CONTRAST AS SEEN IN VISUAL SEARCH REACTION TIMES

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Three pigeons searched arrays of alphabetic letters displayed on computer monitors. On each trial, either an A or an E appeared, and the reaction time and accuracy with which the bird pecked at this target were measured. In each block of trials, each target (A or E) was displayed alone, or together with a number of distractor letters (2 or 18) that varied in their similarity to the target. During a baseline series of sessions, responses to the A and to the E each yielded food reinforcement on 10% of the trials. In the next series of sessions, reinforcement continued at 10% for A, but rose to 30% for E. In a final series, these reinforcement conditions were reversed. As expected, reaction times increased with target-distractor similarity and (for similar distractors) with the number of distractors. Increased reinforcement of E had no effect on reaction times to E, but produced a very consistent increase in reaction times to A; the average increase was constant across the various display conditions. Reversal of the differential reinforcement conditions reversed this contrast effect. Analysis of the reaction time distributions indicated that increased reinforcement to E decreased the momentary probability of response to A by a constant amount, regardless of display conditions. These results are discussed in relation to theories of contrast, memory, and of the search image.

Key words: visual search, contrast, reaction time, reinforcement, similarity, key peck, pigeon

Studies of human visual search have played a prominent role in research on attention and recognition (e.g., Hoffman, 1979; Schneider & Shiffrin, 1977; Treisman, 1986; Treisman & Gelade, 1980). Studies of visual search in non-human animals, though scarce until recently, have had similar purposes; these studies date at least to Tinbergen's (1960) suggestion that the development of an attentional "search image" might account for the preference of foraging animals for the most common food items. Recent research with animals has reproduced in pigeons some of the major empirical findings on human search (e.g., D. Blough, 1979; P. Blough, 1984), and has developed considerable support for Tinbergen's attentional hypothesis as well (e.g., P. Blough, in press; Bond, 1983; Pietrewicz & Kamil, 1979).

Doubtless because visual search has been used to study perception and attention, and because human subjects have been so extensively employed, the effects of motivational or reinforcement variables on search have been of little interest, except as extraneous influences that might confound perceptual-attentional interpretations. For example, the above-

mentioned selection by foraging animals of common food items might happen not because these items come to be *seen* more readily (as implied by the "search image" hypothesis) but because they are chosen in *preference* to equally visible alternatives, as a result of differential reinforcement or for related reasons (Guilford & Dawkins, 1987). Though careful studies have minimized these alternative possibilities (e.g., Bond, 1983; Pietrewicz & Kamil, 1979), the effect of differential reinforcement on search remains largely unknown. The present experiment addresses this matter, first replicating previously reported influences of display variables on search speed and then measuring the effect of differential reinforcement on search speed; interactions among these variables are given special consideration.

METHOD

Subjects

Three male White Carneau pigeons served. They all had considerable experience with search tasks in which they saw a variety of forms. The birds had once searched among letters of the alphabet, but these had not been seen for many months. The birds were maintained at approximately 80% of their free-feeding weights, and they usually received their entire food ration of mixed grain during experimental sessions.

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Fig. 1. Three examples of the displays used. Displays varied in three ways: the target letter (A or E), the number of distractors (0, 2, or 18), and the similarity of the distractors to their respective targets (P or Z with A, F or W with E).

Apparatus and Stimuli

Birds were trained and tested in operant chambers, two that were 31 cm wide, 35 cm deep, and 35 cm high and one that was 35 cm wide, 35 cm deep, and 40 cm high. Directly above a centrally located feeder was a black-and-white video monitor that measured 13 cm diagonally. The screen was overlaid by a frame that left a 10.5 cm wide and 6 cm high window exposed. Recessed in the top and bottom of this frame were rows of infrared detectors and emitters that permitted the localization of pecks to the screen within six contiguous vertically oriented strips. ATARI 800® personal computers provided control and data recording. Additional details of the display and response sensing systems are provided in D. Blough (1986).

The display on each experimental trial consisted of black letters on a white background. Each letter was formed within a 5 by 7 dot matrix 2.0 mm wide and 2.8 mm high. The target letter A was associated with distractor letters P (similar to A) or Z (dissimilar to A), and the target letter E was associated with

distractor letters F (similar to E) or W (dissimilar to E). The choices of similar and dissimilar letters were based on the data of D. Blough (1985, Table 1), and their exact shape is reproduced in the same article (D. Blough, 1985, Figure 1). The letters were randomly placed in a matrix of 24 locations 4 cm high (four rows) and 12 cm wide (six columns), with the column placements horizontally perturbed. The displays are specified further below; samples appear in Figure 1.

Procedure

A trial began when one or more letters appeared on the previously blank white screen. The letters A and E were designated as targets; one and only one of these letters appeared on each trial. Pecks were recorded in any of the six regions, defined by the photocell detectors, that horizontally spanned the screen and corresponded to columns of letters (Figure 1). When two successive pecks were made to any region, the forms disappeared and the screen remained blank white until the start of the next trial 3 s later. If the first of two pecks to the region containing the target letter occurred within 4.25 s of trial onset, a correct response and its reaction time (time to first peck or RT) were recorded, and food was presented after the second peck on some fraction of trials, as described below. When food was given, the feeder was activated for approximately 2 s, with the time adjusted to hold each bird's weight approximately constant across days. If the pecks were made to a nontarget region, or to any region after 4.25 s, an error was recorded, food was never presented, and a correction trial was initiated. On the first such trial after an error, the display was repeated; after a second error, the target appeared alone (with no distractors) in the same place as on the previous trial. On correction trials, responses were reinforced according to the same rules as on other trials, but the data were discarded.

Experimental sessions were conducted at approximately the same hour daily and each lasted from 1 to 2 hr. A session began with four warm-up trials, during which each target was twice displayed alone. The session then consisted of 90 blocks (Phase 1) or 50 blocks (Phases 2 and 3) of 10 trials each. In a block, each target, A or E, appeared alone or with its associated distractors in five combinations,

as follows: target alone (A or E); target with similar distractor in a small display (A + 2P or E + 2F) or a large display (A + 18P or E + 18F); target with dissimilar distractor in a small display (A + 2Z or E + 2W) or a large display (A + 18Z or E + 18W). Thus, within each session, parallel conditions were conducted for each target, with orthogonal variation in number of distractors and in target-distractor similarity.

Pretraining. As noted above, these birds were highly experienced on search tasks, but this specific task was novel for them. Training was given for 13 sessions. The procedure described above was followed, beginning with 30% reinforcement for each target with gradual reduction to 10% on the ninth session; during this period the number of blocks per session was increased from 60 to 90.

Phase 1: Baseline. The procedure reached at the end of pretraining continued for six sessions, with 90 blocks of trials per session, yielding a total of 540 trials for each display type. Correct pecks to each target were reinforced on 10% of trials.

Phase 2: Differential reinforcement. The procedure continued unchanged, except that pecks to the E target yielded reinforcement on 30% of trials, whereas A remained at 10%. The number of blocks per session was reduced to 60, and 11 sessions were conducted.

Phase 3: Reinforcement reversal. This phase was the same as the previous phase in all respects, except that the reinforcement conditions were reversed: Pecks to the A target yielded reinforcement on 30% of trials, whereas E shifted back to 10%.

RESULTS

Mean Percentages Correct and Reaction Times

Data were analyzed for the six Phase 1 sessions and the last nine sessions of Phase 2 and of Phase 3. Because more sessions of fewer blocks were conducted in Phases 2 and 3, each phase yielded 540 trials for each display type. Response accuracy was consistently high, with a mean of 94% over all birds and conditions. Accuracy varied little across conditions. Mixed-model, repeated measures analyses of variance revealed only one significant effect: Percentage correct fell with increased display size in the baseline phase, $F(1, 2) = 38.2$, $p < .03$. It is

likely that accuracy suffers from a ceiling effect in this task, and this measure was not considered further.

Search RTs were more sensitive to experimental manipulations, and we shall consider the effects on RT of each independent variable in turn. Mean RTs were analyzed statistically with mixed-model, repeated measures 2 by 2 by 2 factor ANOVAs, the results of which appear below. These statistical analyses excluded the target alone condition because target-distractor similarity is meaningless for this condition, and display size is of questionable meaning when no search among distractors is called for. Figure 2 compares mean RTs for each bird under each display condition for Phase 1 and Phase 2; the mean across birds is shown in the bottom panel. Figure 3 presents a similar comparison between mean RTs for Phases 1 and 3. The left half of each panel shows the results for displays containing the A target; the right half of each panel shows corresponding results for displays containing the E target. The different reinforcement treatments and the distractor conditions apply to all the panels and are indicated in the top and the bottom panels.

Effects attributable to the specific forms employed. Mean RTs for Phase 1 appear in Figures 2 and 3. The level and pattern of RTs were very similar for A and E, except that for Birds 142 and 476 the E with W displays yielded somewhat lower RTs and flatter display-size functions than the A with Z displays. Overall, the ANOVA showed no statistically significant target main effect, $F(1, 2) = 0.43$, $p > .58$, nor did any interaction involving targets approach significance.

Effect of display size. Predictably, the target-alone conditions (no distractors) produced the swiftest search, and the presence of distractors increased search RTs. However, the number of distractors had a powerful effect only for similar distractors (A with P, E with F). When the distractors were dissimilar to the target, the increase from 2 to 18 distractors yielded no consistent increase in RT. Because of this powerful interaction (discussed below), the main effect of display size was not statistically significant $F(1, 2) = 8.39$, $p > .10$.

Effect of target-distractor similarity. Inspection of Figure 2 shows that the similar distractors (P or F) consistently yielded higher RTs overall than dissimilar distractors; this

Fig. 2. Mean reaction times for the various display conditions in the baseline condition (Phase 1, open symbols) and in the first differential reinforcement condition (Phase 2, closed symbols). The top three panels show data from individual birds; the bottom panel shows the mean across birds.

Fig. 3. Mean reaction times for the various display conditions in the baseline condition (Phase 1, open symbols) and in the second differential reinforcement condition (Phase 3, closed symbols). The top three panels show data from individual birds; the bottom panel shows the mean across birds.

was confirmed statistically, $F(1, 2) = 95.8$, $p < .01$.

Similarity/display-size interaction. The most striking pattern in the baseline data was the sharp increase in RT with display size for similar target-distractor pairs, together with little or no such increase for dissimilar pairs. Statistically, this interaction was highly significant, $F(1, 2) = 175$, $p < .01$. This pattern is classic in the search literature and will be touched on below.

Effect of differential reinforcement. In Phase 2, reinforcement of pecks rose from 10% to 30% for the target E while remaining at 10% for A. Remarkably, it was RTs to A, for which reinforcement was unchanged, that were affected by this transition, showing a striking rise in all conditions for all birds; statistically, this rise was highly significant, $F(1, 2) = 165$, $p < .01$. RTs to E, however, were generally unaffected by the rise in reinforcement for E, $F(1, 2) = 0.04$, $p > .87$; in only one case (Bird 772) was there an indication of a decrease in RTs to the E. Thus, a change in search RT conceptually akin to negative behavioral contrast (see Mackintosh, 1974) dominated the reinforcement effect.

The results of Phase 3 (reinforcement reversal) show an overall contrast pattern similar to that for Phase 2. Though reinforcement for E in Phase 3 returned to the same rate (10%) as in Phase 1, RTs to E were in every case higher in Phase 3 than in Phase 1 (Figure 3, right panels); however, because of the large variability of this effect across birds, it failed to reach significance in the ANOVA, $F(1, 2) = 4.66$, $p > .16$. Reinforcement for A was higher in Phase 3 (30%) than in Phase 1 (10%), yet RTs to A were only slightly lower in Phase 3 than in Phase 1, on average, individual cases were very mixed, and the difference was not significant, $F(1, 2) = 1.13$, $p > .4$. Thus, although the overall pattern of Phase 3 results is consistent with that of Phase 2, the data were so noisy that only Phase 1 and Phase 2 data were used in the quantitative analyses below.

Reaction Time Distributions

We have seen that display size, target-distractor similarity, and relative reinforcement all influence mean RT. As discussed below, increased display size and increased target-

distractor similarity are commonly held to increase RT by affecting the speed of a detection process. Does differential reinforcement also act on this detection process, or on some other aspect of search behavior? To answer this question, it is not very informative to compare the effects of the variables on mean RT alone, because ordinal changes in a mean can be only up or down; it is quite likely that two variables will change mean RT in the same way for different reasons. It is more informative to compare the effects of the variables on entire RT distributions. Because the RT distribution is a function rather than a single number, relative values of the function can change in a very large number of ways. It is unlikely that two variables will yield just the same pattern of changes in such a function. Thus, if changes in display variables and changes in reinforcement both affect RT distributions in the same way, we have some evidence that the underlying processes are similar.

In a previous discussion (D. Blough, 1988), I assumed that individual search RTs are made up of two component time intervals, each of which is influenced by a different set of variables. One component is not affected by the search display; it is assumed to vary from trial to trial around a fixed mean and to have an approximately Gaussian (normal) distribution. The time taken for the pigeon to move its head contributes to this component, for example. The second RT component reflects influences on the moment-to-moment probability of target detection, which include characteristics of the search display. Such influences add a negative exponential factor to the RT distribution.¹ The RT on any trial thus consists of one time interval drawn randomly from a distribution that is independent of the search display and one time interval drawn

¹ To appreciate the source of the negative exponential component proposed here, consider the case in which the chance of finding the target during any 0.1-s interval is .5. In this case, the target will be found in the first interval on half of the trials, and the trial will end. On the other half of the trials, search will continue. The probability that search will end in the second interval is $.5 \times .5 = .25$, that it will end in the third interval is $.5 \times .5 \times .5 = .125$, and so on. The sequence .5, .25, .125, . . . , is a discrete approximation of the negative exponential. It describes the relative frequency of the search-related component of RT that is being proposed here.

randomly from a negative exponential distribution whose decay constant is a function of display parameters. When such RTs are collected over many trials, their distribution assumes a known form that is, mathematically, the convolution of the Gaussian and the exponential distributions.

In the previous paper (D. Blough, 1988), I was able to fit six search RT distributions, derived from displays that differed in target-distractor similarity, with the convolution just described. This fit was accomplished with an identical Gaussian for all six curves; only the decay constant of the exponential component varied. Thus, it appeared that the effect of target-distractor similarity could be described solely as an effect on the momentary probability of finding the target, in line with a perceptual interpretation.

We shall use the same idea of RT components to help determine whether the effect of differential reinforcement described above is similar to the effects of the display variables. The strategy is to start with baseline RT distributions and use them to predict RT distributions obtained under differential reinforcement. If the change from equal reinforcement to differential reinforcement acts, like a display variable, to reduce the momentary probability of target detection, the new distributions should correspond to the convolution of a negative exponential function with the baseline distributions.²

It is important to note that a rise in mean RT could be produced in many ways other than the proposed change in momentary response probability. For example, extra reinforcement of the alternative target might add

a constant interval to search RT, causing the entire RT distribution to shift to the right, or it might slow down all components of the search process proportionally, thus multiplying the resultant RTs by a constant.

To test the idea that differential reinforcement influenced momentary probability as just described, distributions from Phase 1 (baseline) were used to predict corresponding distributions from Phase 2. The more variable data from Phase 3 were not used. For clarity, we look first at data from a single bird; more extensive analysis from data combined across birds is carried out below. Many exponential functions with different decay constants were convolved with each Phase 1 RT distribution from Bird 476, and the single resulting curve that best fit (in terms of maximum variance accounted for) the corresponding Phase 2 RT distribution was selected. The results appear in Figure 4. Each panel covers one display condition; at left is the empirical Phase 1 distribution (baseline); at right is the empirical Phase 2 distribution (contrast), together with the distribution calculated from Phase 1 as described above. The empirical curves clearly depict the regular shift in RT induced by increased reinforcement to the other target, and the calculated curves seem to represent this shift reasonably well. In each case, the calculated data accounted for more than 99.95% of the variance of the Phase 2 data. Results from the other 2 birds (not shown) were similar; the contrast curves for 1 bird were slightly less well fit by the curves calculated from baseline, and the fit was somewhat better for the other bird.

If the calculated curves in Figure 4 are taken as an acceptable fit to the data, this suggests that reinforcement-induced contrast affects search RT in the same general way as does an increase in target-distractor similarity (D. Blough, 1988), and, more precisely, that both effects can be attributed to a reduction in the momentary probability of response. Of course, one cannot rule out other unimagined possibilities, but it is clear that some alternatives will not work. For example, the contrast curves are not generated from the baseline curves by the addition of a constant or multiplication by a constant, both of which might be plausible outcomes of a motivational process.

A still more detailed look at the data was facilitated by combining the individual RT dis-

² In the analysis of RT distributions discussed in the following paragraphs, an exponential distribution is convolved with a baseline RT distribution, not with a Gaussian, to yield each new, predicted RT distribution. This greatly simplifies the computation, because it bypasses the estimation of an underlying Gaussian, and it yields the same predictions as an analysis that uses an estimated Gaussian. This is true because of the assumption that all the RT distributions, including the baseline distributions, represent Gaussian-exponential convolutions. Variables of interest, such as display size, similarity, and relative reinforcement, are assumed to affect the decay constant of the exponential component. Changing the exponential decay constant associated with the baseline distribution is mathematically equivalent to convolving that distribution with a new exponential, as was done to generate the predictions shown in Figures 4 through 7.

Fig. 4. Search RT distributions for Bird 476, showing data from each display condition. The leftmost curves in each panel are from baseline (Phase 1). To the right in each panel are empirical distributions from Phase 2, together with predicted distributions (dotted lines), that result from the convolution of the Phase 1 curve with a negative exponential function (see text).

tributions, thereby reducing the irregularity of the curves. Distortion of the shape of the distributions was kept to a minimum by following a procedure recommended by Ratcliff (1979), which is equivalent to "Vincentizing": The correct RTs for each phase and bird were ordered from least to greatest, and the ordinally corresponding RTs were averaged across birds. The resulting mean RTs were distributed into 0.1-s bins just as though they had come from 1 subject.

With the combined curves, we can investigate some additional questions. First, we ask

whether the present data confirm the influence of target-distractor similarity that I previously measured on quite different stimuli (D. Blough, 1988). Figure 5 shows this effect for each target in the large display (18 distractors) as it appeared in baseline data combined across the 3 birds. It can be seen that the fits are reasonably good, although the empirical curves fall a bit below the calculated curves to the right of the mode, as did those in the previous study (D. Blough, 1988).

We next ask if the other display variable, display size (that is, number of distractors)

Fig. 5. Search RT distributions, combined across 3 birds, comparing data from the conditions under which targets and distractors were dissimilar (left curves in each panel) to those for similar targets and distractors (right curves). Also shown are predicted distributions for the similar condition (dotted lines) that result from the convolution of the dissimilar distributions with a negative exponential (see text).

produces a similar effect on RT distributions. Baseline data under the similar condition, combined across 3 birds as indicated above, appear in Figure 6. Again the fit is reasonably good. The data appear to be consistent with the idea that both display variables affect the momentary probability of response, as proposed above.

Although the display variables may act in similar ways, we saw above that they interact very strongly. However, the mean data (Figures 3 and 4) did not suggest any systematic interaction of reinforcement with these other variables. It would be quite interesting if contrast could be summarized as a constant change in momentary response probability that happens regardless of other factors. To investigate this possibility in more detail, the same procedure was followed as above; that is, the combined data for each display condition of Phase 1 was convolved with an exponential function to predict the corresponding data of Phase 2. However, this calculation was carried out using the same exponential decay parameter across all display conditions, rather than fitting each pair of curves separately; that is, a single parameter was estimated for the whole set of data. This corresponds to the idea that the contrast effect reflects a constant shift in momentary response probability across all display conditions. Figure 7 depicts the results. As in Figure 4, each panel covers one display con-

dition. Despite the use of a single parameter, these fits are quite close; the variance accounted for was 99.99% in all cases. Within the limitations of this method, then, the results seem consistent with the idea that differential reinforcement exerts a constant influence on momentary probability with which a search response will be emitted, regardless of display conditions. There is no evidence of interaction such as that found between the similarity and display-size variables (Figures 2 and 3).

DISCUSSION

The major findings may be summarized as follows. First, the data replicate previously reported effects of display size, target-distractor similarity, and the interaction of these variables. For similar target-distractor pairs, RT was relatively high and increased sharply with display size; for dissimilar pairs, RT was lower and was relatively unaffected by display size. Second, tripling the reinforcement frequency associated with one target left RTs to that target relatively unaffected while markedly increasing RTs to the other target. Reversal of the reinforcement conditions produced a corresponding, although somewhat more variable, change. Third, analyses of the RT distributions suggested that all the RT effects could be modeled as changes in the momentary probability of response, reflected in changes in

Fig. 6. Search RT distributions, combined across 3 birds, comparing data from small displays (left curves in each panel) to those from large displays (right curves). Also shown are predicted distributions for the large condition (dotted lines) that result from the convolution of the small distributions with a negative exponential (see text).

the decay constant of an exponential component of the RT distribution. Although the display variables strongly interacted with each other, reinforcement did not interact with them.

These results are sufficiently clear that they should constrain hypotheses about the nature of search and contrast. As mentioned above, the main similarity and display-size effects, and their interaction, are standard results in both the human and animal search literature (e.g., P. Blough, 1984; Schneider & Shiffrin, 1977). They are taken as support for the dominant model of search as a two-stage process (see P. Blough, 1984; Hoffman, 1979; Schneider & Shiffrin, 1977; Treisman, 1986; Treisman & Gelade, 1980). When the target is sufficiently dissimilar from distractors, it is said to "pop out" perceptually from the background; that is, the display is analyzed as a whole ("parallel processing"), so additional distractors do not add to search time. When the target and distractors are similar, the display items must be scanned sequentially ("serial processing") and thus search time increases with their number (cf. Treisman, 1986; Treisman & Gelade, 1980).

The results describe one new finding with respect to display variables. Like similarity, display size appeared to exert its effect by its influence on the momentary probability of response (Figure 6). This result is not surprising and is consistent with the perceptual interpretation of display effects. Readers may be

curious about an apparent anomaly in the display-size data from Bird 772, particularly notable in Figure 3. For this bird, the most dissimilar condition (E with W) yielded lower RTs for the larger display than for the smaller. There is, in fact, precedent for this result and a reasonable explanation of it. When pigeons search for a target that is defined only by being different from the distractors ("odd-item search"), RTs are distinctly lower for large displays than for smaller (D. Blough, 1989). It appears that identification of the target is enhanced by the addition of distractors; probably perceptual isolation ("pop-out") is improved. This enhancement of search for large displays was particularly strong for very dissimilar target-distractor combinations. Because the displays in the present experiment consisted of a target on a background of identical distractors, it is reasonable that this perceptual effect played some role, apparently overriding, for Bird 772, the otherwise negative effect of larger displays. (See D. Blough, 1989, for further discussion.)

Because the display effects are relatively well understood, we devote most of our attention to the contrast phenomenon. There seem to be no previous reports of contrast effects on visual RTs. The present results are probably closest in character to those summarized by Mackintosh (1974) as "discrete-trial simultaneous contrast," with time as the dependent variable. For example, Ludvigson and Gay (1967) re-

Fig. 7. Search RT distributions based on RTs combined across birds, showing results from each display condition. The leftmost curves in each panel are from baseline (Phase 1). To the right in each panel are empirical distributions from Phase 2, together with predicted distributions (dotted lines), that result from the convolution of the Phase 1 curve with a negative exponential function. The same exponential function was used to generate all the predicted curves (see text).

ported that rats receiving 12 food pellets for running in a black alley and only one pellet in a white alley (or vice versa) ran more slowly in the alley associated with one pellet than rats that got only one pellet in both alleys. Similarly, in a discrete-trials single-key experiment, Brownlee and Bitterman (1968) gave pigeons eight pellets for 20 pecks to a red key and only one pellet for 20 pecks to a green key. The birds completed the trials to the green key more slowly than to the red and also more slowly than did birds in a control group that were given one pellet for both colors. When

reinforcement for the 8-1 group was equated at 1 for both colors, the time to complete the trial diminished to the green key, only to rise again when the 8-1 condition was reinstated.

These and related contrast results have been interpreted previously within the conceptual frameworks of conditioning theory and behavior analysis. Before turning to those ideas, however, we consider whether the contrast effect might be an instance of a "search image" change—that is, the result of an attentional shift (Bond, 1983; Tinbergen, 1960). For example, increased reinforcement might favor an

E search image, making the A more difficult to find. Three main criteria have been used to conclude that an attentional shift has caused a change in relative responsiveness to alternative targets (e.g., Bond, 1983; Pietrewicz & Kamil, 1979). First, the change follows an operation, such as repeated exposure to one target, that provides information about the relative likelihood of future appearances of the target. Second, the change occurs even if the targets have been equally associated with reinforcement. Third, the change interacts strongly with display variables, which in the search-image literature are said to affect "crypticity."

None of these criteria for an attentional effect are met in the present study. The various displays always appeared equally often, so the subjects had no way to predict which target might appear. The contrast effect was obtained through differential reinforcement, not in its absence. Most important, even the detailed examination of RT distributions failed to show a systematic interaction between the contrast effect and display variables. Strong contrast occurred even for targets displayed on an otherwise blank screen; attentional tuning would seem superfluous in such a display, and recent data confirm that attentional priming does not influence RT to such targets (P. Blough, *in press*).

If an attentional account seems inappropriate, have the present results any bearing on the various accounts of contrast in the conditioning literature? The key idea, common to most accounts, is the relativity of reinforcement, the notion that the strength or probability of a response is determined not only by the level of reinforcement associated with that response but also by other reinforcement in the situation. This influence of reinforcement context has been variously modeled (see Balsam & Tomie, 1985), and the models have been applied to somewhat different sorts of data. Some major conceptualizations may be roughly characterized as follows: (a) overall reinforcement influences the associative strength of background stimuli, which in turn affects the "surprise value" of reinforcement associated with a specific target (e.g., Rescorla & Wagner, 1972); (b) the performance of a response to a target depends on the waiting time to reinforcement in the presence of that target, relative to overall waiting time to reinforce-

ment (e.g., Gibbon, 1981; Jenkins, Barnes, & Barrera, 1981); (c) response to a target follows the matching law, which incorporates relative reinforcement (e.g., Herrnstein, 1970); (d) response to a target is subject to an inhibitory influence from overall reinforcement (Catania, 1973; Williams & Wixted, 1986); (e) frustration is associated with a less reinforced target (e.g., Amsel, 1971).

All of these ways of looking at contrast seem to predict the results reported here in a general way, provided that search speed is presumed to act like other dependent measures. Specifically, if pecking at A and pecking at E are considered different responses, a decline in relative reinforcement to one of these responses should reduce its speed, as happened here. However, the results challenge the models in at least two ways. First, several if not all of the models imply that the increased reinforcement associated with E in Phase 2 and with A in Phase 3 should have increased the strength (in this case, reduced the RT) of those responses. The absence of such an effect suggests that a process-limited speed ceiling occurs in this situation. A second unexplained aspect of the data is the particular form taken by the contrast effect, as expressed in RT distributions. We next consider another theory that might address this issue.

Why does reinforcement contrast appear as a shift in momentary response probability that is constant across display conditions? The accounts described so far do not address this question, so we consider finally a cognitively oriented model that may do so. According to this view, "looking for something" involves a continuous comparison between sensory information and stored information; the searched-for object is found when there is a match between the input and the stored information. Specific predictions for RTs can be derived from various models of this sort (see Luce, 1986). Let us consider one that is relatively close to home, namely Heinemann's memory model for decision processes in pigeons (Heinemann, 1984). According to this model, the outcome of each discrimination trial is stored in a memory that holds about 1,000 records, each new record randomly overwriting an old one. The stored record lists the stimuli present on the trial, the response made, and the reinforcement received. In the present situation, these records correspond to search trials. When

a display is presented, the subject retrieves a small sample of positive records, which are records of past trials on which reinforcement was received. The subject responds if the information in this sample of records is sufficiently similar to the current input from the display. However, if the display and the records do not correspond adequately, a new sample of records is retrieved, and the process continues until a correspondence is reached.

The iterative retrieval process of Heine-mann's (1984) memory model offers a way to account for the reinforcement effects observed here. When the target E and the target A are equally reinforced, the large memory store should contain about equal numbers of positive records from E trials and positive records from A trials. Thus, most positive samples from this store will contain records of both sorts. If re-sampling of memory is necessary (due, for example, to variations in the display), the chance of reaching a match in any time interval is equal for the two targets, so the mean RT and the RT distributions should be comparable. However, after reinforcement to E increases, positive records for E will eventually outnumber those from A by three to one. Thus, many small samples may contain only E records and will not provide an adequate match for an A target. For both initial sampling and resampling, the chance of finding a matching record for an E display will be consistently higher than that for an A display. In consequence, the momentary probability of response to A will drop, relative to that to E. This outcome explains the relatively greater mean RT to A found in Phase 2 and to E in Phase 3 (Figures 2 and 3). Also, because the retrieval process is iterative and has a constant probability of termination at any point, its time of termination is described by an exponential decay function. Thus, the model predicts the specific form of the changes in RT distributions that were associated with contrast in the present results (Figures 5 and 7).

This simple version of the memory model predicts that mean RTs to differentially reinforced targets may diverge, but without additional assumptions it cannot predict how much of this divergence will come from an RT increase to one target and how much from a decrease to the other. In the present data, the main contributor was an increased RT to the relatively less reinforced target. The absence

of a decreased RT to the more reinforced target could occur because of a floor effect; for example, in both phases 1 and 2, most samples from memory might contain enough E records to generate a speedy response.

The RT data reported here can guide modeling, as just illustrated in a highly tentative account. More broadly, the data suggest that search RTs can be an effective measure of reinforcement effects. This result was not obvious; in past research, visual search speed has been treated as reflecting, and limited solely by, the requirements of information processing. If this were true, relative reinforcement might have made little difference. The fact that it did make a difference suggests that such influences must be incorporated in future "processing" models. The descriptive simplicity of the contrast effect, expressible by a single constant across a number of different conditions, also makes this paradigm an attractive candidate for further study.

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