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BRIEF PRESENTATIONS ARE SUFFICIENT FOR PIGEONS TO DISCRIMINATE ARRAYS OF SAME AND DIFFERENT STIMULI

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Four pigeons first learned to discriminate 16-item arrays of same from different pictorial stimuli. They were then tested with reduced exposure to the pictorial arrays, brought about by changes in the stimulus viewing requirement under fixed-ratio (FR) and fixed-interval (FI) schedules. Increasing the FR requirement enhanced discriminative performance up to 10 pecks; increasing the FI requirement enhanced discriminative performance up to 5 s. Exposures to the stimulus arrays averaging only 2 s supported reliable discrimination. Pigeons thus discriminate same from different stimuli with considerable speed, suggesting that same–different discrimination behavior is of substantial adaptive significance.

Key words: same–different discrimination, sample duration, fixed-interval schedules, fixed-ratio schedules, pecking, pigeons

Despite decades of unsuccessful efforts to document abstract relational learning by pigeons, recent researchers (e.g., Cook, Cavoto, & Cavoto, 1995; Wasserman, Hugart, & Kirkpatrick-Steger, 1995) have found that these birds can learn and generalize same–different discriminations involving multiple pictorial items, such as the 16-icon displays pictured in Figure 1. Rather than exhibiting stimulus control by the *qualitative* same–different relation among the pictorial items (Delius, 1994), however, pigeons appear to exhibit stimulus control by the *quantitative* relation among the items—their variability or ''entropy'' (Wasserman, Young, & Nolan, 2000; Young & Wasserman, 1997; Young, Wasserman, & Garner, 1997).

As adept as the pigeon is at learning and generalizing a same–different discrimination involving multiple visual items, we do not yet know just how quickly the pigeon can, on any particular trial, extract the necessary pictorial information that appears to control its discriminative behavior. So, in the present experiment, we systematically manipulated display exposure in two different ways: by varying display presentation time on fixed-ratio (FR) schedules of 1, 5, 10, and 20 pecks, and by varying display presentation time on fixed-interval (FI) schedules of 1, 5, 10, and 20 s.

We obtained four key results: (a) Increasing the FR enhanced discriminative performance up to 10 pecks, (b) an FR as small as one peck supported reliable discrimination, (c) increasing the FI enhanced discriminative performance up to 5 s, and (d) an FI as brief as 1 s supported reliable discrimination.

The pigeon thus discriminates same from different stimulus displays with great speed. Such speed suggests that same–different discrimination utilizes neural mechanisms of substantial adaptive significance to the pigeon in its daily activities. Nevertheless, the pigeon does profit by increased exposure to the pictorial stimuli. Such profit suggests that either the increased number of pecking responses or the increased time of stimulation enhances the pigeon's discrimination or processing of the visual items (Blough, 1996; Foster, Temple, Mackenzie, DeMello, & Poling, 1995; Parr, Hunt, & Williams, 1999; Spetch & Treit, 1986; Urcuioli, DeMarse, & Lionello, 1999; White, 1985).

METHOD

Subjects

Four feral pigeons were kept at 85% of their free-feeding weights by controlled daily feeding. Fluorescent lighting in the colony

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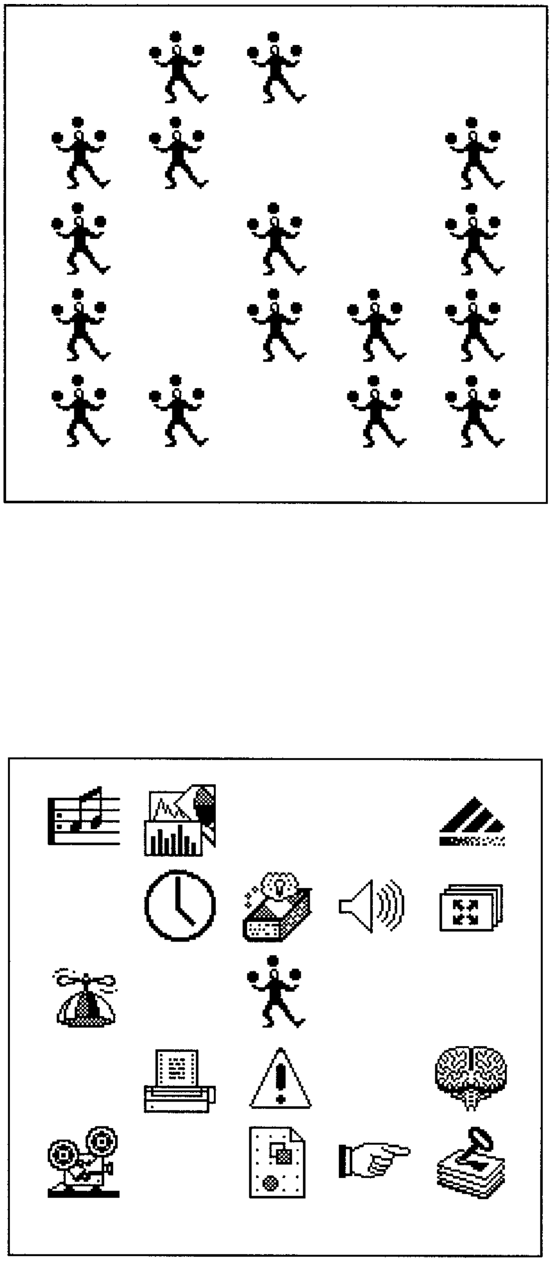

Fig. 1. Representative same and different arrays of 16 computer icons.

room was on from 7:00 a.m. to 9:00 p.m. daily. The pigeons had previously been trained over a period of several weeks to discriminate 16-icon same displays from 16-icon different displays. Two pigeons (49B and 17W) were trained with the color and the position of the same and different response areas counterbalanced from the outset; the other 2 pigeons (91W and 32Y) had first been trained with two of the four possible color–position combinations and the remaining two combinations were added later.

Apparatus

The experiment used four specially constructed chambers. One plywood wall of each chamber contained a large opening with an aluminum frame attached to the outside of the box. The frame held a clear touch screen (Accutouch Model 002744-FTM-K1; Elographics, Oak Ridge, TN); pecks on the touch screen were processed by a serial controller board (Model E271-2210, Elographics, Oak Ridge, TN). A brushed aluminum panel was placed directly in front of the touch screen to allow the pigeon access to circumscribed portions of a video monitor (13-in. AppleColor™ high-resolution RGB) that was located 0.9 cm behind the touch screen at its center and 1.1 cm at the outer edges (the difference being due to the slight convex curvature of the face of the monitor). There were five openings in the panel: a central "display" area (7 cm by 7 cm square) in which the icon arrays appeared and four round "report" areas (1.9 cm diameter) located 2.3 cm from each of the four corners of the central opening. Only the lower two report areas were used; the lower left area and the lower right area could each be lit either green or red. A clear Plexiglas food cup was centered on the rear wall of the chamber to discourage the pigeons from perching on the food cup; it was recessed into the wire mesh floor so that the top of the cup was level with the floor. A pellet dispenser (Model ENV-203M; MED Associates, Lafayette, IN) delivered 45-mg Noyes pigeon pellets through a vinyl tube into the food cup. A houselight, mounted on the upper rear wall of the chamber, provided illumination during experimental sessions. The houselight and pellet dispenser were controlled by a digital I/O interface board (Model NB-DIO-24, National Instruments, Austin, TX).

Control of the peripheral stimuli (via the I/O interface card) and recording of the pigeons' responses (via the serial controller board) were accomplished by four Apple Macintosh® 7100 computers. A distribution amplifier (Model MAC/2 DA2, Extron Electronic, Santa Fe Springs, CA) connected each computer to the pigeon's monitor and to an identical monitor located in an adjacent room. Programs driving the presentation of video stimuli and controlling the chamber houselight and feeder were developed in HyperCard (Version 2.3).

Visual stimuli. Twenty-four highly distinguishable Macintosh icons were chosen as the total item pool; these icons were used by Wasserman et al. (1995). For any given same training array, a single icon from the pool was randomly chosen and was used to make up an array of 16 identical icons. For any given different training array, 16 of the 24 icons in the set were randomly chosen with no repetitions. The 16 same or 16 different icons were randomly distributed to 16 of the 25 possible locations in an invisible 5×5 grid; thus, 16 of the 25 locations contained icons and 9 were blank. Sample same arrays and different arrays are shown in Figure 1.

Procedure

The pigeons were given extensive discrimination training on the same arrays and the different arrays with an FR 30 display observing requirement until choice responding was stable. During this training period, pecks to the red report area on same trials and to the green report area on different trials were correct and were reinforced with one or two pellets (depending on each pigeon's 85% weight); pecks to the incorrect area resulted in repetition of the trial until the correct response was made. After all of the pigeons had reached an accuracy of 85% correct, they were given a range of FR and FI values of stimulus presentation to help select the values that were ultimately presented during testing; the selected values bracketed the smallest integral FR and FI values and the largest FR and FI values that seemed to sustain asymptotic discriminative performance.

Each trial of discrimination training began by illuminating the display area with a white field containing a black cross in the center. A single peck anywhere in the display area turned on the icon array as a black-on-white picture in this area. After either a fixed number of pecks to the display area or a fixed number of seconds (in different training sessions), the icon array reversed to a white-on-black picture (to signal the availability of the two report areas) and the lower two report areas were lighted green and red, with each color appearing equally often in each position. A correct choice darkened the display area and the report areas and delivered reinforcement; an incorrect choice response darkened the report areas, returned the picture to its black-on-white state, extinguished the houselight for 5 or 6 s, and began a series of one or more correction trials that were not scored in data analyses. Intertrial intervals averaged 8 s (range, 6 to 10 s).

The discrimination training sessions involved a randomized block design. There were four different types of trials, created by crossing the same displays and the different displays with the left and right report areas illuminated either green or red. The 160 trials were created by giving 10 blocks of trials, each block containing four of each of the four types of trials.

A total of 40 daily testing sessions followed: The first 20 sessions randomly arranged four different FR (1, 5, 10, and 20 pecks) schedules within each session, and the second 20 sessions randomly arranged four different FI (1, 5, 10, and 20 s) schedules within each session. In each session, the four different FR or FI schedule values were crossed with same displays or different displays and with the two choice areas illuminated red (left) and green (right) or green (left) and red (right), resulting in 16 trial types. These 16 trial types were each presented twice in five randomized blocks of 32 trials each for a total of 160 trials.

RESULTS

Initial analyses of variance of the percentage of correct choice responses on same and different trials indicated that no systematic trends held across the two methods (FR and FI) of stimulus exposure. Analyses of variance also failed to disclose any statistically significant disparities in performance on same and different trials. Therefore, we concentrated on the overall percentage of correct choice responses in our quantitative analyses of the pigeons' same–different discrimination performance. Here, we found that discrimination accuracy generally increased with larger FRs and longer FIs.

Figure 2 shows mean choice accuracy of each of the 4 pigeons as a function of the

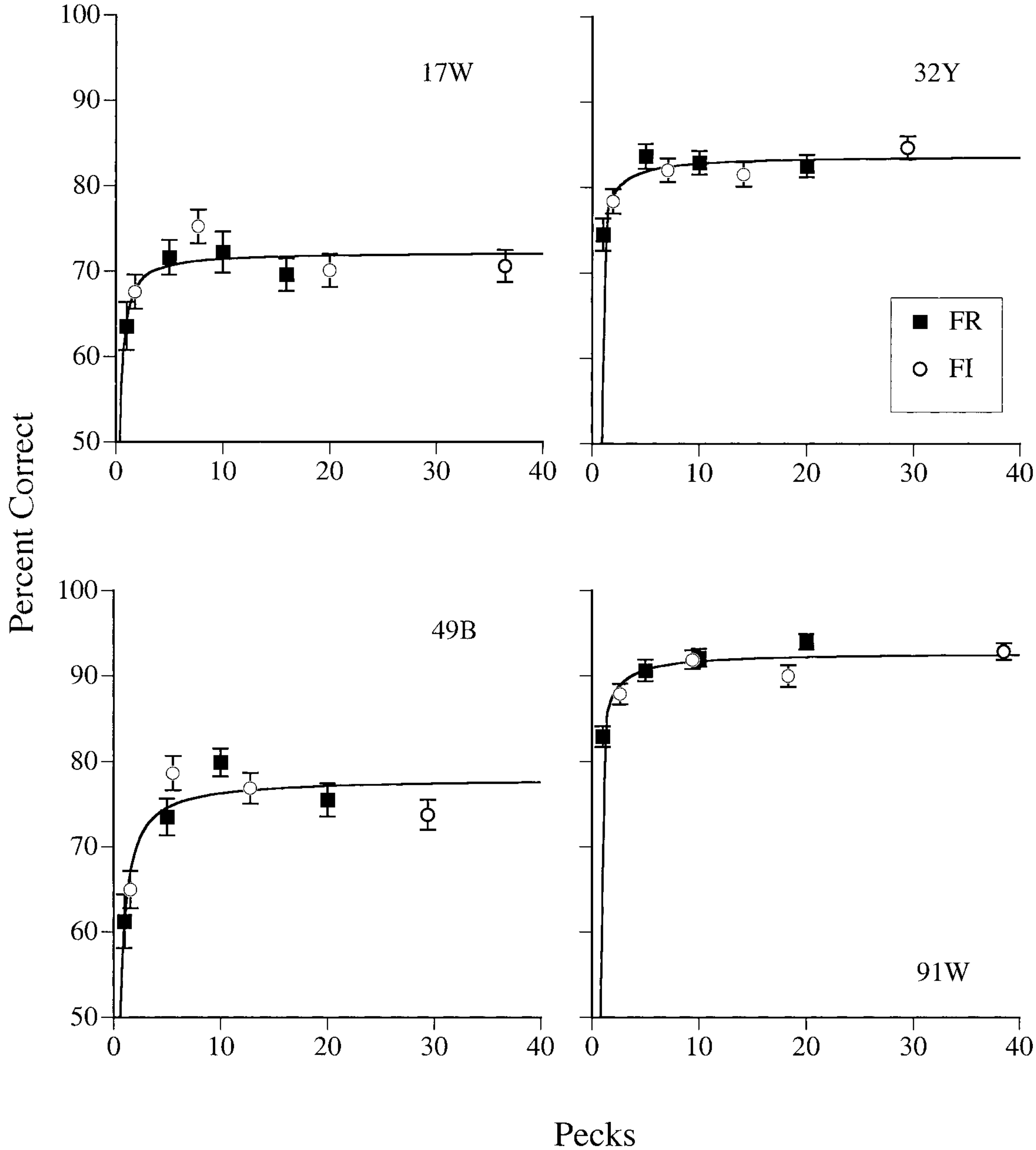

Fig. 2. The filled squares show the mean choice accuracy of each of the 4 pigeons as a function of the four scheduled FR values. The open circles show choice performance on the FI schedules as a function of the mean number of pecks at 1, 5, 10, and 20 s for each pigeon. Standard errors are also depicted.

four scheduled FR values. Figure 3 shows mean choice accuracy across all 4 pigeons as a function of the four scheduled FR values; overall accuracy rose from about 70% correct with one required peck to the stimulus display to about 80% correct with five or more required pecks to the stimulus display. Although there was a slight drop in accuracy at longer ratios for 2 of the pigeons (17W and 49B), these drops were small (5% to 6%) and may have been due to the extinction of observing behavior.

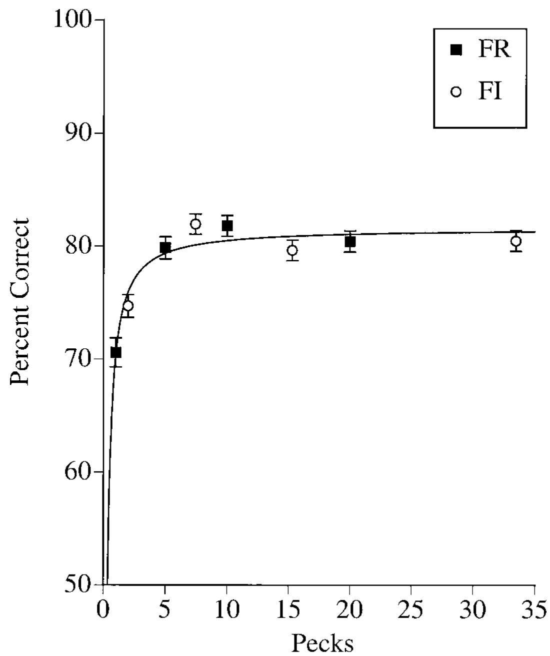

Fig. 3. The filled squares show mean choice accuracy across all 4 pigeons as a function of the four scheduled FR values. The open circles show choice performance on the FI schedules as a function of the mean number of pecks at 1, 5, 10, and 20 s across all 4 pigeons. Standard errors are also depicted.

Figure 4 shows mean choice accuracy of each of the 4 pigeons as a function of the four scheduled FI values. Figure 5 shows mean choice accuracy across all 4 pigeons as a function of the four scheduled FI values; overall accuracy rose from about 75% correct at FI 1 s to about 80% correct at FI 5 s or longer. Again, there was a slight drop in accuracy at longer intervals for the same 2 pigeons (17W and 49B).

We recorded the total time to complete the FR schedules, the total number of pecks made during the FI schedules, and the choice latency, thereby allowing us to describe more precisely the effects of time and pecks on same–different discrimination performance. Because the stimulus remained present until a choice was made, the computed stimulus durations included both the time that passed before the reversal of the display (from black-on-white to white-on-black) and the choice latency. Including the choice latency added a virtually constant small value to the computed stimulus durations (M = 1.17 s). Analyses of variance revealed that choice latency did not vary as a function of the use of the FR or FI schedules of stimulus exposure or the response and time values required by each schedule; latencies did, however, vary from pigeon to pigeon (Ms = 1.29, 1.05, 1.09, and 1.28 s for Pigeons 17W, 32Y, 49B, and 91W, respectively). The consideration of choice latencies did not affect our analysis of the effect of the total number of pecks to the stimulus displays on discrimination performance because there was rarely a peck at the stimulus display after the two choice areas were lit.

Figure 2 also shows choice performance on the FI schedules as a function of the mean number of pecks at 1, 5, 10, and 20 s for each individual pigeon. Figure 3 correspondingly shows choice performance on the FI schedules as a function of the mean number of pecks at 1, 5, 10, and 20 s across all 4 pigeons. These eight-point functions (describing performance on both the FR and FI schedules) were all essentially continuous, even though some pigeons (91W) emitted more pecks in the same amount of time than did others (49B).

Figure 4 shows choice performance on the FR schedules as a function of mean stimulus duration for 1, 5, 10, and 20 pecks for each pigeon. Figure 5 correspondingly shows choice performance on the FR schedules as a function of mean stimulus duration for 1, 5, 10, and 20 pecks across all 4 pigeons. These eight-point functions (describing performance on both the FR and FI schedules) were all essentially continuous, even though some pigeons (32Y) took longer to emit the same number of pecks than did others (91W).

Figures 2, 3, 4, and 5 also show fits of each of the eight empirical points in each plot. Our aim with these fits was to statistically estimate the asymptotic performance and the impact of pecks or duration for each pigeon in each condition. Because it was not our aim to evaluate which function or function class provided the best possible fit of our results, we used a simple discrimination function,

$$\text{choice accuracy} = b - a(1/x), \qquad (1)$$

in which b is the predicted asymptotic performance at an infinite number of pecks (or an infinite duration of stimulus exposure), a is how quickly accuracy declined with fewer pecks (or shorter stimulus durations), and x

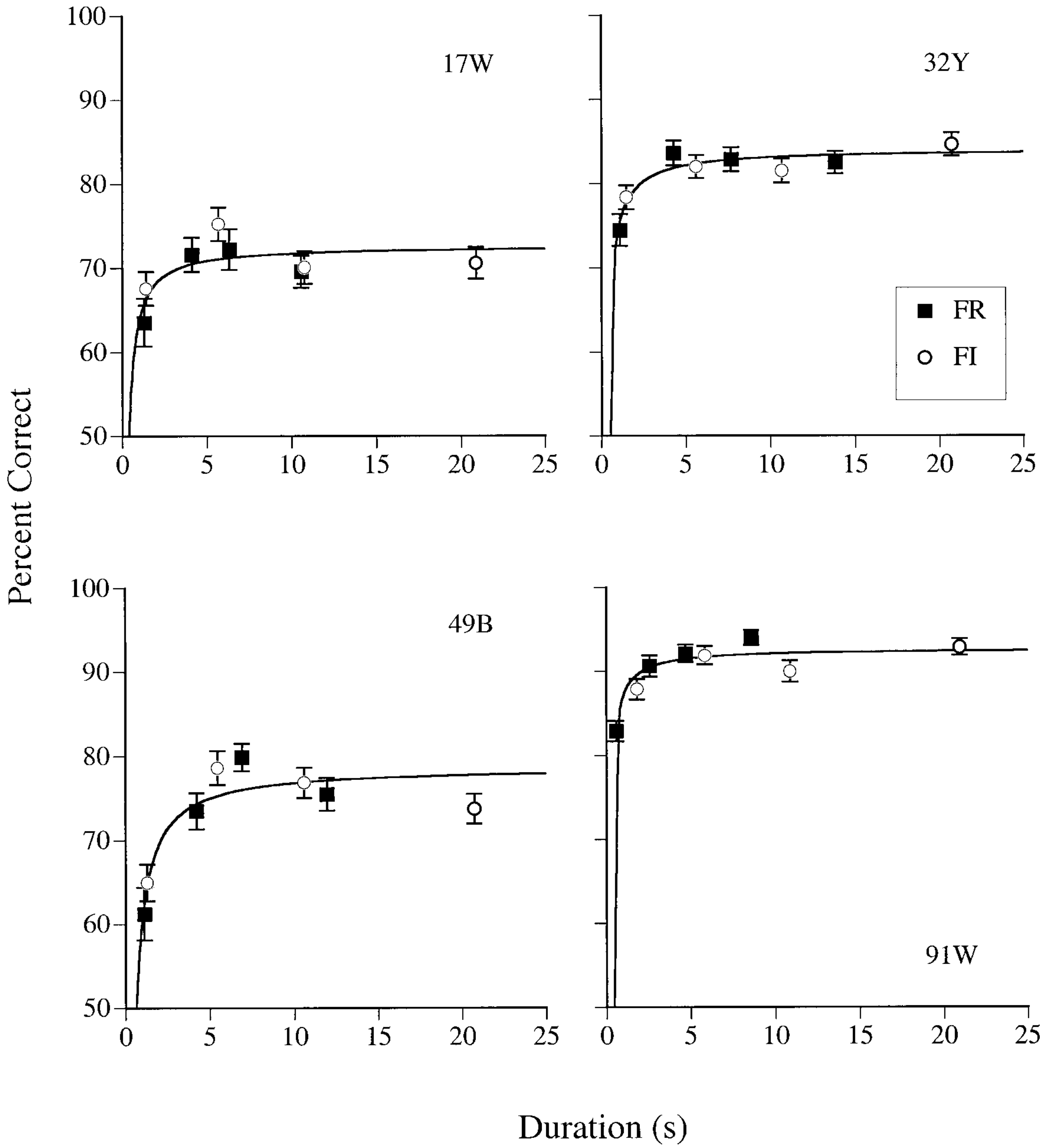

Fig. 4. The open circles show the mean choice accuracy of each of the 4 pigeons as a function of the four scheduled FI values (these durations include the average choice latency). The filled squares show choice performance on the FR schedules as a function of mean stimulus duration for 1, 5, 10, and 20 pecks for each pigeon (these durations include the average choice latency). Standard errors are also depicted.

is the number of pecks (or the duration of stimulus exposure). Table 1 shows the estimated parameters of each of the 4 pigeons and the average of all 4 pigeons for the data depicted in Figures 2, 3, 4, and 5.

The individual-pigeon regression fits used the average accuracy at each FR and FI schedule value (a total of eight points) as the criterion variable and the average number of pecks or seconds of stimulus duration as the predictor. The overall regression fit was conducted similarly, except that "pigeon" was in-

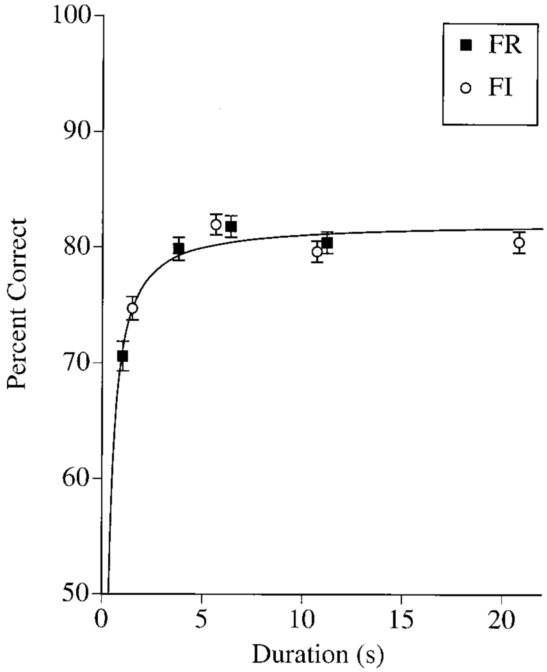

Fig. 5. The open circles show mean choice accuracy across all 4 pigeons as a function of the four scheduled FI values (these durations include the average choice latency). The filled squares show choice performance on the FR schedules as a function of mean stimulus duration for 1, 5, 10, and 20 pecks across all 4 pigeons (these durations include the average choice latency). Standard errors are also depicted.

cluded as a blocking variable and in an interaction term to adjust for individual differences. This modification allowed us to fit all 32 data points rather than averaging scores across pigeons (which would have yielded only eight data points), thus improving our statistical power. The measure of overall effect size was a partial Ω^2 (separating any individual difference effects) to obtain a pure assessment of the effect size.

The overall peck and time fits were each very good. It is interesting to note that the overall peck fit (Ω^2 = .811) was statistically superior to the overall time fit (Ω^2 = .740, p < .01), a trend that held for each of the 4 pigeons. Our goal, however, was not to assess the relative suitability of number of pecks and duration as predictors (cf. Parr et al., 1999; Rilling, 1967) of our pigeons' same–different discrimination. It is possible that the equation that we used to fit the data (Equation 1) was better suited to capturing the relation between number of pecks and accuracy than that between stimulus duration and accuracy.

Table 1

Estimated parameters of the individual pigeons and the average of all 4 pigeons for the data shown in Figures 2, 3, 4, and 5.

	Pecks			Duration		
Pigeon	*a*	*b*	Ω^2	*a*	*b*	Ω^2
17W	−.082	.723	.606	−.141	.730	.498
32Y	−.093	.837	.875	−.182	.848	.820
49B	−.173	.780	.813	−.336	.800	.796
91W	−.101	.927	.869	−.151	.940	.859
Overall	−.112	.817	.811	−.203	.829	.740

Finally, we assessed whether the observed levels of same–different discrimination performance at all four ratios and at all four intervals were reliably higher than would have been expected by chance alone. Binomial tests confirmed that each of the individual and average scores surpassed the 50% mark (p < .05; the threshold level of discrimination accuracy for an individual pigeon at each ratio or interval value was 60.625%).

DISCUSSION

Prior research has shown that the pigeon is highly adept at learning and generalizing a same–different discrimination involving multiple pictorial items (e.g., Cook et al., 1995; Wasserman et al., 1995; Young & Wasserman, 1997); however, we did not know how quickly the pigeon could extract the necessary pictorial information that appears to control its discriminative behavior. Therefore, in the present experiment, we systematically manipulated stimulus exposure in two different ways: by varying stimulus presentation on FR schedules of 1, 5, 10, and 20 pecks, and by varying stimulus presentation on FI schedules of 1, 5, 10, and 20 s.

We found that increasing the FR requirement enhanced discriminative performance up to 10 pecks, beyond which we saw no further improvements in accuracy. Indeed, an FR as small as one peck—producing an average exposure duration of 1.88 s—supported reliable discrimination. We also found that increasing the FI requirement enhanced discriminative performance up to 5 s, beyond which we saw no further improvements in accuracy. Even an FI as brief as 1 s—producing an average exposure duration of 2.25 s—supported reliable discrimination. Such processing speed suggests that same–different discrimination may utilize neural mechanisms of true adaptive significance to the pigeon in its daily life. Recognizing flocks of conspecifics and sites of varied grains may exploit the pigeon's talent for discriminating same from different stimulus arrays, respectively.

Most important for future process accounts of this discrimination behavior is the rapid extraction of same–different information that our pigeons evidenced. Such speed makes it difficult, but not impossible, for the pigeon to foveate all 16 of the pictorial items in the stimulus displays. But, if the pigeon were to fail to detect items when it is given smaller FR and briefer FI requirements, then would this detection failure be expected to lead to a deterioration in its discrimination of same from different displays?

Our prior research (Wasserman et al., 2000; Young & Wasserman, 1997; Young et al., 1997) suggests that the answer to this question is an unequivocal "yes." The pigeon's same–different discrimination is a positive function of the number of displayed items. Nevertheless, a mere six or eight items appear to be sufficient for the pigeon to reliably discriminate same from different displays.

It is important to note that in our prior investigations of the effects of the number of visual items on same–different discrimination behavior, we observed a striking asymmetry: Reducing the number of items produced large decrements in discrimination accuracy to different displays but not to same displays (Wasserman et al., 2000; Young & Wasserman, 1997; Young et al., 1997). This surprising result can be explained by the reduction in entropy that occurs when the number of items is reduced in different displays, but not when the number of items is reduced in same displays (where entropy is always zero).

The failure to observe this asymmetry in discrimination performance in the present study is telling; it suggests that the performance deficit that we observed here to reduced stimulus exposure was not due to the pigeons' inability to detect a sizable number of the displayed items. Thus, decreasing exposure to the stimulus arrays was not equivalent to decreasing the number of items in the displays.

We now know that the pigeon can discriminate stimulus variability very rapidly—within approximately 2 s of exposure. Such speed argues against explanatory constructs that appeal to sequential pecking responses (e.g., pecking at any one icon only once before finding and pecking another). It is also clear that increasing stimulus duration improves accuracy, but this increase reaches asymptote at a level well short of perfect performance (averaging around 82% across pigeons).

Although we know that the mechanisms that underlie this same–different discrimination behavior operate rapidly and that protracted training is necessary for the pigeon to achieve good discriminative performance, the precise nature of the mechanisms remains unknown. The results of the current project constrain the likely candidate mechanisms for this complex discriminative behavior.

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