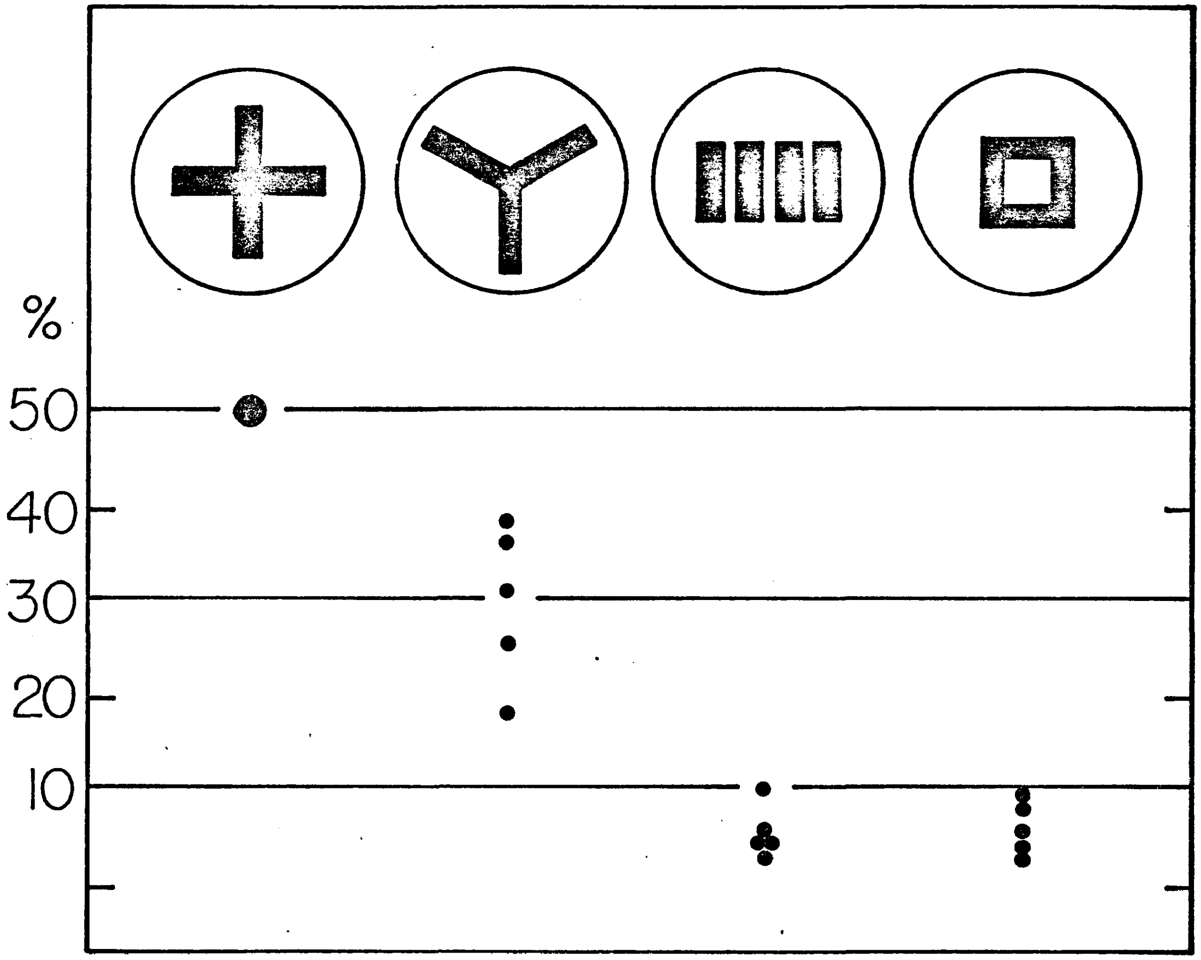


FIGURE 16: Results of testing bees trained to the cross, using the cross as the standard. Each point represents the percent choice of 100 bees.

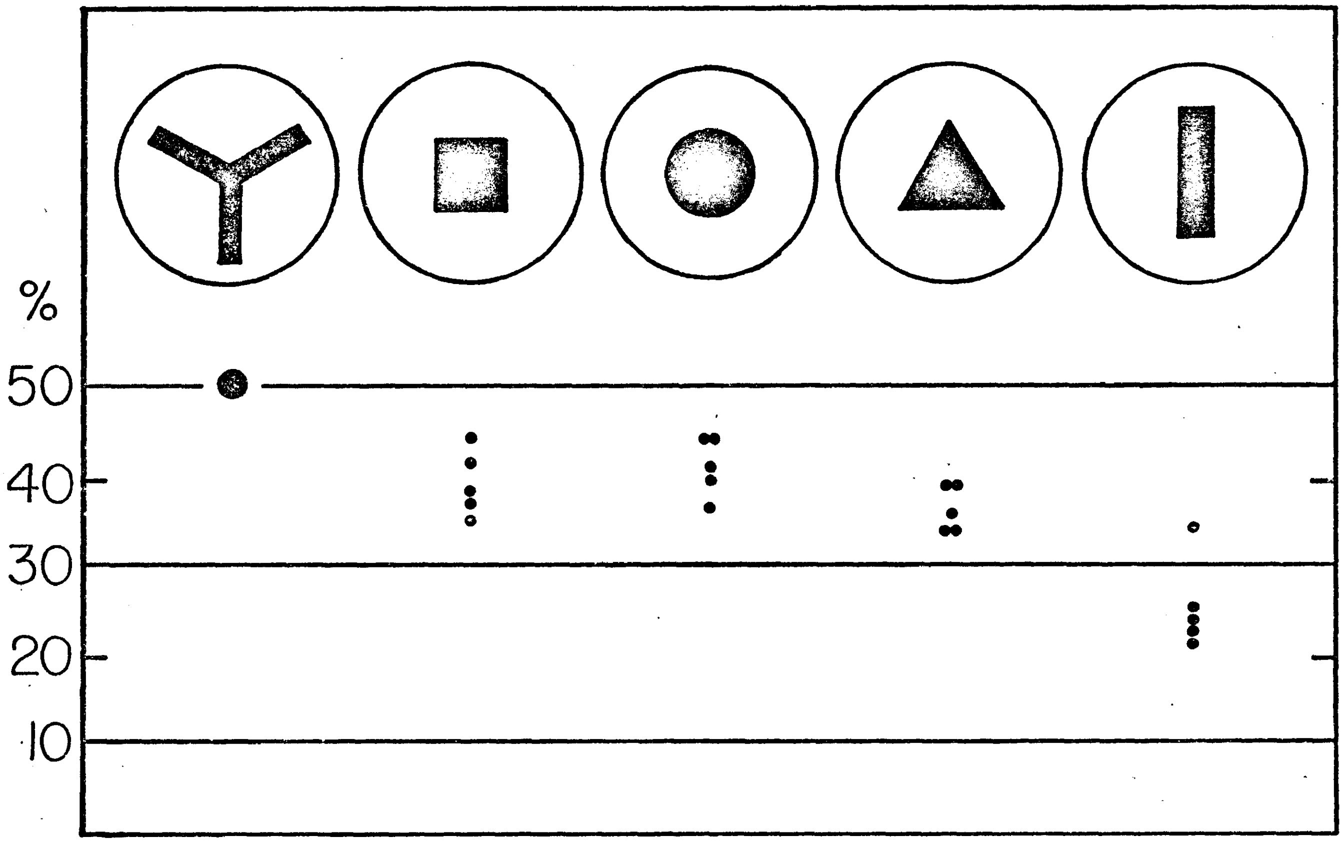


FIGURE 17: Results of testing bees trained to the Y, using the Y as the standard. Each point represents the percent choice of 100 bees.

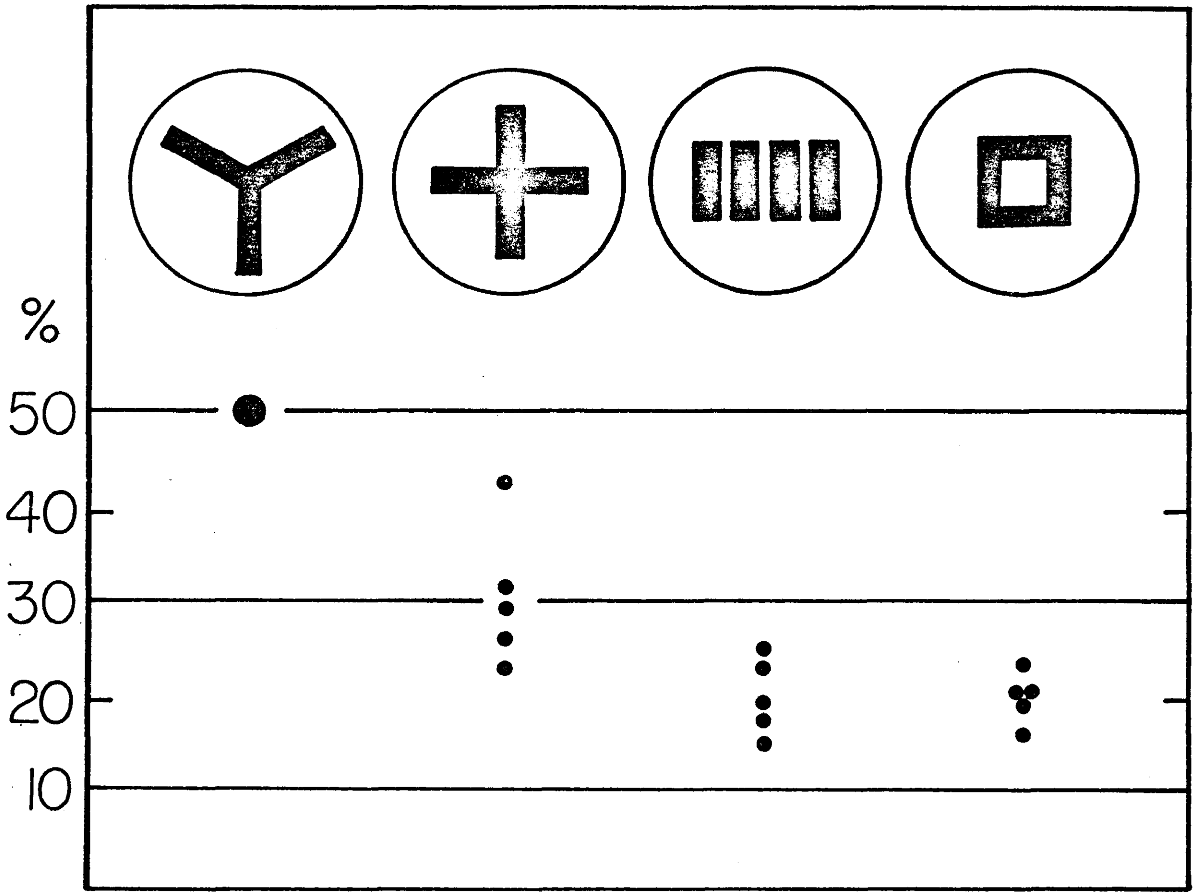


FIGURE 18: Results of testing bees trained to the Y, using the Y as the standard. Each point represents the percent choice of 100 bees.

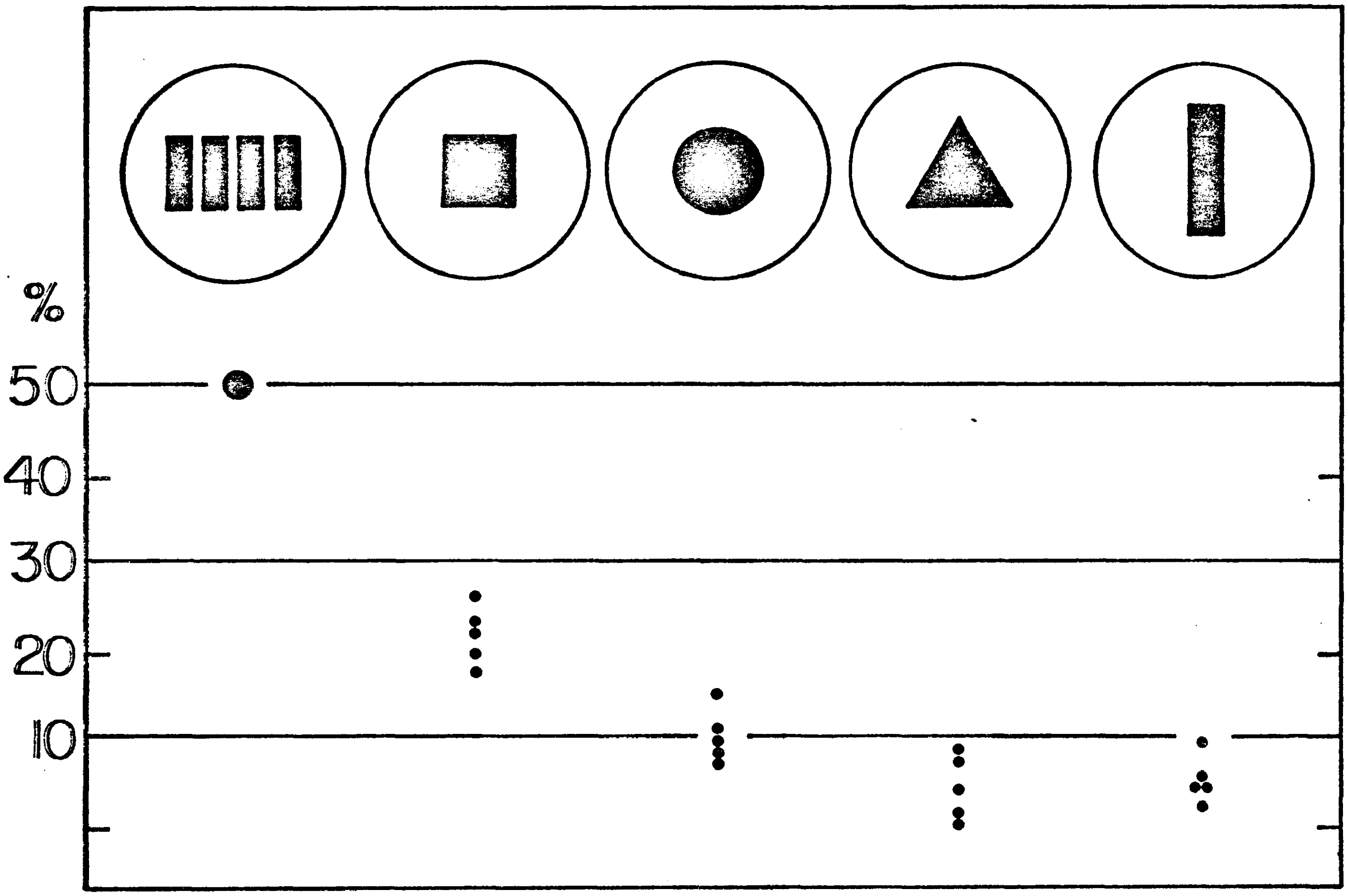


FIGURE 19: Results of testing bees trained to the four parallel bars, using the four parallel bars as the standard. Each point represents the percent choice of 100 bees.

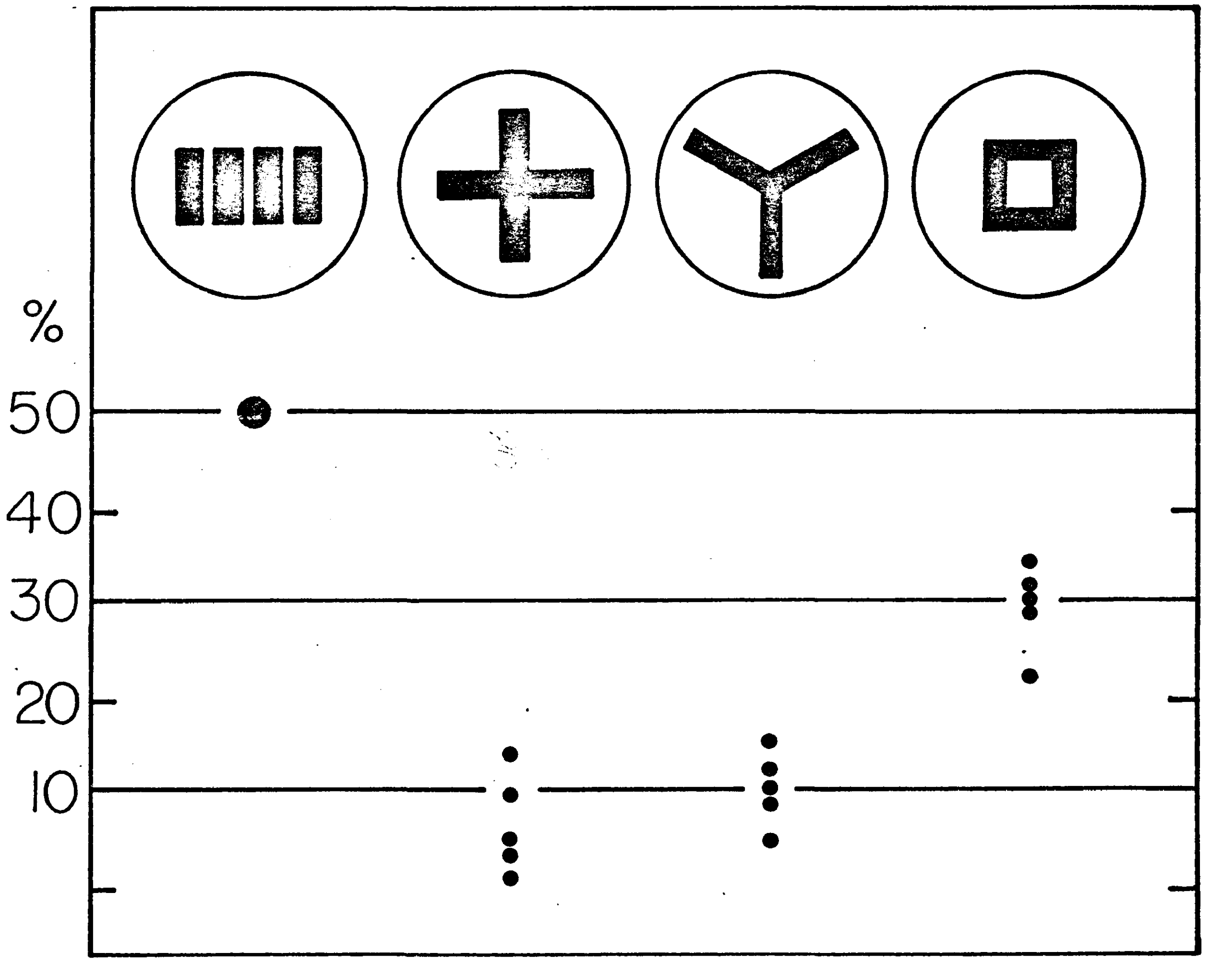


FIGURE 20: Results of testing bees trained to the four parallel bars, using the four parallel bars as the standard. Each point represents the percent choice of 100 bees.

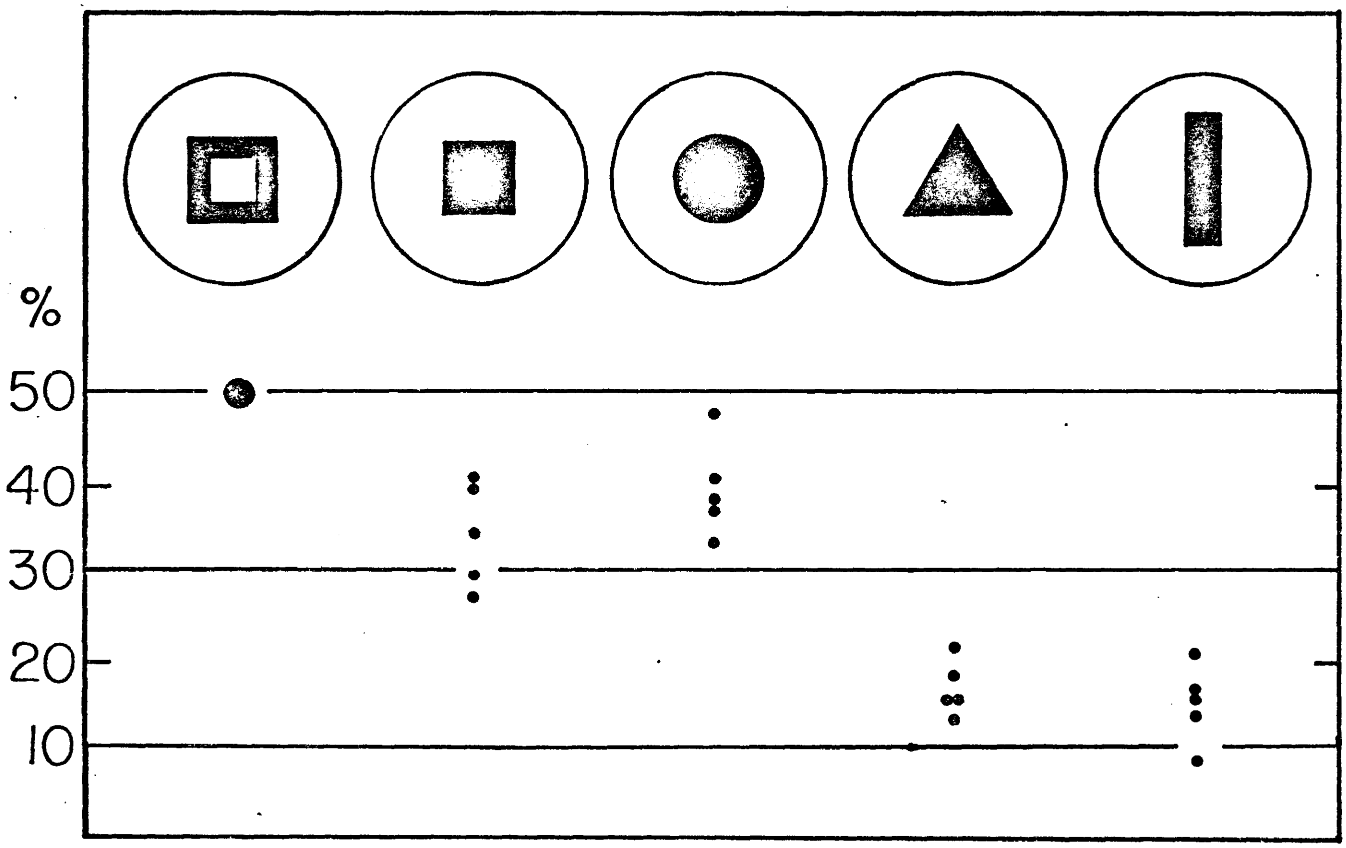


FIGURE 21: Results of testing bees trained to the hollow square, using the hollow square as the standard. Each point represents the percent choice of 100 bees.

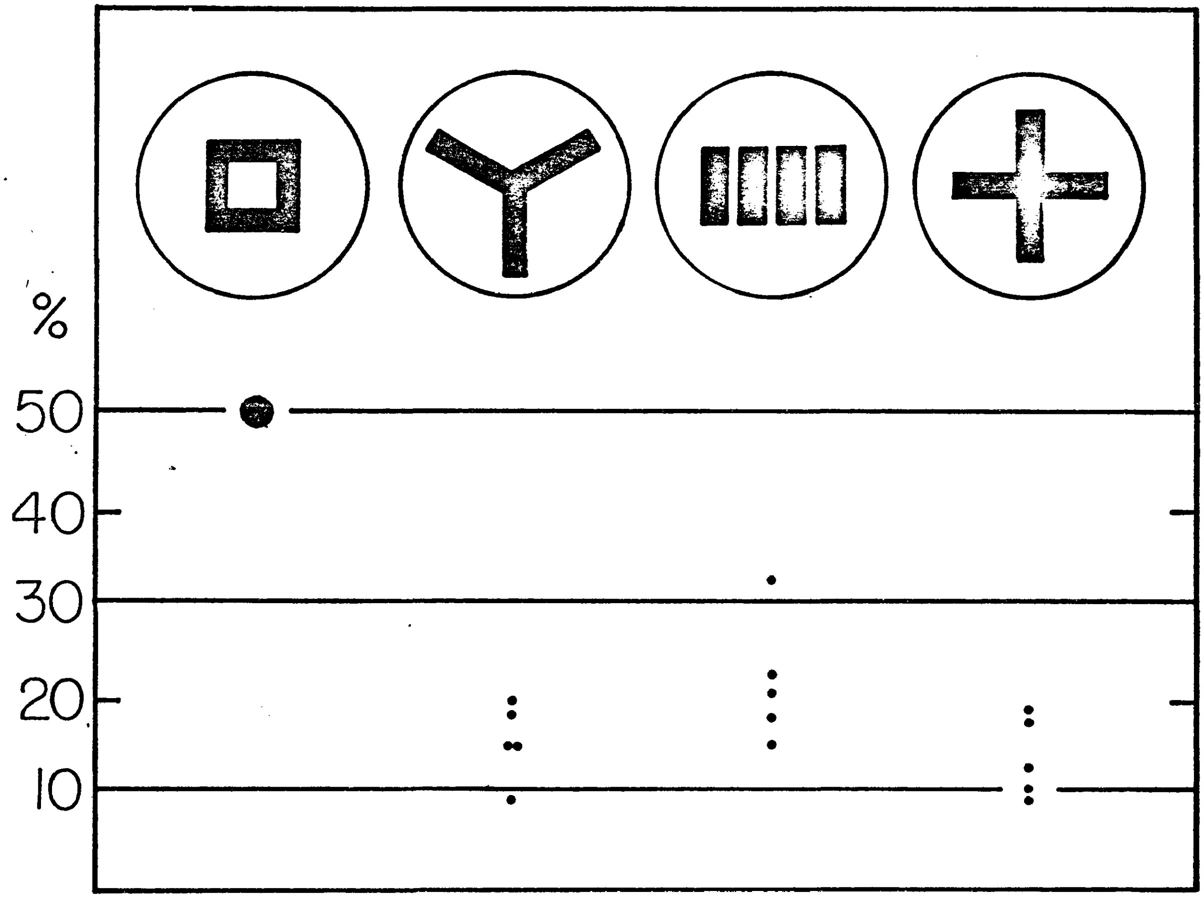


FIGURE 22: Results of testing bees trained to the hollow square, using the hollow square as the standard. Each point represents the percent choice of 100 bees.

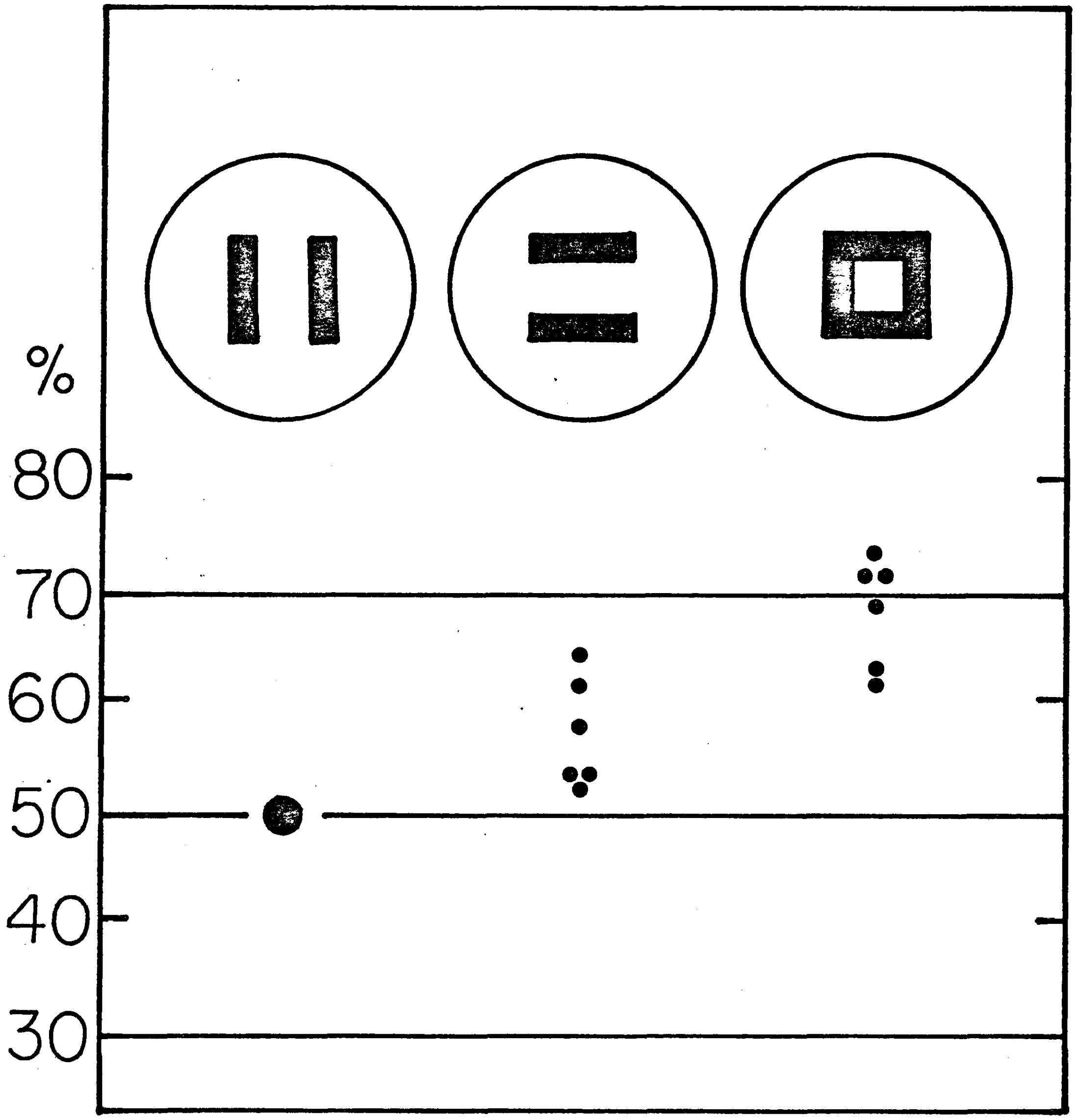


FIGURE 23: Results of testing bees trained to the solid square, using the vertical components of the hollow square as the standard. Each point represents the percent choice of 100 bees.

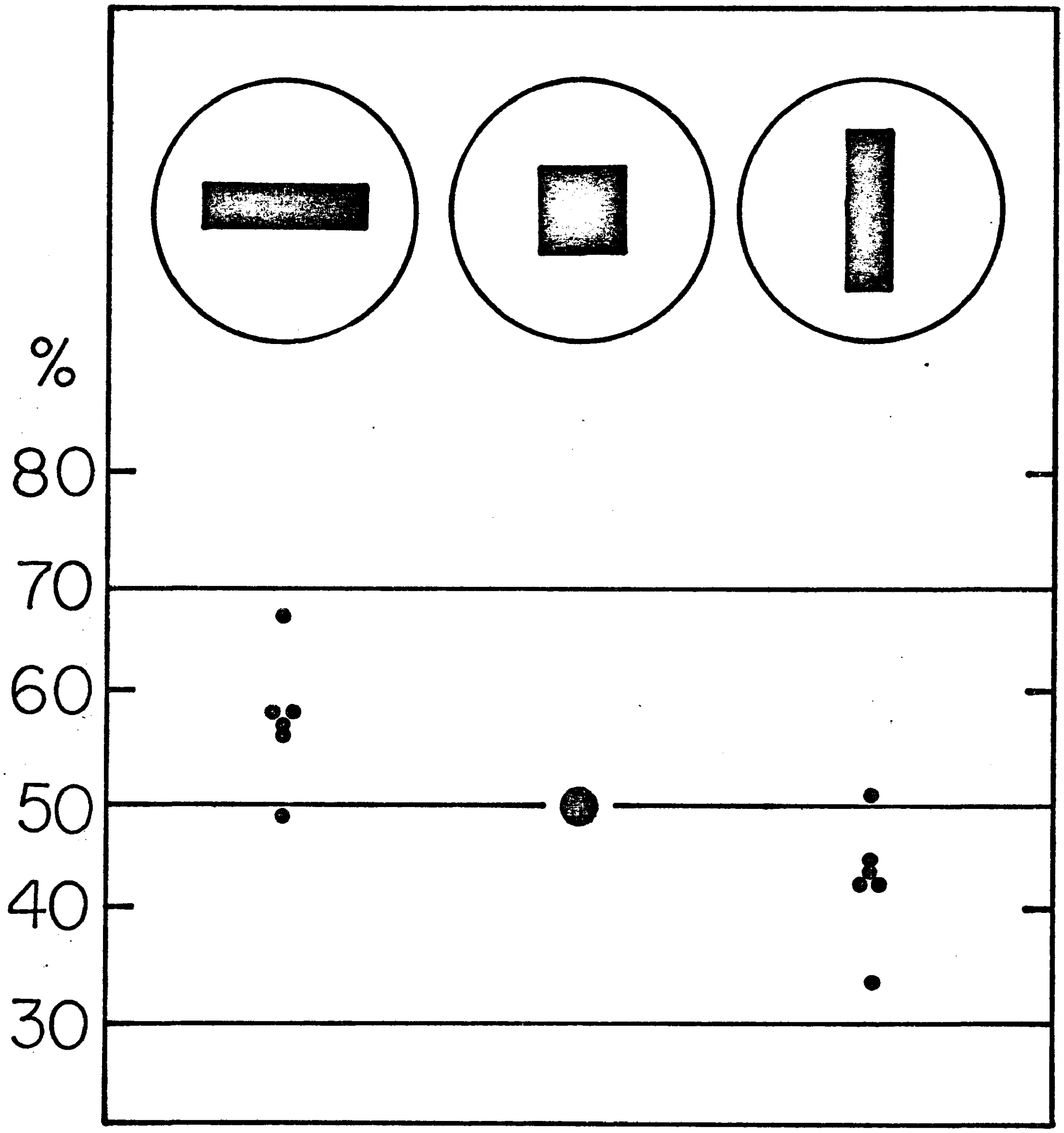


FIGURE 24: Results of testing bees trained to the solid square, given a choice between a horizontal and vertical rectangle. Each point represents the percent choice of 100 bees.

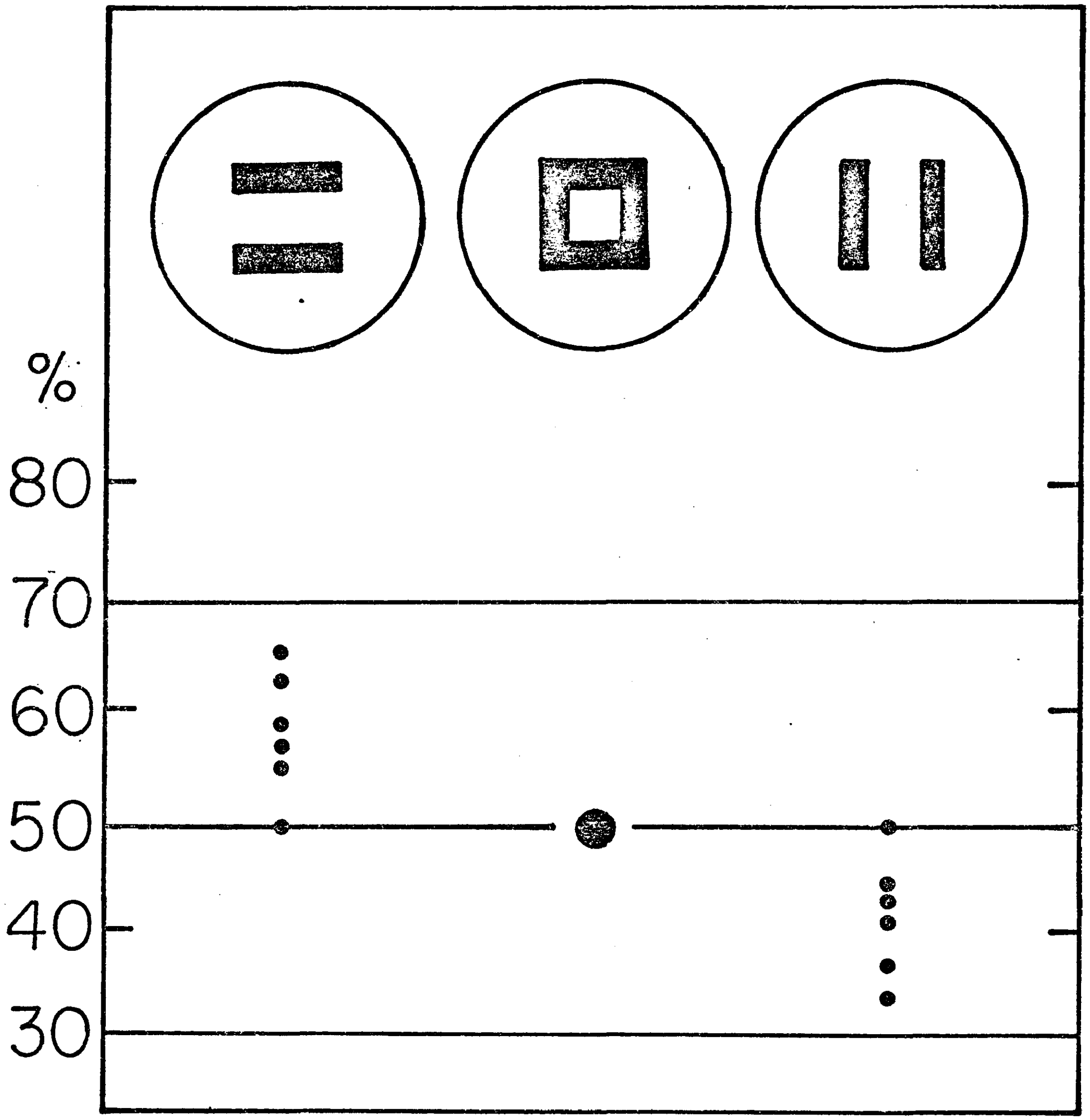


FIGURE 25: Results of testing bees trained to the hollow square, given the horizontal and vertical components of the shape as choices. Each point represents the percent choice of 100 bees.

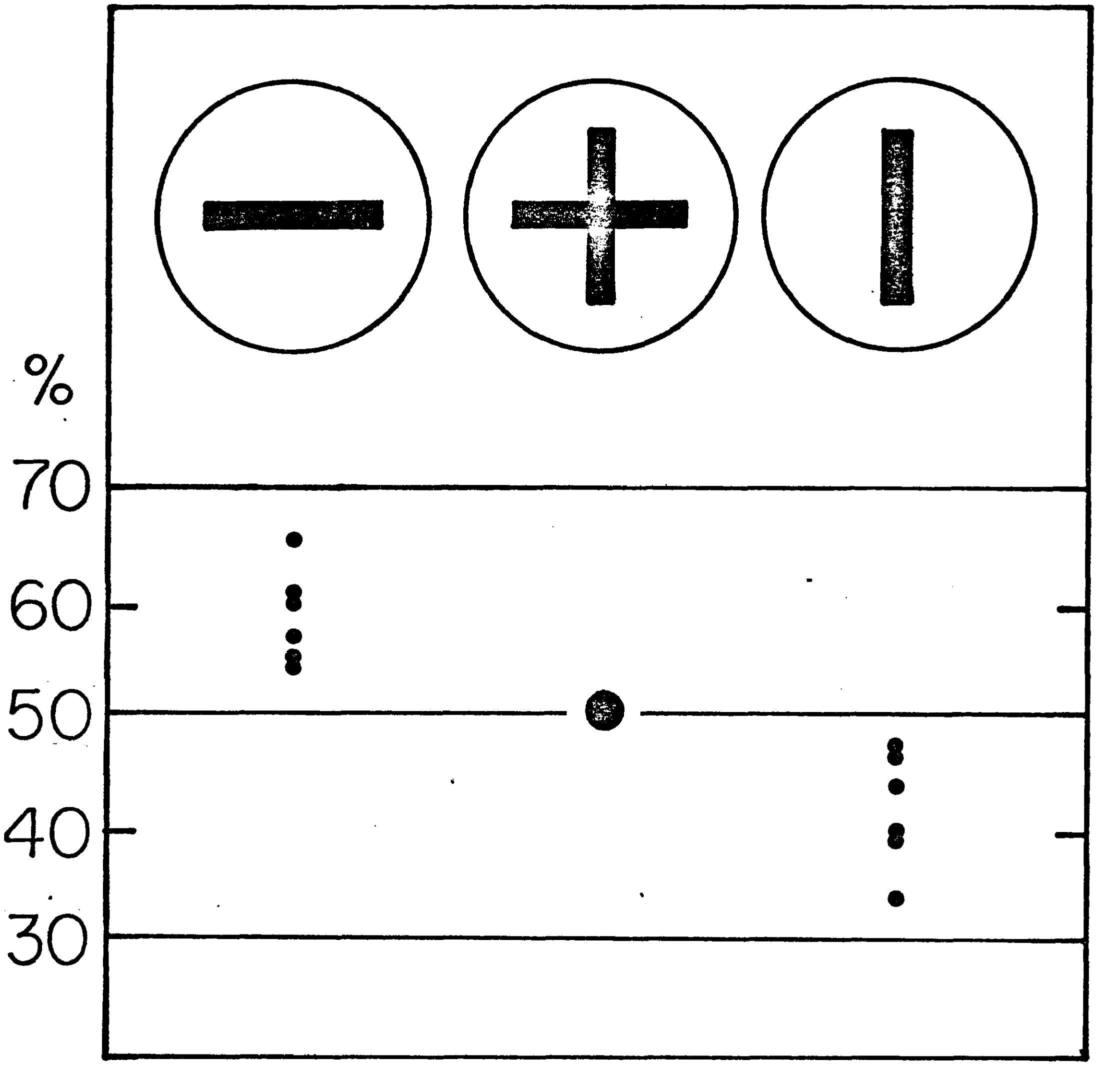


FIGURE 26: Results of testing bees trained to the cross, given a choice between the horizontal and vertical bar. Each point represents the percent choice of 100 bees.

Table 1. ANOVA table for test where bar was the standard.

Results of A posteriori test on same data.

ANOVA TABLE

LEVEL	SS	DF	MS	FS
1	663.042	6	110.5070	16.2453
0	190.467	28	6.8024	

Significant at $p < .005$

A posteriori test: Student-Newman-Keuls Test

Table of Sorted Means (Data in arcsine units):

Sample	N	Mean	Standard Error
Y	5	25.4949	0.90416
Bars	5	28.0631	0.96478
Hollow square	5	28.3411	1.04181
Cross	5	31.6534	1.90022
Square	5	31.9200	1.00645
Triangle	5	36.3687	0.98183
Circle	5	38.6311	1.04972

Maximum Nonsignificant Ranges:

Subset	Samples
1	Bars through square
2	Y through hollow square
3	Triangle and circle

Significant at $p < .05$

Table 2. ANOVA table for test where circle was the standard.

Results of A posteriori test on same data.

ANOVA TABLE

LEVEL	SS	DF	MS	FS
1	3000.433	6	500.0720	41.8187
0	334.827	28	11.9581	

Significant at p < .001

A posteriori test: Student-Newman-Keuls Test

Table of Sorted Means (Data in arcsine units):

Sample	N	Mean	Standard Error
Y	5	14.6440	1.17861
Hollow square	5	16.5216	1.62498
Bars	5	19.8983	2.52322
Cross	5	27.0992	0.28485
Bar	5	29.3216	2.11753
Triangle	5	36.9382	1.04807
Square	5	40.6111	0.82552

Maximum Nonsignificant Ranges:

Subset	Samples
1	Y through bars
2	Cross through bar
3	Triangle and square

Significant at p < .05

Table 3. ANOVA table for test where square was the standard.

Results of A posteriori test on same data.

ANOVA TABLE

LEVEL	SS	DF	MS	FS
1	4382.066	6	730.3442	29.9795
0	755.206	31	24.3615	

Significant at $p < .001$

A posteriori test: Student-Newman-Keuls Test

Table of Sorted Means (Data in arcsine units):

Sample	N	Mean	Standard Error
Y	5	10.7248	2.15471
Bars	5	11.5258	1.29915
Hollow square	5	11.7575	1.58547
Cross	5	12.4331	2.17774
Bar	5	21.3181	1.91083
Triangle	5	33.0387	3.31551
Circle	5	38.0513	2.25997

Maximum Nonsignificant Ranges:

Subset	Samples
1	Y through cross
2	Triangle and square

Significant at $p < .05$

Table 4. ANOVA table for test where triangle was the standard.
Results of A posteriori test on same data.

ANOVA TABLE

LEVEL	SS	DF	MS	FS
1	773.670	6	128.9450	13.7666
0	262.262	28	9.3665	

Significant at $p < .005$

A posteriori test: Student-Newman-Keuls Test

Table of Sorted Means (Data in arcsine units):

Sample	N	Mean	Standard Error
Bars	5	25.1944	1.30047
Cross	5	25.8597	1.33448
Hollow square	5	27.8917	1.04807
Bar	5	32.4205	0.92888
Y	5	34.4271	1.90295
Square	5	36.1128	1.28544
Circle	5	37.7881	1.55118

Maximum Nonsignificant Ranges:

Subset	Samples
1	Bars through hollow square
2	Bar through square
3	Y through circle

Significant at $p < .05$

Table 5. ANOVA table for test where Y was the standard.

Results of A posteriori test on same data.

ANOVA TABLE

LEVEL	SS	DF	MS	FS
1	900.200	6	150.0333	17.8741
0	235.028	28	8.3939	

Significant at $p < .001$

A posteriori test: Student-Newman-Keuls Test

Table of Sorted Means (Data in arcsine units):

Sample	N	Mean	Standard Error
Bars	5	26.7542	0.97082
Hollow square	5	26.8053	0.98761
Bar	5	30.3185	1.03246
Cross	5	33.6064	1.44444
Triangle	5	36.3678	1.98690
Square	5	38.7487	1.36676
Circle	5	40.1517	0.93023

Maximum Nonsignificant Ranges:

Subset	Samples
1	Bars through bar
2	Triangle through circle
3	Bar and cross
4	Cross and triangle

Significant at $p < .05$

Table 6. ANOVA table for test where four parallel bars was the standard.

Results of A posteriori test on same data.

ANOVA TABLE

LEVEL	SS	DF	MS	FS
1	1913.398	6	318.8997	24.9134
0	358.410	28	12.8003	

Significant at $p < .001$

A posteriori test: Student-Newman-Keuls Test

Table of Sorted Means (Data in arcsine units):

Sample	N	Mean	Standard Error
Triangle	5	11.7124	1.08174
Bar	5	13.4905	1.30821
Cross	5	14.2360	2.06640
Circle	5	18.2771	1.20881
Y	5	18.3736	2.28321
Square	5	28.1935	1.63762
Hollow square	5	32.9140	1.18862

Maximum Nonsignificant Ranges:

Subset	Samples
1	Bar through Y
2	Triangle through cross

Significant at $p < .05$

Table 7. ANOVA table for test where hollow square was the standard. Results of A posteriori test on same data.

ANOVA TABLE

LEVEL	SS	DF	MS	FS
1	1423.536	6	237.2560	17.9645
0	369.794	28	13.2069	

Significant at $p < .001$

A posteriori test: Student-Newman-Keuls Test

Table of Sorted Means (Data in arcsine units):

Sample	N	Mean	Standard Error
Cross	5	21.4213	1.70917
Bar	5	22.7211	1.36733
Y	5	22.9399	1.12230
Triangle	5	24.2733	1.79252
Bars	5	27.6547	1.54803
Square	5	35.7209	1.96890
Circle	5	38.7357	1.71849

Maximum Nonsignificant Ranges:

Subset	Samples
1	Cross through bars
2	Square and circle

Significant at $p < .05$

Table 8. ANOVA table for test where cross was the standard.

Results of A posteriori test on same data.

ANOVA TABLE

LEVEL	SS	DF	MS	FS
1	2347.643	6	391.2737	24.8627
0	440.647	28	15.7374	

Significant at $p < .001$

A posteriori test: Student-Newman-Keuls Test

Table of Sorted Means (Data in arcsine units):

Sample	N	Mean	Standard Error
Hollow square	5	13.9155	2.80076
Bars	5	13.9985	0.93838
Square	5	29.1054	1.57884
Circle	5	29.1616	1.39717
Triangle	5	32.1261	2.33483
Y	5	32.9042	1.18524
Bar	5	34.7683	1.41650

Maximum Nonsignificant Ranges:

Subset	Samples
1	Square through bar
2	Hollow square and cross

Significant at $p < .05$

DISCUSSION

The results conclusively demonstrate that honeybees can discriminate between simple geometric patterns. Hertz and others tested bees at feeding stations where the patterns were placed horizontally. The design of this work placed patterns vertically, adding the dimensions of up and down and left and right to the bees' perception of the shape. The innate preference of the homing bee for unbroken patterns possibly aided the bees in learning the simple shapes. Mazokhin-Porshnyakov stated that Hertz's figures were too large relative to the size of the bee for discrimination. Figures used in these tests were larger than those employed by Hertz; for example, her circle had an area of 23.75 cm^2, whereas mine was 224.20 cm^2. Therefore, at least in this method of testing, the size of the patterns does not prevent the bees from discriminating between them.

It is possible that when bees are tested at feeding stations it is necessary to train them to figures of increasingly less contour density in order to have them distinguish simple shapes (Anderson, 1972). It was observed in this work that homing bees tended to differentiate more between the solid patterns than they did between the broken ones. In spite of this preference for solid shapes, however, they had no trouble distinguishing between the broken patterns. The fact that among test patterns solid figures were less often considered equivalent when being tested against broken patterns than broken ones were when being tested against solid patterns tends to support the preference of homing bees for simple shapes.

The similarity in treatment of some of the test patterns might be explained by equivalent amounts of contour density or by the gross similarity of the shapes. The square and the circle, and the circle and the triangle closely approximate one another in both these respects. The hollow square and the four parallel bars have similar vertical components and nearly equal broken area. Although the cross and the four parallel bars both have vertical elements, they seem to lack an overall resemblance in shape, and the four bars would appear to have a higher contour density. It may be that the trends illustrated rely on more factors than contour density and a general likeness in shape.

When bees were trained to a pattern and then given a choice between two identical shapes, one oriented vertically and the other oriented horizontally, in all cases they chose the horizontal figure. The design of these tests did not permit conclusions to be made regarding whether this observation relates to the dorsoventral asymmetry of the honeybee's visual field as described by Wehner (1972). It does lend support to Anderson's findings that bees make more horizontal than vertical runs across the front of a pattern. This causes the bees to prefer a horizontally over a vertically extended pattern, because the latter appears to have a much higher contour density than a horizontally extended shape during a horizontal run across the pattern. In my tests, where the choice of the bees was limited to isolated horizontal or vertical elements of the training pattern, the bees chose the horizontal shape, probably because it more closely approximates the degree of brokenness of the shape to which they were trained. As Anderson notes, the predominance of horizontal scans may in part be due to the design of the test apparatus. When the test patterns lie on a line, a bee flying from one to the other would by necessity cross the pattern horizontally.

A redesign of the original experimental method of testing simple pattern recognition in honeybees, these experiments demonstrate conclusively that honeybees can distinguish between simple shapes. Trends become evident in the similarity of certain shapes to the bees. The parameters which cause this similarity are not definitely known, but testing of vertical and horizontal components of some shapes demonstrates the preference of bees for the horizontal elements of a pattern. More tests are required to determine if this finding is a result mainly of the test design, or also holds true in nature.

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