METHODS & DESIGNS

Odd-item search by pigeons: Method, instrumentation, and uses

DONALD S. BLOUGH

Brown University, Providence, Rhode Island

In odd-item visual search, subjects confront a display on which a number of stimulus items appear. All but one of these items are identical; the subject must respond to the one item (the target) that in some way differs from all the others (the distractors). The time required to find the target reflects the similarity between the target form and the distractor form. A matrix of search times for all possible pairs of a set of 20 or more items can be obtained in a single session. Such similarity matrices may reflect stimulus features, dimensions, and categories, among other things. A method is described through which pigeons learn odd-item search rapidly and perform with high accuracy despite the appearance of each form as a target on some trials and as a distractor on others. The paper also describes the essential apparatus and exemplifies displays and data.

How the world appears to beings other than ourselves is a question that has long fascinated philosophers and researchers. In attempting to answer it, investigators of species from bats to bees have enriched our understanding of perceptual processes and have provided essential links between physiological and behavioral data. Comparative data on form perception might similarly enhance the study of pattern recognition (see Commons, Herrnstein, & Kosslyn, in press), but the methods for studying form perception in nonprimates are few and are generally cumbersome. The method presented here, odd-item search, is more efficient than most and seems especially suited to provide data on similarities among many forms. In this task, the subject chooses the one item (the target) in a multi-item display that differs from all the others (the distractors), which are identical. The time taken to find this odd item is used to represent the similarity between the target and the distractors. Because many trials with many pairs of items appear in single sessions, odd-item search generates quantities of data. These data may, among other applications, help to answer questions about stimulus categories, features, dimensions, and scaling.

We have used the odd-item search method extensively with pigeons. It combines aspects of several familiar procedures, among them oddity learning, visual search, and paired comparison. It is similar to the classic oddity task, except for the much larger number of items simultaneously displayed. It is a visual search task, but differs from most such tasks in that all stimulus items are treated equally, with none consistently serving as targets or non-targets only. In this respect, odd-item search is similar

to a classic paired-comparison task, in which all possible pairs from a large set of stimuli appear in single sessions. Other characteristics and uses of the method are outlined below.

METHOD

Subjects

In our experiments in odd-item search, we have used White Carneaux pigeon subjects under standard deprivation conditions (1 day deprived, 80% of free-feeding weight). Other birds should make good subjects, and so might other animals, such as primates, that can somehow point to a target.

Apparatus and Control

We have run the odd-item procedure with ATARI 800 personal computers, selected because at the time of purchase they provided the best display characteristics for the least expense. These and similar machines have been largely superseded by more powerful computers. In selecting a machine, one should look for high-resolution, ghost-free graphic display; digital input and output capabilities; an accessible internal clock; and the potential for high speed, either through compiled programs or through simple machine language subroutines. Quite important also is an arrangement for uploading the data to a powerful machine that can perform complex analyses, such as multidimensional scaling.

Input and output. Search displays appear on the face of the computer display monitor; pigeons peck directly at this screen (Figure 1). The absence of mechanical response keys makes cleaning easy, and peck position corresponds well with target position. Peck position is sensed

Address correspondence to: Donald S. Blough, Department of Psychology, Brown University, Providence, RI 02912.

Figure 1. Display screen and response sensing array used in odd-item search, with a typical odd-item display.

by two rows of 12 infrared emitter-detector pairs, aligned opposite each other across the top and bottom of the screen (Figures 1 and 2). In our experiments, a target appears in one of six possible horizontally displaced locations. Two emitter-detector pairs are assigned to each of these locations. Detector and emitter units alternate along the rows; this arrangement minimizes the influence of an emitter on detectors other than the one immediately opposite it. The units are recessed to further reduce crosstalk and sensitivity to light from the display screen. We do not record the vertical position of the beak during pecks, for two reasons. First, in this relatively wide frame, the photodiodes would be so far apart that sensitivity would be marginal and localization poor. Second, when pigeons peck, the vertical position of the beak is variable (D. S. Blough, 1979), and the beak often opens so wide that its vertical position is poorly defined.

The frame containing the sensing photocells is made of Plexiglas painted flat black; it is mounted slightly in front of the display screen, which also curves somewhat (Figure 2). Pigeons usually tap the screen lightly when they respond; increased frame-to-screen distance should increase sensitivity, as a thicker part of the beak would intercept the photo beams.

The ATARI 800 allows digital input and output through its game controller ports, at +5 and 0 V. We use the circuit described by Clauson, Izatt, and Shimp (1985) to convert a break in the photocell beam to the switching voltage; a gate is added to OR the output from each pair of detectors. Figure 3 shows the circuit for a single emitter-detector pair. Emitter-detector pairs vary considerably in output; these individual differences can be compensated by choosing the best R2 between about 50 k Ω and 1 M Ω (Figure 3). This adjustment need be made only once, after the units are installed. R3, a 10-turn potentiometer,

provides fine adjustment of trigger levels. The units should detect the beak but not respond to slight intensity variations or drifts due, for example, to an accumulation of pigeon dust during a session. A glass plate glued over each row of cells keeps dust from the units; these plates and the display screen are dusted daily. The detectors are set to respond to a rod 1.1 mm in diameter and to ignore a 0.6-mm rod.

Output to the experimental chamber serves the food magazine and feeder light. The 0 and +5 V levels available from the computer must drive switches that will carry the load of these devices. Our interface uses some old relay equipment and is not very efficient; better ones are widely available (e.g., see Chiodo, 1977).

Software. Programs for experimental control and data collection are conveniently written in BASIC, which is fast enough to perform most functions for a single experimental box. However, to prepare a display during the desired 2-sec intertrial interval (ITI), BASIC calls a short machine language subroutine that rapidly inserts new displays into the screen memory. For additional speed, experimental programs begin by defining each stimulus form as four 8×8 pixel quadrants. Then the program redefines the computer character set to correspond to this set of quadrants. For example, the upper left quadrant of the first form might replace the letter A, the upper right the letter B, and so on. Since a single operation places a whole character on the screen, a form may be displayed in four PRINT operations instead of the 256 ($4 \times 8 \times 8$) PLOT operations required for point-by-point mapping. Tricks such as this may make it possible to dispense with machine language subroutines altogether.

Computers differ considerably in the availability of user-accessible timers, and this is a key criterion in selecting one to run a search experiment. The ATARI 800 has internal registers that permit precise timing; we use the simplest one, which is accurate to $1/60$ sec.

Visual display. Our typical odd-item search displays have the following characteristics. Doubtless many alter-

Figure 2. Detail of the infrared response detector frame. Emitters and detectors are mounted in holes and connect to small circuit boards. Also on the boards, but not shown, are sets of resistors R1 and R2 (see Figure 3). Two adjacent emitter-detector pairs are assigned to each of six "key" areas (see text).

Figure 3. Peck sensor circuit; this is the same for each of the 12 emitter-detector pairs shown in Figure 2. Two pairs are ORed together at the right. Circuit modified from "An infrared system for the detection of a pigeon's pecks at alphanumeric characters on a TV screen: The dependency of letter detection on the predictability of one letter by another" by H. D. Clauson, E. J. Izatt, and C. P. Shimp, 1985, *Journal of the Experimental Analysis of Behavior*, 43, 257-264.

natives would work; our reasons for choosing various special characteristics are described.

The display appears on the face of a monochromatic 5-in. monitor. (The Digilog units we use are no longer sold; Panasonic and Sony units are currently available.) We usually use black (low-luminance) forms on a white (high-luminance) ground, for two reasons. First, the faint black lines between raster scans become part of each form, making it a solid black. In contrast, white forms always have a slightly serrated appearance. Second, the number of illuminated pixels in a white form may cause the amount of light from a form to interact with size as a variable. That is, a large white form on a black screen may gain prominence simply because the light from that form is a relatively large part of the total light in the display. In contrast, the proportional energy in a black-on-white display hardly changes with variation in the size of a single form. Whatever the color of the display, users should be aware that, like a TV, the screen flickers, and that flicker invisible to humans might be seen by nonhuman subjects.

Forms appear within an area on the display screen approximately 4.2 cm high and 9 cm wide. This area comprises 112×240 pixels mapped into 420 "characters" (see Software, above) whose luminance is controlled by computer commands. Each form is defined within a 16×16 pixel (4-character) matrix. The "height" adjustment on the monitor is set to make this matrix square, approximately 6.4 mm on a side. Most of our forms have filled less than half of this area, running 2 to 4 mm in each dimension.

Our typical display consists of 32 forms distributed regularly or somewhat randomly across the display. Figure 1 shows the situation, including a pigeon for scale; two typical displays (from different experiments) appear in Figure 4. There are 31 identical distractor forms and one target form. In our experiments, the target form may be found (on a given trial) in any one of the six interior columns of the display and in either of the two interior

rows. Thus, the target may be in any one of 12 locations, but it is always surrounded by distractors.

Procedure

Search trials. A trial begins with the appearance of a stimulus matrix on the previously blank (white) monitor screen. As noted above, pecks are recorded in any of six regions spanning the screen, which we shall call "keys." If two successive pecks to the target key occur within 8.5 sec after the display appears, the forms change color from black to white for approximately $\frac{1}{3}$ sec; then the forms disappear and the feeder light comes on for 1 sec.

Figure 4. Two typical displays, from different experiments, as they would appear on single trials. In each case, just two forms from a larger set appear. The target is the odd item surrounded by many copies of the distractor. The top display is from the experiment whose results are shown in Figure 7; the bottom display is from a size-scaling experiment, and illustrates a perturbation of position designed to reduce configural factors in the search task.

The feeder light stays on and food is presented, for example, for 3 sec on 7% of such trials; these values depend on the stage of training and the bird's feeding rate. A 2-sec ITI follows. A "correct" reaction time (RT) is recorded if the trial was not a correction trial, as specified below. A new combination of forms appears on the next trial.

If the target fails to receive two successive pecks within 8.5 sec, the trial terminates after two pecks to any key; the screen goes blank and a "miss" is recorded. (For most analyses, such a miss is counted as an RT of 8.5 sec.) One or more correction trials follow a miss. The first correction trial is a re-presentation of the missed display. After a second miss, a very easy correction trial is presented: the target appears on an otherwise blank screen, or with extremely dissimilar distractors. Such trials almost invariably elicit a correct response, and a new display follows. Data are not recorded on correction trials.

It should be noted that a bird may peck one or more incorrect keys and still complete a "correct" trial if it pecks the correct key within 8.5 sec. This somewhat unorthodox procedure need not be followed. However, it yields RTs on some trials that would otherwise be recorded simply as "incorrect." For quite similar forms, such RTs allow distinctions that might otherwise be lost.

Trial blocks. Trials may be arranged in various ways to balance the use of targets, distractors, and keys. Our scheme for a set of 16 stimuli is given here as an example.

Each session begins with a warm-up block comprising a single presentation of each target form alone on an otherwise blank screen. Pecks to the target on the first trial bring food. Subsequent reward is intermittent, as specified above, and misses are very rare.

The test session comprises six full blocks of 240 trials, for a total of 1,440 test (noncorrection) trials. In each full block, each possible pair of two different forms appears twice, once with each of the pair serving as target. Each of these full blocks contains eight subblocks of 30 trials. Each form appears twice as a target in a subblock; distractors are chosen randomly except for the full-block constraint just stated. In each session, each target-distractor combination is associated once with each correct-key position.

Training. Experimentally naive pigeons are reduced to approximately 80% of free-feeding weight and are trained to eat from the food magazine. They are then auto-shaped to peck the display screen, usually with a form larger than and very different from the forms to be used experimentally; hand shaping is sometimes necessary to get the birds to peck readily at the training form.

From this point, procedures may vary depending on the purpose of the experiment. For a typical study of inter-stimulus similarity, the pigeon is next familiarized with the entire set of stimulus forms, which are presented singly in random order on an otherwise blank screen. The birds usually peck readily at these isolated forms. After a session or so (about 1,500 trials) the birds go on to the final

procedure described above. They receive a great many correction trials early in training, but performance usually improves rapidly. Asymptotic performance with fairly discriminable stimuli typically exceeds 95% "correct" trials.

Data Reduction and Reliability

The mechanics of data reduction depend on the purposes of the experiment and on available computation facilities. Two general recommendations are these: (1) Store on disk as much information as possible from each run (specifically, RTs from individual trials), since unanticipated questions may arise (e.g., about trial-order effects or RT distributions). (2) Configure the system so that data can readily be uploaded to a powerful computer that runs programs for such things as cluster analysis, multidimensional scaling, and multiple regression. Odd-item search probes so many different stimulus combinations that simple statistics and analyses (e.g., ANOVAs) cannot adequately reveal their structures. We upload data to the Brown University mainframe (IBM 3081), and we have used procedures of the SAS data analysis package (SAS Institute, 1982) to transform, scale, and fit the data. Some of these analyses are exemplified below.

An indication of the reliability of odd-item RT data comes from three unpublished experiments from our laboratory, each run with a set of 16 forms. (The forms used in one of these experiments appear in Figure 6.) In each experiment, 3 birds were run for 12 sessions each; across these sessions, each stimulus item appeared 72 times as the target, with each other item as the distractor. To permit computation of reliability, means from two sets of 36 drawn from alternate blocks were computed. Correlation of the two resulting data matrices yielded split-half reliability estimates. The mean such correlation within birds was .966 (range .936-.988). The split-half reliabilities for 3-bird means in the three experiments were .995, .980, and .982.

APPLICATIONS

Several applications of odd-item search are suggested below; each relates to a large literature that cannot be summarized here (see, for example, D. S. Blough, 1979, 1985, in press; D. S. Blough & Franklin, 1985; P. M. Blough, 1984).

Form Classification

Search RT serves to measure stimulus similarity in the odd-item task, if we assume that RT increases monotonically with the similarity of the target to the distractors. However, with a matrix of RTs, we can look beyond individual pairs and ask which stimuli are similar in the sense that they yield similar patterns of RTs across a number of comparisons. For example, forms A and B may yield similar patterns of RTs when each is paired with C, D, E, and F. Cluster analysis identifies such patterns of response, typically by grouping stimuli that are closest on a distance measure defined across the set of stimulus pairs. Many cluster procedures are available; they differ

notably in, for example, whether or not they allow stimuli to belong simultaneously to different groups. A hierarchical analysis that restricts stimuli to single groups is exemplified in Figure 5 (CLUSTER, SAS Institute, 1982). The procedure was applied to odd-item data based on forms composed of all combinations of four stimulus aspects: color, shape, size, and orientation. The cluster diagram shows that the input dimensions are reflected in RT patterns; that (for this particular set) color is most salient, followed by shape; and that size and orientation interact with shape (see D. S. Blough, in press). Since interactions could have been much stronger, this outcome is consistent with the idea that aspects are processed somewhat independently. This demonstration of form classification on known stimulus dimensions also suggests that the method may help to isolate salient aspects in stimuli of unknown dimensionality, such as natural objects (see D. S. Blough, in press).

Dimensions in Psychological Space

One of the most common ways to conceptualize similarity relations among numerous stimuli is spatial; in such a representation, dissimilarity increases with distance. We used this method to depict relations among 16 forms composed of two independently varying dimensions. The matrix of odd-item RTs for these forms was fed to ALSCAL (SAS Institute, 1982), a program that uses a Euclidean algorithm to determine interstimulus distances. The result appears in Figure 6. This spatial representation clearly reflects the two variable aspects of the stimuli, which were the length of the upper line and the size of the lower block. Combination rules for such dimensions can be tested by direct comparison of predicted with ob-

Figure 6. Two-dimensional configuration produced by the ALSCAL procedure from search speeds in odd-item search. The configuration reflects two independently variable aspects of the stimulus forms: line length and block size.

tained data values, or by manipulating the algorithm used to determine distances and seeing which provides the best fit.

As with cluster analysis, multidimensional scaling is often most informative when the effective dimensions are unknown. In a recent study, we found that a spatial relation among features, in addition to certain features themselves, constituted an important dimension in search among a set of simple forms. This outcome is contrary to a hypothesis based on suggestions of Julesz and Triesman (D. S. Blough & Franklin, 1985), and it awaits further exploration.

Feature Identification

The finding of D. S. Blough and Franklin (1985) relates to the classic suggestion that simple forms may be defined in terms of the presence or absence of a limited number of features (Zusne, 1970). Although controversy surrounds this approach to form perception, it continues to hold promise. For example, cluster analysis of pigeon letter-similarity data (Figure 7) suggests features such as *open center*, *vertical line*, and *open on top*. Such features are listed in more detail by D. S. Blough (1985) and by D. S. Blough and Franklin (1985).

It might seem that for two stimuli, A and B, A is as similar to B as B is to A. However, measurement often fails to confirm this intuition of symmetry (Tversky, 1977), and search RTs may exhibit interesting asymmetries. For example, some of our data suggest that if forms A and B differ only in the presence of a feature in A and its absence in B, A may be found more rapidly on a background of Bs than the other way around. This is a way to define a feature, and it also suggests how features are involved in search. In this case, a kind of Weber's law for feature detection may operate: The presence of a given feature on a background otherwise devoid of such features is more detectable than the absence of that feature from one item in an array, when it appears repeat-

Figure 5. Hierarchical clusters produced by the CLUSTER procedure (SAS Institute, 1982) from odd-item search involving 16 geometric forms. The forms vary in four binary dimensions: color, shape, size, and orientation. Distance up the ordinate is proportional to the logarithm of the greatest "distance" within a cluster at that level.

Figure 7. Hierarchical clusters produced by the CLUSTER procedure (SAS Institute, 1982) for alphabetic letter search data. The method was a "texture" version of odd-item search, and the data in this instance were percentages correct, rather than reaction times. Data from "Pigeon discrimination of letters and other forms in texture displays" by D. S. Blough and J. J. Franklin, 1985, *Perception & Psychophysics*, 38, 523-532.

edly elsewhere in the array (see D. S. Blough, in press; Triesman & Souther, 1985).

Psychophysical Scaling

Either search time or some derived measure, such as psychological distance, may be expressed as a quantitative function of a physical measure such as stimulus length. Such scales have been hard to determine, with animal subjects, across sizable ranges of stimuli that differ by suprathreshold amounts. A typical display that might be used in a size-scaling experiment is shown at the bottom of Figure 4.

Learning and Memory

The above examples concern perceptual similarity rather directly. Equally interesting are the roles of learning and memory in search processes. We have used other search tasks to study these matters (e.g., P. M. Blough, 1984), but important questions can be addressed with the odd-item method. Early data suggest, for example, that pigeons must be familiar with the targets in odd-item search, but not with the distractors. The role of experience in form categorization and search may be particularly open

to study with nonhuman subjects, because their histories of experience with form elements may readily be manipulated.

GENERAL DISCUSSION

Odd-item search has been presented here primarily as a way to measure form similarity: categories, features, dimensions, and scales may be explored through the analysis of search RTs. The method seems particularly appropriate for such purposes because it quickly provides data for many stimulus pairs, and because the stimuli are treated equally, so bias and order effects are minimized. In contrast, experiments in which subjects are trained to identify specific targets may take a long time and order effects may confound the results. For example, D. S. Blough (1985) had pigeons learn each letter of the alphabet as a specific target; the same target letter appeared on each trial for several sessions together with two distractor letters, which varied from trial to trial. Percentage correct (but not RT) was an effective measure of similarity. However, because the letters had to be learned one by one, the experiments took many sessions, and, more importantly, letters recently learned as targets induced many errors when they later appeared as nontargets.

Search for specific items has been used in a few experiments with animals, not to supply similarity matrices, but rather to study discriminative processing; such matters as memory set size, display size, search images, and attention have been explored (e.g., D. S. Blough, 1979; P. M. Blough, 1984; Bond, 1983; Pietrewicz & Kamil, 1979). The odd-item method may also be useful in such research, as contrasts between odd-item and other data already suggest. For example, why is odd-item search readily performed by pigeons, whereas more familiar oddity tasks are difficult and "true oddity" tasks (tested by transfer to new stimulus sets) may be impossible for these birds (e.g., D'Amato, Salmon, & Columbo, 1985)? One factor is surely the number of items in the display. Odd-item search reduces to classic three-choice oddity when the display shrinks to three items. Zentall, Hogan, and Edwards (1980) found that an increase in the number of incorrect alternatives improves oddity performance in a multiple-key situation; they suggested that this improvement might result from the enhancement of the perceptual figure-ground relationship in the many-alternative case.

The present method, which eliminates such irrelevant features as key boundaries, might especially favor perceptual enhancement. Indeed, data from human subjects suggest that search is particularly fast if target and distractors differ sufficiently on key features to yield a perceptual "pop-out" of the target (e.g., Julesz, 1981). Under these conditions, search may proceed in parallel across the visual field, as contrasted with a possible serial search when pop-out fails. One would expect such processing differences to be reflected in odd-item data, but as yet

they have not been found (see D. S. Blough & Franklin, 1985).

Perceptual interpretations are complicated by the finding that search for a specific item deteriorates with large displays, at least when the target and distractors are similar (D. S. Blough, 1979; P. M. Blough, 1984). Thus, it seems that added distractors speed search when the target is not known in advance, but retard search when the target is known in advance. The effect of added distractors in the odd-item case may thus have less to do with finding a target than with deciding which form is the target. This interpretation may still be consistent with a figure-ground account, but the hypothesized processes must be stated clearly enough to predict at least the differences between the data from the two methods.

Further research on display size should not neglect another factor, the speed-accuracy trade-off (e.g., Swenson, 1972; Mulvanny, 1976). In the present case, RT is an informative measure because response is generally withheld until the target has been found. We have observed that a difficult choice task with few response alternatives (for example, similar forms in two or three possible target positions) appears to encourage rapid response and many errors. This is probably because there is substantial payoff for errors when a hit occurs by chance on every two or three trials. By contrast, in search with many potential target positions, payoff for chance hits is low and bias swings toward withholding response until the correct target is found. RT can also be informative in go/no-go tasks in which there is sufficient incentive to withhold responses to nontargets (D. S. Blough, 1978; D. S. Blough & P. M. Blough, 1978).

As the above discussion suggests, the discriminative processes that underlie odd-item performance must influence the pattern of similarity data produced by the method. We should therefore be alert for differences between similarity data based on search RTs and data from other sources. For example, the standard generalization method presents a single stimulus for comparison with a remembered target. The resulting similarity data might differ in interesting ways from those generated by the odd-item procedure, in which target and distractor are both present. This comparison might, for example, help us to sort out the possible perceptual effects noted above (see D. S. Blough & Franklin, 1985, for some data related to this matter). Evidently, an understanding of the search process itself must accompany a full understanding of form similarity as reflected in search RTs.

REFERENCES

- BLOUGH, D. S. (1978). Reaction times of pigeons on a wavelength discrimination task. *Journal of the Experimental Analysis of Behavior*, **30**, 163-167.
- BLOUGH, D. S. (1979). Effects of the number and form of stimuli on visual search in the pigeon. *Journal of Experimental Psychology: Animal Behavior Processes*, **5**, 211-223.
- BLOUGH, D. S. (1985). Discrimination of letters and random dot patterns by pigeons and humans. *Journal of Experimental Psychology: Animal Behavior Processes*, **11**, 261-280.
- BLOUGH, D. S. (in press). Form similarity and categorization in pigeon visual search. In M. L. Commons, R. J. Herrnstein, & S. Kosslyn (Eds.), *Quantitative analyses of behavior: Pattern recognition and concepts in animals, people and machines*. Hillsdale, NJ: Erlbaum.
- BLOUGH, D. S., & BLOUGH, P. M. (1978). The reaction-time/luminance relationship for pigeons to lights of different spectral compositions. *Perception & Psychophysics*, **23**, 468-474.
- BLOUGH, D. S., & FRANKLIN, J. J. (1985). Pigeon discrimination of letters and other forms in texture displays. *Perception & Psychophysics*, **38**, 523-532.
- BLOUGH, P. M. (1984). Visual search in pigeons: Effects of memory set size and display variables. *Perception & Psychophysics*, **35**, 344-352.
- BOND, A. B. (1983). Visual search and selection of natural stimuli in the pigeon: The attention threshold hypothesis. *Journal of Experimental Psychology: Animal Behavior Processes*, **9**, 292-306.
- CHIDO, L. A. (1977). A versatile low-cost interface module that features optical isolation. *Behavior Research Methods & Instrumentation*, **9**, 256-258.
- CLAUSON, H. D., IZATT, E. J., & SHIMP, C. P. (1985). An infrared system for the detection of a pigeon's pecks at alphanumeric characters on a TV screen: The dependency of letter detection on the predictability of one letter by another. *Journal of the Experimental Analysis of Behavior*, **43**, 257-264.
- COMMONS, M. L., HERRNSTEIN, R. J., & KOSSLYN, S. (Eds.). (in press). *Quantitative analyses of behavior: Pattern recognition and concepts in animals, people and machines*. Hillsdale, NJ: Erlbaum.
- D'AMATO, M. R., SALMON, D. P., & COLUMBO, M. (1985). Extent and limits of the matching concept in monkeys (*Cebus apella*). *Journal of Experimental Psychology: Animal Behavior Processes*, **11**, 35-41.
- JULESZ, B. (1981). Textons, the elements of texture perception, and their interactions. *Nature*, **290**, 91-97.
- MULVANNY, P. J. (1976). *Pigeon discriminative reaction time: Comparison of incremental and all-or-none models*. Unpublished doctoral dissertation, Brown University, Providence, RI.
- PIETREWICZ, A. T., & KAMIL, A. C. (1979). Visual detection of cryptic prey by blue jays (*Cyanocitta cristata*). *Science*, **195**, 580-582.
- SAS INSTITUTE. (1982). *SAS system* [Computer program]. Cary, NC: Author.
- SWENSSON, R. G. (1972). The elusive tradeoff: Speed vs accuracy in visual discrimination tasks. *Perception & Psychophysics*, **12**, 16-32.
- TRIESMAN, A., & SOUTHER, J. (1985). Search asymmetry: A diagnostic for preattentive processing of separable features. *Journal of Experimental Psychology: General*, **114**, 285-310.
- TVERSKY, A. (1977). Features of similarity. *Psychological Review*, **84**, 327-352.
- ZENTALL, T. R., HOGAN, D. E., & EDWARDS, C. A. (1980). Oddity learning in the pigeon as a function of the number of incorrect alternatives. *Journal of Experimental Psychology: Animal Behavior Processes*, **6**, 278-299.
- ZUSNE, L. (1970). *Visual perception of form*. New York: Academic Press.

(Manuscript received June 6, 1986;
revision accepted for publication September 18, 1986.)