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Priming of Attention to Local or Global Levels of Visual Analysis

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Humans can shift attention between parts and wholes, as shown in experiments with complex hierarchical stimuli, such as larger, *global* letters constructed from smaller, *local* letters. In these experiments, a target stimulus appears at either the local or the global level, with a distractor at the other level. A shift of attention between levels is said to be demonstrated through a form of priming, whereby targets at one level are presented with a higher probability than at the other level. This base-rate type of priming can facilitate speed of responding to targets, as seen in shorter reaction times to targets at the primed level. Experiment 1 demonstrated such a priming effect in pigeons. Experiment 2 confirmed this priming, by showing that accuracy remained high for familiar targets, at either level, even when distractors at the other level were novel.

Flexible attentional systems may have evolved to deal with the complexities of naturalistic environments. The visual world in particular seems to demand shifts of attention of many different types, including shifts between global and local features of the environment. This distinction between the whole and that of its parts has long been central, of course, to discussions about the basic nature of human and nonhuman animal visual perception (Kohler, 1925, 1947; Krechevsky, 1932; Tolman, 1932; Wertheimer, 1945).

Drawing on this classic distinction, Navon (1977) suggested that when we see stimuli like a forest and its component trees, our visual system analyzes the scenes in terms of different levels, and tends, other things being equal, to prioritize more highly the global level of analysis, the forest, at the expense of trees (also see Kinchla & Wolfe, 1979; Lamb & Robertson, 1990; Navon, 1981; Navon & Norman, 1983; Ryle, 1949). This higher prioritization for the global level is termed *global dominance* or *global precedence.* Navon's (1977) suggestion encouraged research on the flexibility of local–global attention, and for the purpose of the present experiments, the most critical subsequent discovery was that humans can indeed shift attention back and forth between global and local levels (Kinchla, Solis-Macias, & Hoffman, 1983; Pomerantz, 1983; L. M. Ward, 1982).

Some nonhuman animals also experience a complex visual world and therefore may also be able to shift attention between global and local levels of visual analysis, although no such demonstration has yet been provided. Avians such as pigeons, whose in-flight visual worlds must surely be dynamic in the extreme, appear to be an ideal example of such an animal. In fact, several lines of evidence encourage the expectation that pigeons might share with humans the ability to shift attention between local and global levels.

First, D. S. Blough (1993) showed that pigeons can shift their attention between features of complex stimuli in a visual search task. This suggests that pigeons have a flexible form of attention that can shift at least from one feature to another.

Second, Cook and his colleagues (Cook, 1992a, 1992b; Cook, Cavoto, & Cavoto, 1996) showed that pigeons readily learn to respond to global aspects of stimuli composed of color and texture differences and ignore local feature changes, indicative of a global processing precedence. Similarly, Honig (1993) suggested, in a manner corresponding to Navon's earlier suggestion regarding humans, that pigeons have a predisposition to attend to global characteristics of the visual environment (see also D. S. Blough, 1992). Honig's and Cook's results, when combined with D. S. Blough's (1993), implied that pigeons can attend to either local or global levels. Pigeons therefore presumably can switch attention between levels, and this ability might be demonstrable within a single experiment.

Third, the visual search procedure has helped confirm in the laboratory the idea originating in behavioral ecology and ethology that a search image facilitates a predator's detection of prey (D. S. Blough & P. M. Blough, 1997; P. M. Blough, 1992; Langley, Riley, Bond, & Goel, 1996; Tinbergen, 1960). Researchers have suggested that a search image's ability to facilitate the speed and accuracy with

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which a predator perceives cryptic prey might be interpretable in terms of the dynamics of selective attention and priming, according to which a target stimulus comes to be primed through repeated exposure (P. M. Blough, 1989, 1991, 1992; Dawkins, 1971a, 1971b; Langley et al., 1996; Pietrewicz & Kamil, 1981; although see Plaisted, 1997). P. M. Blough (1989) ventured to suggest that "priming modifies an attentional mechanism and . . . this effect accounts for search images" (p. 358). This suggestion would be supported by a demonstration that nonhuman animals can in fact shift attention between local and global levels of analysis and that such shifts can be primed. Such a demonstration would suggest that an animal's search image might be dynamically adjustable between the global level of "forest," with some visual patterns of open fields, trees, and foliage corresponding to a particularly desirable prey habitat, on the one hand, and the local level of "trees," with some individual shrubs being especially probable prey habitats, on the other hand.

Fourth, Langley and Riley (1993) showed that the selective attention found in studies of control by elements or compounds of stimuli is in the perceptual processing of the stimuli, not in subsequent short-term memory. This result encourages the view that to understand control by local and global features of a hierarchically organized stimulus, we must consider perceptual processing as well as memory and associative processes.

Fifth, Shimp and Friedrich (1993), with pigeons, and Bushnell (1995) and N. M. Ward and Brown (1996), with rats, found behavioral analogues of attentional shifts between local spatial regions and global, nonspatial aspects of a task. Thus, to date there is evidence for at least one dynamic and flexible attentional system in nonhuman animals.

Sixth, Spetch and Edwards (1988) showed that pigeons can remember both nearby and small-scale cues as well as more distant and large-scale cues in a spatial memory task, which reflects a mnemonic ability that presumably would be required by an attentional system for shifts of attention between local and global levels.

Seventh, Wasserman, Kirkpatrick-Steger, Van Hamme, and Biederman (1993) showed that pigeons' categorizations of complex stimuli are controlled partly by component features and partly by more holistic relational characteristics. Because both types of characteristics, local and global, contribute to the perception of a stimulus, it follows that a pigeon might be able to attend preferentially to one or the other characteristic, depending on the reward consequences for doing so. Indeed, Wasserman et al. (1993) explained the difference between their results and previous results reported by Cerella (1977) in terms of essentially this idea: Different contingencies in the two experiments encouraged subjects to attend to local or global levels of analysis.

These various lines of evidence suggest that birds may have evolved to benefit from the selective advantage of being able to attend either to large- or to small-scale features of complex stimuli (also see Honig, 1993). There might be an advantage to an individual pigeon if it were able to shift attention among multiple levels of visual analysis, such as between a corn patch, a corn stalk, an ear of corn, and a specific kernel of corn. This is just to restate, of course, a classic Gestalt position on visual perception: An organism can selectively attend either to wholes or to parts.

Fulbright-Cavoto (1994), in Robert Cook's laboratory, has recently adapted Navon's (1977) original procedure for use with pigeon subjects to empirically investigate selective attention to local and global levels of hierarchically structured alphabetic characters. She asked whether pigeons, like the humans in Navon's study, show a global dominance, a local dominance, or no dominance at all. To test this, Fulbright-Cavoto randomly presented targets at either the local or the global level of hierarchically structured stimuli and asked whether targets at one level were learned more quickly than targets at the other level. She found that the probability of a correct response increased much more rapidly for local targets than for global targets. This suggested that the birds have a local precedence according to which pigeons perceive local features before global features. Fulbright-Cavoto investigated a variety of other experimental conditions and transfer tests that suggested either a local precedence or no precedence at all. Most often the birds in Fulbright-Cavoto's (1994) task had a predisposition to attend to the local features of her hierarchical stimulus displays. Conversely, recall that Cook and his colleagues (Cook, 1992a, 1992b; Cook, Cavoto, & Cavoto, 1996) found a global precedence when they used hierarchically structured stimuli composed of color and texture differences. This suggests that pigeons' visual processing of hierarchically structured stimuli can be dominated by different levels, at least in different tasks.

Two summary statements seem justified by the preceding considerations. First, it seems clearly established that Navon's (1977, 1981) distinction between local and global levels of human perceptual analysis is critical to an understanding of nonhuman animal perception. Second, it seems plausible, although as yet undemonstrated, that pigeons, like humans, can switch attention between local and global levels in the same task and with the same stimuli. The literature on nonhuman animal attention, including Fulbright-Cavoto (1994), leaves this possibility unevaluated. The present experiments were therefore conducted to demonstrate, in pigeons, shifts of attention between local and global levels of analysis.

The defining evidence for these attentional shifts in humans has been faster responding to targets at either the local or global level of compound alphanumeric stimuli following priming at that level (Kinchla et al., 1983; Pomerantz, 1983; Robertson, Egly, Lamb, & Kerth, 1993; Robertson, Lamb, & Knight, 1988; L. M. Ward, 1982). This priming effect can be demonstrated with as few as four compound stimuli (L. M. Ward, 1982), although eight stimuli are more common (Robertson, 1996; Robertson et al., 1993; Robertson et al., 1988, 1991). The effect can be demonstrated in either of two ways: (a) by blocking trials with a preponderance of targets at a particular level, a base-rate type of priming, or (b) by the use of a priming cue on individual trials to predict a target at a particular level.

In the present experiments, we used the base-rate, or blocking, procedure, to demonstrate faster responding to whichever target level was more frequent and thereby to establish in nonhuman animals a priming phenomenon that in the human literature defines an ability to shift attention between local and global levels. We arranged most targets within a particular condition to occur at a particular level; then, over successive 3-day conditions, we repeatedly reversed the level at which most targets appeared. We asked whether priming targets at a particular level in this manner facilitated speed of responding to targets at that level, as revealed by shorter reaction times (RTs) to those targets.

Experiment 1

Method

Animals

Seven experimentally naive, male white carneaux pigeons (*Columba livia*) were obtained from the Palmetto Pigeon Plant (Sumter, SC). They were maintained at approximately 80% of their free-feeding weights, with supplemental grain provided as needed in their home cages following the daily experimental session. Birds were housed individually in standard pigeon cages with free access to water and grit in a colony room with a 14-hr light–10-hr dark cycle. Experimental sessions occurred during the light cycle at approximately the same time, 5 to 6 days a week.

Apparatus

The experimental chamber had interior dimensions of 38 cm × 34.5 cm × 50 cm (length × width × height). We mounted three clear Plexiglas response keys (3.5 cm × 3.5 cm) side by side within a clear Plexiglas viewing window (17 cm × 7 cm; width × height). The viewing window itself was mounted within the front wall of the chamber, 20 cm above the floor. A 14-in. (35.6-cm) CTX brand color monitor was 5 cm (Birds 1 to 4) or 8 cm (Bird 5) behind this front wall and was visible through the response keys and the Plexiglas viewing window. The experimental chamber and monitor were interfaced to an IBM PS/2 Model 95 computer, which controlled all experimental contingencies and recorded all data. We used a super MVGA video adapter card (Colorgraphics Communications) to keep the computer monitor in the chamber blank before and after experimental sessions. Reinforcement consisted of approximately 2-s access to mixed grain presented in a hopper located beneath the Plexiglas window, directly below the center response key. White noise helped to mask extraneous sounds.

Procedure

Stimulus composition. All the stimuli were hierarchical in the loose sense that each stimulus consisted of a global character composed of smaller, local characters. Some stimuli (for Birds 3, 4, and 5) were hierarchical in the more rigorous sense that global stimuli were composed of local stimuli that resembled small versions of global stimuli.

Of note, in analogous human research, global and local target stimuli sometimes, but not always, have the same name and roughly the same shape: Small exemplars of the letter "A" might be a local target in the context of a large distractor letter, and a large letter "A" composed of small exemplars of some other distractor letter might be a global target. This procedural convention is conducive to use of the term *hierarchically structured stimuli* but is not generally necessary for the study of local–global attention (Navon, 1977; Robertson, 1996): Forests do not look like very large trees, and trees do not look like very small forests. Similarly, forests and trees do not have the same names. We therefore did not try to fully conform to a common but not universal convention for hierarchically structured stimuli with human participants, where local and global targets are often both orthographically and nominally similar.

Each stimulus had a target at one level and an irrelevant distractor at the other level; global targets were always composed of local distractor characters, and local targets always formed a global distractor character. As a result, no stimulus had targets simultaneously at both local and global levels, and every stimulus had a target at some level. That is, there was always exactly one target for any given stimulus.

Stimuli were generated in standard text mode and were presented on a black background on the CTX color monitor in the experimental chamber and on a second monitor in the control room. There were two different global targets for each bird. We composed all global targets by inserting various local distractors, white ASCII characters 3 mm wide × 5 mm high, in a 5 × 5 grid of characters that was approximately 15 mm wide × 34 mm high. For Birds 1 and 2, global targets were a line tilted up to the left (left key correct) or a line tilted up to the right (right key correct). For Birds 3, 4, and 5, global targets were a letter "H" (left key correct) or a letter "S" (right key correct). For Birds 1 and 2, local distractors consisted of either the letter "B" or the letter "X." For Birds 3, 4, and 5, local distractors consisted of either the letter "T" or the letter "E." Figure 1 represents the four global target–local distractor patterns for each bird. These representations appear similar to the actual stimuli but involve slight modifications imposed by the Apple printer on which they were printed.

There were also two different local targets. For Birds 1 and 2, they were the letter "T" (left key correct) or the letter "O" (right key correct). For Birds 3, 4, and 5, they were the letter "H" (left key correct) or the letter "S" (right key correct). We organized these two local targets to form a global distractor. For Birds 1 and 2, the global distractors were a vertical line or the letter "X." For Birds 3, 4, and 5, they were the letter "T" or the letter "E." Figure 1 shows the four local target and global distractor patterns for each bird. In summary, for each bird there were eight stimuli, four with local targets and four with global targets.

Visual angles subtended by the various stimuli were approximately as follows: For Birds 1 to 4, the visual angle subtended by global stimuli was approximately 21° vertical and 9° horizontal. Local stimuli subtended approximately 3° vertical and 2° horizontal. For Bird 5, global stimuli were approximately 16° vertical and 7° horizontal, and local stimuli were 2° vertical and 1° horizontal.

Trial structure. Each day's session consisted of 195 discrete trials. On each trial, a pigeon observed one of the eight hierarchically structured stimuli. A bird's task was to respond to whichever key, left or right, was correct for the particular target present in the hierarchically structured stimulus.

After a 2-s intertrial interval with the houselight on and the screen blank, a white warning rectangle (2.6 cm × 2.4 cm; height × width) appeared on the screen behind the center key. The first peck to the lit center key after 1 s elapsed turned it off and

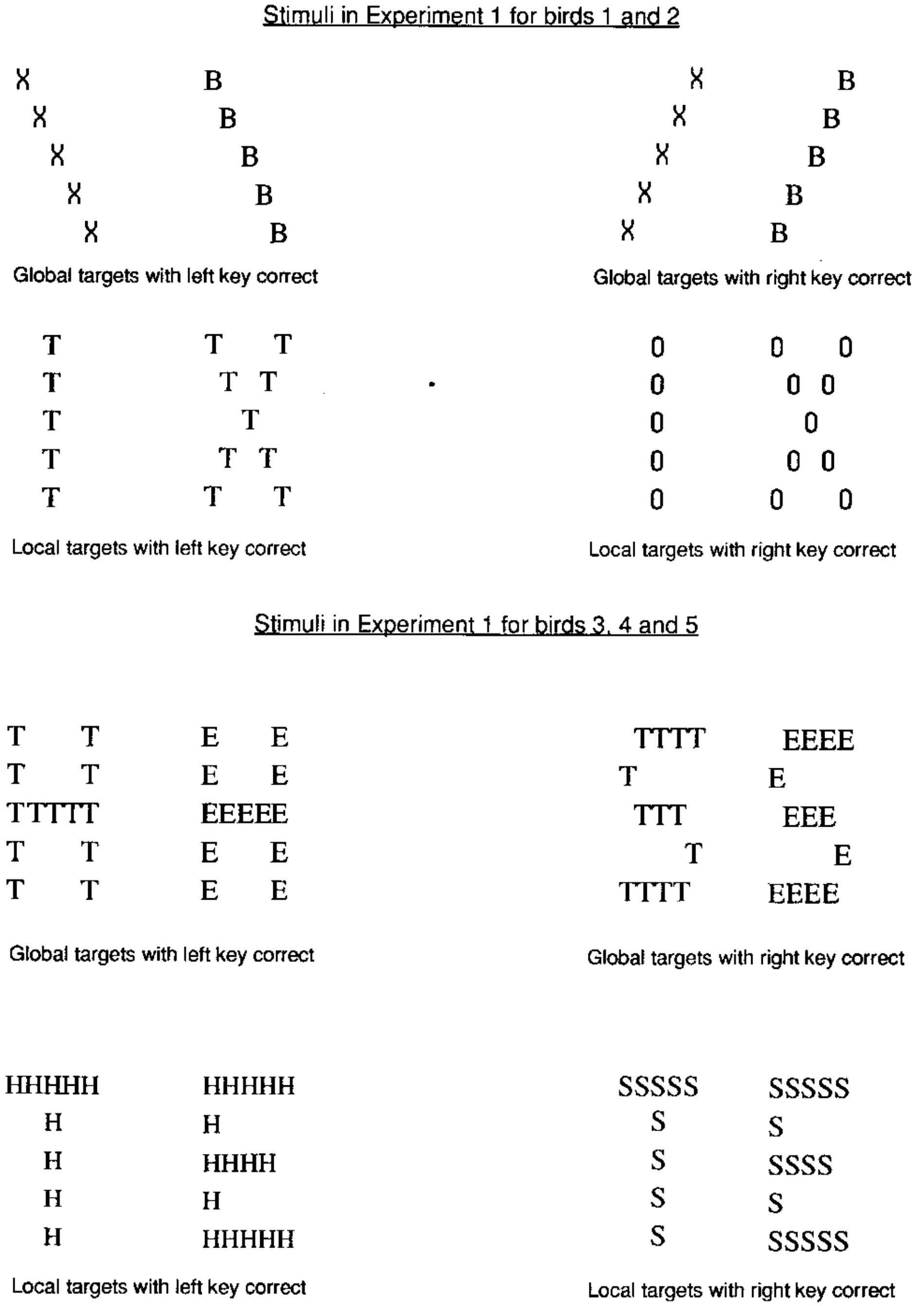

Figure 1. Stimuli in Experiment 1. Each stimulus contained a target stimulus at either the local or global level and an irrelevant distractor stimulus at the other, nontarget level.

randomly began either of two delays, 50 or 250 ms.[1] After the delay had elapsed, a hierarchically structured stimulus appeared behind the center key, and simultaneously, the two side keys were lit: Two white rectangles, each 2.6 cm × 2.4 cm, appeared on the screen, one behind the left key and one behind the right key.

The consequences of a peck to either lit side key depended on whether the peck was to the correct or the incorrect key. If the peck was to the correct side key, reinforcement was delivered with a probability of .4: The hopper light came on and the food hopper

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[1] This delay between the times when the warning light went off and the stimulus came on, functionally similar to a duration often referred to in the human literature as stimulus onset asynchrony (SOA), was incorporated in the procedure to investigate the temporal dynamics of attentional shifts. The two different values were determined by referring to the effects of different SOAs in the related spatial attention literature, where such SOAs often seem to diagnose different attentional processes (Posner, 1980). Nominal

was raised. (This partial reinforcement schedule for correct responses permitted a greater number of trials per day.) The 2-s intertrial interval began immediately after food was delivered or after the correct response was given, if it was not reinforced. If the peck was to the incorrect side key, a correction procedure was initiated, during which the stimulus and the side keys were turned off and the houselight blinked on and off every 0.5 s for 15 s. The side keys and the stimulus then reappeared simultaneously, and the trial proceeded until ultimately a correct response was made and a reinforcer was delivered with a probability of .4.

If no peck to a lit side key occurred within 10 s of stimulus onset, the correction procedure was initiated in the same way as after an incorrect side-key response.

Blocking of targets at a particular level. In any given condition, targets at one level, the primed level, appeared on a random 85% of the trials, and targets at the other level appeared on the remaining 15% of the trials. Each of the two targets at a particular level had equal probabilities of occurrence, as did the two corresponding distractors.

The first 3-day condition was a local condition, during which targets were at the local and global levels 85% and 15% of the time, respectively. Every 3 days thereafter, local and global priming conditions were alternated, for a total of six local biased conditions and six global biased conditions.

Pretraining. The task was complex and required correspondingly complex pretraining. The goal of pretraining was to achieve a high level of accuracy for both local and global target stimuli, with targets appearing equally often at the local and global levels. To achieve this objective, we manipulated the following: visual angle (varied by moving the screen closer to or farther away from the keys), partial versus continuous reinforcement, stimulus exposure duration, whether or not stimuli remained on after side keys were lit, the duration between center-key onset and stimulus onset, target and distractor letters, and the probability of targets at a particular level.

During initial pretraining, a bird was required to peck at the center key while the stimulus was present. The first peck after a minimum stimulus duration turned on the left and right choice keys. Initially, this duration was 5 s. When accuracy reached approximately 90%, the minimum stimulus duration was slowly reduced until no center key response was required to the stimulus; a bird simply pecked the center key with the warning light behind it, and this peck simultaneously turned on the stimulus and the left and right choice keys. Our elimination of the response requirement to the stimulus allowed for measures of both RT and accuracy. Two of the 7 birds failed to sustain at least 90% accuracy while stimulus duration was being reduced, and they were therefore dropped from the experiment during pretraining.

Targets appeared with equal probability at each level over at least the last 10 days of pretraining. The percentage of correct responses averaged over the five birds and the last 3 days of pretraining was 96.

Results

Performance is described in terms of two indexes, accuracy and RT. Responses on the first five trials of each session were excluded from the analysis to reduce the impact of any possible warm-up effects.

Table 1 shows accuracy (percentage correct responding) as a function of target level (local or global) and bias level (85% local target trials or 85% global target trials). Table 1 shows that accuracy averaged over all 12 three-day conditions and both target types was very high, 97%, and suggests that accuracy depended on target level, with accuracy higher for local targets. Table 1 also suggests that there was no priming in terms of accuracy; accuracy to global targets appears nearly identical during global and local bias conditions, as does accuracy to local targets. A three-way within-subject analysis of variance (ANOVA) with repeated measures (Target Level × Biased Level × Condition) suggested a trend toward higher accuracy for local targets, $F(1, 4) = 6.4$, $p < .065$. No other main effects or interactions were significant at the .05 level. The absence of a reliable interaction in the ANOVA between target level and biased level confirms the visual analysis from Table 1 that accuracy did not depend on which target level was primed, $F(1, 4) = 3.6$, $p < .13$. This failure of accuracy to reveal a priming effect is to be expected, given the very high overall accuracy and given that priming in analogous human tasks is typically defined, in part because of this same ceiling effect, in terms of facilitation of speed of responding, not accuracy.

In summary, in terms of accuracy, performance was very high, there was a trend toward a local precedence effect, and there was no priming effect.

Now let us consider the results in terms of the more typical measure, RTs for correct responses. We reported mean median RTs, which are often used to represent central tendency of RT distributions because of their asymmetric shape (e.g., see Robertson et al. 1993).

First, Did processing of either level display precedence over the other? Mean median RT, averaged over the 12 three-day blocks, was identical for local and global targets (762 ms). Thus, in terms of RT, there was no precedence effect.

Second, and most important for the purpose of the experiment, Did biasing targets at a level prime those targets, that is, facilitate speed of responding to them? The upper left panel in Figure 2 shows the overall group average and suggests that biasing targets at a specific level did facilitate speed of responding to targets at that level. RT was faster to local targets than to global targets when targets appeared more frequently at the local level. Similarly, RT was faster to global targets than to local targets when targets appeared more frequently at the global level. The upper left panel in Figure 2 therefore suggests that priming occurred at both global and local levels. A three-way within-subject

Table 1
Mean Percentage of Correct Responses for Experiment 1

Conditions	Local targets	Global targets
Global bias	97.9	95.2
Local bias	98.1	94.6
All	98.0	94.9

50- and 250-ms SOA durations were actually 55.9 and 255.0 ms because of timing limitations related to screen refresh rates and video gun synchronization times. As it turned out, no differences in performance were obtained for these two delays. Thus, this temporal variable is ignored in all the results presented in this article: All results are averages over these two SOAs.

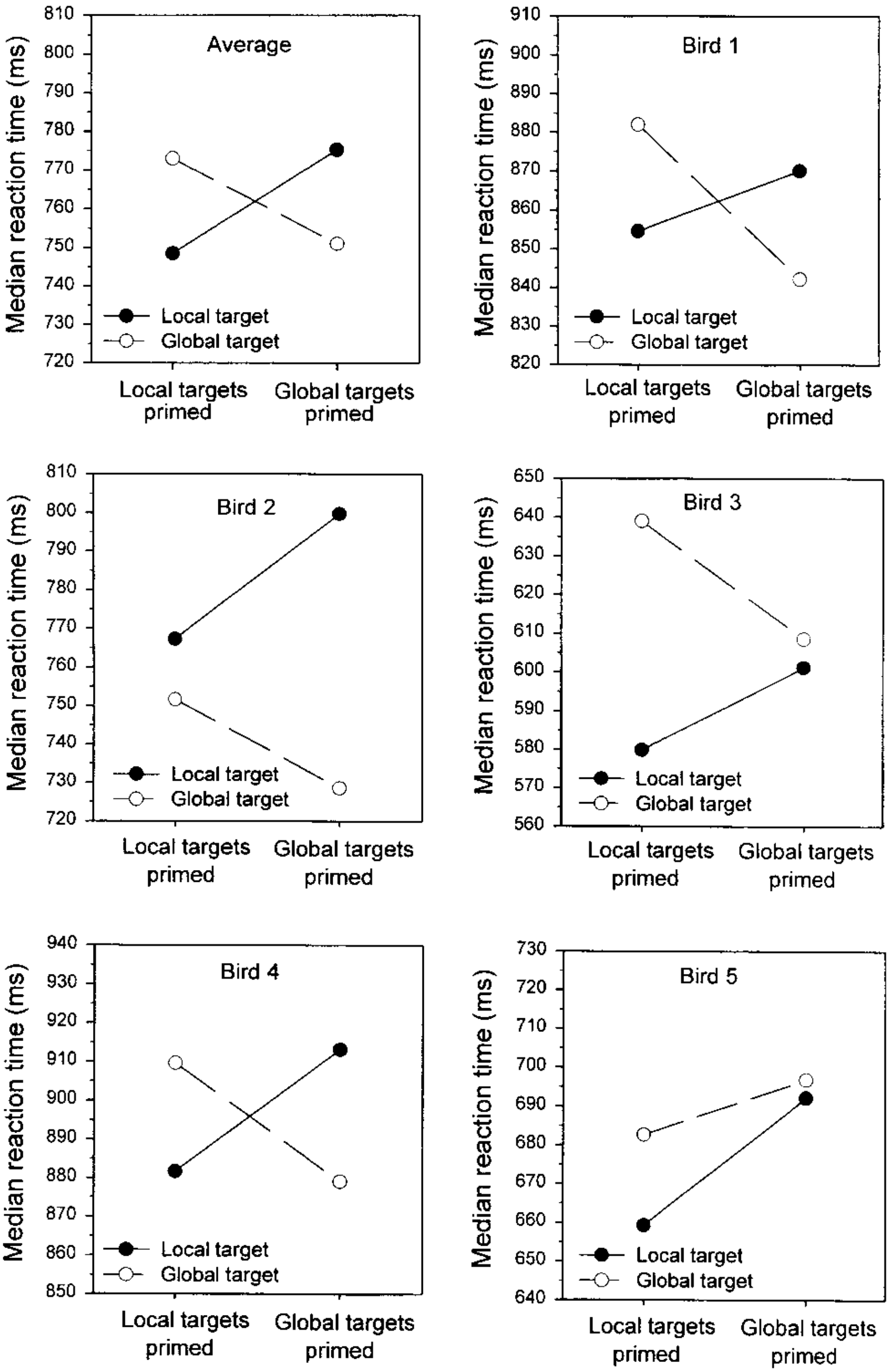

Figure 2. Reaction time to local targets and to global targets for the two priming conditions. Eighty-five percent of the targets were at either the local or the global level. The upper left panel shows that group average.

ANOVA with repeated measures (Target Level × Bias Level × Condition) confirms this visual inspection. There was a Target Level × Bias Level interaction, $F(1, 4) = 40.5$, $p < .003$, with no other reliable main effects or interactions. A Newman–Keuls' post hoc test showed that RT was faster to local targets than to global targets when targets appeared more frequently at the local level and that RT was faster to global targets than to local targets when targets appeared more frequently at the global level, ($p < .05$). In addition, RT to local stimuli was faster during local bias conditions than during global bias conditions, and RT to global stimuli was faster during global bias conditions than during local bias conditions ($p < .05$).

The remaining panels in Figure 2 show individual bird results, corresponding to the group results in the upper left panel. These individual results show that the average result in Figure 2 was not simply due to some of the birds showing a large priming effect when others showed perhaps smaller or even opposite effects. Individual panels in Figure 2 show that biasing a level facilitated speed of responding to targets at that level for each bird, with the solitary exception of priming of local targets for Bird 5, even though different birds displayed different precedence effects, some with the local level dominant (Birds 3 and 5), one with the global level dominant (Bird 2), and the other two with no dominance. (Recall that there was no reliable group dominance effect.)

Discussion

The principal goal of Experiment 1 was accomplished. Biasing targets at a particular level of perceptual analysis primed responding to targets at that level, as defined by faster RTs to those targets: Birds responded faster to more probable targets. This phenomenon defines a pigeon's ability to shift attention to a primed level, either local or global, of a complex stimulus. This ability is therefore not uniquely human.

This first demonstration of priming of attention to a local or global level of analysis does not indicate whether the effect is peripheral or central. In this sense, the effect resembles early demonstrations of short-term memory (Blough, 1959) and of spatial attention (Shimp & Friedrich, 1993), where linear chaining and various postural adjustments were viewed as possible peripheral mechanisms responsible for the phenomena. Short-term memory and spatial attention are now most commonly interpreted, of course, in terms of central mechanisms (Bushnell, 1995; Roberts, 1972; Roitblat, 1982; Shimp & Friedrich, 1993; N. M. Ward & Brown, 1996). The present demonstration does not resolve whether the priming obtained here is central or peripheral, but evidence from Experiment 1 suggests that a purely peripheral account may be unlikely.

For example, consider the following peripheral account, which may be as plausible as any. Suppose a bird could better identify either local or global features if it kept its head closer to, or further away from, the display, respectively. Biasing the local level might therefore encourage a bird to keep its head closer to the key panel and thereby produce a priming effect at the local level through faster processing of local than of global features. Similarly, biasing the global level might encourage a bird to keep its head further away and thus be able to process global features faster. This account correctly predicts a priming effect for both local and global targets, because within either type of biasing condition, targets at the more probable level would be processed more effectively and therefore would be more quickly identified than those at the less probable level. However, this peripheral account would probably incorrectly predict an overall local precedence in terms of RTs, because RTs to global targets would be longer, owing to the greater distance a bird's head would have to travel. (One would presumably assume more or less equal processing times for local and global targets.) Recall that not only was this effect not reliable, but overall RTs to local and global targets were virtually identical, so that this peripheral account does not seem to be entirely compatible with the present data. If past history with short-term memory and spatial attention is any guide, we may anticipate an increasing tendency to interpret shifts in attention between local and global levels in terms of central processes. Regardless of the role played by peripheral processes in the present effect, it continues to satisfy the behavioral definition of attentional priming to different levels of visual analysis and opens up for investigation the nature of the underlying mechanisms, including questions about peripheral or central processes. In particular, to investigate the role of peripheral head movements, we suggest exploring the role of visual angle, which in humans does not appear to greatly affect switching of attention between levels, although it may well affect dominance, with larger visual angles encouraging attention to the local level (Kinchla & Wolfe, 1979; Lamb & Robertson, 1990; but see Navon, 1981; Navon & Norman, 1983).

Recall that we obtained no overall precedence effect in terms of accuracy. Moreover, the literature currently displays global precedence (Cook, 1992a, 1992b; Cook et al., 1996; Honig, 1993), local precedence, or no precedence at all (Fulbright-Cavoto, 1994). This wide range of precedence effects in birds may suggest that numerous procedural differences encourage precedence at one level or the other and that precedence at any level is not so powerful that it cannot be overcome by appropriate training.

Lastly, our results suggest the advisability of looking at more than one dependent variable if a goal is to identify whether an attentional phenomenon exists. Consider that the existence of priming and precedence effects in Experiment 1 depends on whether phenomena are defined in terms of RTs or accuracy. Experiment 1 showed neither a precedence effect nor a priming effect in terms of accuracy, very likely because of the same ceiling effects that led investigators researching corresponding human local–global attention to report very high accuracy and then to report attentional phenomena only in terms of RT data (Kinchla & Wolfe, 1979; Navon, 1977; Robertson et al., 1993). Alternatively, in terms of RT, we found that there still was no precedence effect, but there was a clear priming effect. These results warn us that attentional effects may depend critically on the dependent variable. Given the current level of understanding of attentional phenomena in nonhuman animals, perhaps it may be important to report both RTs and accuracy when a central question asks whether an attentional effect exists, because the answer may depend on the dependent variable.

Experiment 2

Experiment 1 demonstrated priming of attention to wholes or to parts but did not control for some possible simple explanations. One way animals might solve the local–global task is to search for some unknown (to the experimenters) fixed pattern of features that generally, if not perfectly, distinguishes between stimuli associated with left- and right-key reinforcement. It is known that a somewhat related search behavior can be taught to pigeons with alphanumeric stimuli (D. S. Blough, 1992). Another way subjects might solve the local–global task is to memorize the eight specific stimulus patterns and associate each with a left or right response (Wright, Cook, Rivera, Sands, & Delius, 1988). To evaluate the likelihood that the pigeons developed such strategies on the basis of specific stimuli, rather than switched attention between levels, we ran transfer tests in which the original targets from Experiment 1 were preserved but the irrelevant distractors at the nontarget level were changed. Of course, a change in distractors might degrade performance simply by indirectly changing the appearance of a target itself, but to the extent to which such transfer tests cause relatively little degradation in performance, it would seem more likely that birds switch attention between local and global levels and less likely that birds search only for a specific set of features. In short, we asked in Experiment 2 whether performance suffered when distractors were novel.

Method

Animals and Apparatus

We used the same animals and apparatus as were used in Experiment 1.

Procedure

Immediately following the completion of Experiment 1, we conducted transfer tests in which the local and global distractors used in Experiment 1 were replaced with novel stimuli. Each of two transfer tests replaced one of the original distractors with a different novel distractor. For example, global target stimuli with the local distractor consisting of the letter "B" had the letter "B" changed to the letter "A."

Each transfer test lasted 5 days. The first 3 days in each 5-day test reinstated the task from Experiment 1, with exactly the same eight stimuli, but with equal base rates of local and global targets, so that in transfer tests, neither level was primed by appearing more often than the other. The last 2 days in each 5-day test involved a novel distractor, as shown in Figure 3. Thus, on the last 2 days of a transfer test, six of the original stimuli from Experiment 1 remained the same, and two were changed; a distractor, but never the target, changed.

The level at which a distractor changed was different across the transfer tests, with the first involving a change in a local distractor and the second involving a change in a global distractor. Figure 3 shows the stimuli with novel distractors.

Results

The basic question was, Did novel distractors impair performance? Or, alternatively, Were birds able to continue to respond to local and global targets in basically the same way, even when the irrelevant distractor at the other level was novel? Novelty of irrelevant distractors could affect performance in terms of either accuracy or RT.

Table 2 shows response accuracy for both transfer conditions. It shows mean percentage of correct responses to targets with novel distractors averaged over the 2 days (Days 4 and 5) and to those same targets on the preceding 2 days (Days 2 and 3) when the distractors were familiar. Although there was a slight decrease in percentage of correct responding with novel distractors, a repeated measures two-way within-subject ANOVA (Distractor Level × Novel vs. Familiar Distractor) showed there was no significant difference in accuracy on Days 2 and 3, when the distractors were familiar, compared with Days 4 and 5, when distractors were novel, $F(1, 4) = 3.4$, $p < .14$. No other main effects or interactions were significant.

The preceding analysis averaged transfer behavior over the entire 2 days following a distractor change. In principle, it would be possible for a bird to respond initially during a 2-day test to some fixed pattern of features common to both levels and then to learn quickly over the course of the 2-day test to respond to features unique to local or global levels. It is therefore important to see how a bird responded immediately following a distractor change. Accordingly, Table 2 also shows mean percentage of correct responses to targets with novel distractors based only on the first 10 presentations with novel distractors and on the first 10 presentations of those same targets on the preceding day with familiar distractors. Although there was a slight decrease in percentage of correct responding with novel distractors, a repeated measures two-way within-subject ANOVA (Distractor Level × Novel vs. Familiar Distractor) showed no significant difference, $F(1, 4) = 5.0, p < .09$. No other main effects or interactions were significant.

In addition, Table 2 shows mean median RT for both transfer tests. (Median RT was not analyzed for the first 10 trials of either baseline or transfer tests, owing to the excessive variability inherent in a sample of only 10 RTs.) An ANOVA shows there was no significant difference between response speed on Days 2 and 3 when the distractors were familiar and response speed on Days 4 and 5 when the distractors were novel, $F(1, 4) = 1.5, p < .29$. No other main effects or interactions were significant.

Discussion

The transfer tests clarify the nature of the attentional shifts obtained in Experiment 1. In particular, they control for the possibility that a bird solved the task of attending either to local or to global levels by looking instead for a specific feature or set of features across levels that permitted the bird to perform accurately. For instance, if local stimuli were different from global stimuli in terms of presence or absence of a particular feature, say a bright spot in the middle of the screen, then that feature could be the basis for accurate or rapid responding, and the resulting mechanism for discrimination might have little or nothing to do with perceptual levels.

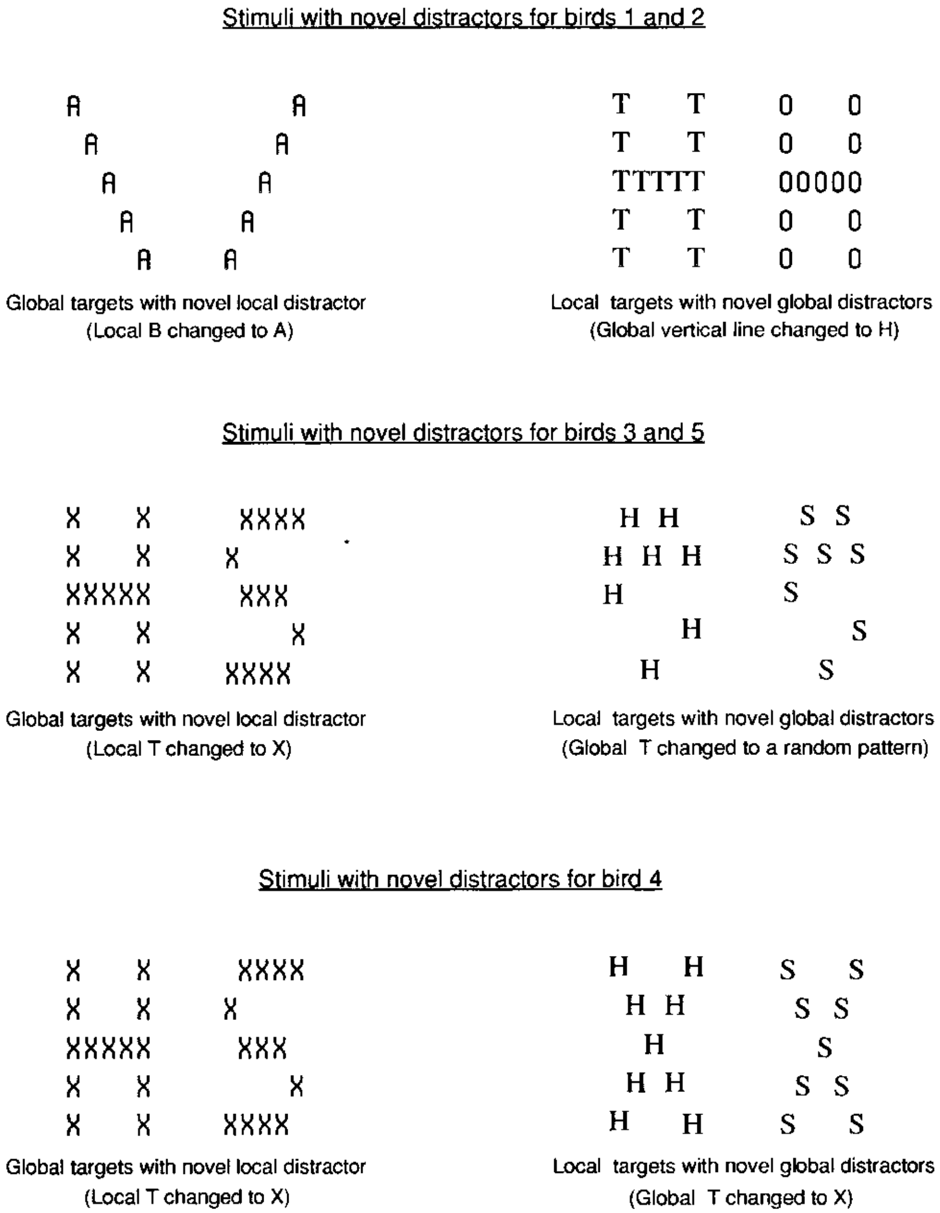

Figure 3. Stimuli with novel distractors in Experiment 2. Each stimulus contained a target at either the local or the global level and an irrelevant distractor at the other, nontarget level. In each of two transfer conditions, one familiar irrelevant distractor was changed to a novel irrelevant distractor. In the first and second transfer conditions, a local and global distractor, respectively, were changed.

The transfer tests also address the still more general possibility that birds memorized the eight specific stimulus patterns and associated each with a left or right response. There is evidence that pigeons can and do solve some perceptual problems in such a manner (e.g., see Wright et al., 1988). The transfer tests suggest that the birds did not base their performance on a few specific features unrelated to the difference between local and global levels and did not memorize specific entire stimulus patterns, because the novel irrelevant stimuli used in the transfer tests would have been expected to remove any such features or to significantly modify any such entire stimulus pattern.

According to either of these alternative explanations, accuracy, and perhaps response speed as well, on the transfer tests should have been substantially impaired on trials with novel distractors, yet the novel distractors had no reliable effect on either accuracy or response speed. The combination of the outcomes of Experiments 1 and 2 may be said essentially to define what it means to say there is an empirical attentional shift.

Table 2
Mean Percentage of Correct Responses and Mean Median Reaction Times (RTs) for Experiment 2

Stimulus condition	% correct	Median RT (ms)
Transfer Test 1		
Days 2–3 (familiar local distractor)	96	809
Days 4–5 (novel local distractor)	89	818
First 10 trials with familiar local distractor	94	
First 10 trials with novel local distractor	86	
Transfer Test 2		
Days 2–3 (familiar global distractor)	96	740
Days 4–5 (novel global distractor)	83	816
First 10 trials with familiar global distractor	98	
First 10 trials with novel global distractor	86	

General Discussion

The present experiments provide to our knowledge, the first explicit demonstration in nonhuman animals of the priming of shifts of attention between local and global levels of visual analysis. Priming was demonstrated by presenting more targets at a level and seeing that speed of responding was thereby facilitated to targets at that level.[2]

The priming effect demonstrated in this article shows that (a) nonhuman animals can shift visual attention between global and local levels of analysis and (b) these shifts depend flexibly on recent environmental experience. Such flexibility would seem to be a hallmark of an adaptive attentional system and is shared by at least one other nonhuman animal attentional system, namely, spatial attention. Pigeons (Shimp & Friedrich, 1993) and rats (Bushnell, 1995; N. M. Ward & Brown, 1996) can shift attention between two different spatial regions, and these attentional shifts are flexible in the sense that they depend on knowledge acquired from environmental experience. Spatial attention depends on base-rate likelihoods with which targets appear in different locations or on likelihoods with which trial-by-trial priming cues predict targets in different locations (Bushnell, 1995; Posner, 1980; Shimp & Friedrich, 1993; N. M. Ward & Brown, 1996). Thus, there is now evidence for at least two different types of flexible visual attentional systems in nonhuman animals: spatial attention, and, according to the present results, local–global attention.

The present results bear on a classic problem in visual perception: How does one's acquired knowledge affect what one sees? More specifically, how does what one expects to see affect what one sees (Bartley, 1958; Wertheimer, 1945; Wittgenstein, 1953)? An extreme answer to this question, that one sees virtually only what one knows, is well known in history and philosophy of science and is closely linked to the controversial epistemology variously known as social constructionism, contextualism, relativistic epistemology, and postmodernism (Goethe, quoted in Hanson, 1969, p. 105; Keller, 1985; Rorty, 1979). In the literature on human cognition, many sources of support exist for a more middle-ground position in terms of which perception is partly but not completely driven by acquired knowledge. Some well-established examples include the phenomena of phonemic restoration (Warren, 1970), the word superiority effect (Reicher, 1969), scene perception (Biederman, Glass, & Stacy, 1973), and several priming effects (Meyer & Schvaneveldt, 1971; Neely, 1991). Of course, the human local–global experiments on which the present experiments were based also contribute to this literature, because one possible mechanism for the priming effect is that an organism sees targets at an expected level more clearly, more quickly, or somehow more meaningfully than targets at a nonprimed level. All these experiments with human participants involve a role for language, either in the instructions read to participants or in expectations acquired through experience in the experiments. Demonstrations of an effect of acquired knowledge on seeing in nonhuman animals are therefore rarer and more controversial. The present experiments appear to provide such a demonstration because they were patterned so closely after the human experiments. Specifically, the birds were trained with different target base rates, and their acquired knowledge about base-rate biases affected what they saw.

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[2] Although the present study was not designed to examine the costs and benefits associated with attentional shifts to one level or the other, we note in passing that a crude cost–benefit analysis is nevertheless possible. Recall that neither level was primed in either the last 3 days of pretraining or the first 3 days of Experiment 2. In both cases targets were equally likely at each level. Thus, one can examine potential costs and benefits of priming the local or the global level by comparing the median reaction time with local and global targets averaged over those 6 days of equal-bias trials to the corresponding RTs averaged over the six local-bias conditions or over the six global-bias conditions. During the equal-bias contexts, average RTs to global targets and to local targets were identical, 767 ms. RT to stimuli with local targets was 749 ms and 775 ms, and RT to stimuli with global targets was 773 ms and 751 ms, during local- and global-bias conditions, respectively. Thus, RT in a neutral, equal-bias condition was intermediate, and therefore the data are consistent with the possibility that there are both costs and benefits associated with shifts in attention to a particular level. However, neither costs nor benefits were reliable by Newman–Keuls's post hoc tests conducted subsequent to an ANOVA showing a reliable Condition × Target Level interaction. Future research with suitably designed methods should clarify whether the present suggestive effects are generally reliable.

Behavioral ethology provides still another example of how experience can change what a bird sees. A bird searching for a target in a complex stimulus in the present experiments may in some ways resemble a predator searching for cryptic prey. The idea of a *search image* was developed to describe a temporary selection bias when birds forage for cryptic prey (de Ruiter, 1952; Tinbergen, 1960; see also Krebs, 1973; Pietrewicz & Kamil, 1981). More specifically, it has been suggested that "a search image is a perceptual expectancy set by repeated encounters with a particular type of prey" (Langley, Riley, Bond, & Goel, 1996, p. 150). If one further adds Tinbergen's (1960) characterization of a search image as involving a bird's learning to see a particular prey and his suggestion that a bird can simultaneously retain several search images, then one has a good beginning of a description of the present data on attention to local or global levels, as well as of the idea of a search image.

A search image is usually said to involve a bird's selectively attending to features (Langley, 1996; Langley et al., 1996). The present results encourage the view that a bird can selectively attend to one or another entire perceptual level, not just to specific stimulus features. This implies that a search image might be more flexible than others have previously suspected. In particular, if a bird has flexible attentional systems for spatial regions (Shimp & Friedrich, 1993) as well as for levels of perceptual analysis, then it is not obvious why these systems would not play a role in determining the function of a search image. If they do, then the conceptual gap between the idea of a search image, and the more general idea of a visual expectation, is narrowed. The latter notion, familiar from traditional Gestalt psychology and very common in contemporary cognitive psychology, is a visual representation that has much of the flexibility that we think of as part of everyday visual experience. Classic examples from nonhuman animal psychology are Kohler's (1925), Tolman & Honzik's (1930), and Krechevsky's (1932) descriptions of how animals solve problems by reorganizing mental visual images. The discovery of flexible attentional systems in nonhuman animals seems to make this type of description more plausible and seems to encourage a correspondingly more flexible notion of a search image.

We do not intend to imply that the processing of search images is identical to the processing of hierarchically structured stimuli, because in fact, methods by which the two types of processing are studied are different in several regards, including differences between real cryptic prey in naturalistic settings (de Ruiter, 1952; Tinbergen, 1960), or at least static images of real cryptic prey (Pietrewicz & Kamil, 1981) versus arbitrary ASCII characters in laboratory settings. Similarities nevertheless are striking from a cognitive perspective; both presumably impose a high perceptual load, both develop from repeated exposures to stimuli (D. S. Blough & P. M. Blough, 1997; P. M. Blough, 1991; Langley, 1996; Langley et al., 1996), and both are reversible. Perhaps future research will identify the properties of a search image that uniquely set it apart from other visual expectations acquired from experience. In the meantime, we suggest that it is useful to keep in mind P. M. Blough's (1989) succinct suggestion that a search image's general functional properties can be interpreted in terms of priming and attentional processes.

Finally, we emphasize that although we claim to have demonstrated the empirical phenomenon of local–global attentional shifts, we make no claims about having identified underlying mechanisms. If the corresponding human literature is any guide, it will be some time before these mechanisms are clear, because the human literature displays continuing debates over the nature of the processes underlying local–global attentional phenomena. Consider some possibilities that might apply to the present demonstration: One possible account of these attentional shifts is that they result from differing levels of active memory traces (e.g., Plaisted, 1997). Recall that stimuli with targets at the primed level occur more frequently than those with targets at the nonprimed level. Thus, on average, a memory trace for a stimulus with a target at the primed level is more likely to be active, or more highly active, than a memory trace for a stimulus with a target at the nonprimed level. As a result, perceptual processing might be more likely to involve more highly active traces on trials with targets at the primed level than on trials with targets at the nonprimed level. Perceptual processing might thereby be facilitated on more trials with primed targets than with nonprimed targets, resulting in faster responding.

Although attractive in its simplicity, such a hypothesis does not seem to account for local–global attentional shifts in humans (Robertson, 1996; Robertson et al., 1993). In addition, such a memory trace–decay model does not seem to account for sequential priming effects shown by pigeons in a visual search task (P. M. Blough & Lacourse, 1994). With this in mind, we are skeptical that such a memory trace theory will be found to completely explain local–global attentional shifts in nonhuman animals.

Another possible interpretation of the present local–global attentional shifts is that biasing targets at a level might promote a subject's expectation of a target at that level; an organism might learn to expect the more frequent target level and accordingly to respond faster, perhaps because it learns to sustain attention to the level at which most targets occur and more quickly perceive them when they appear. This interpretation is an adaptation of Navon's (1977) original argument for global precedence, is compatible with P. M. Blough and Lacourse's (1994) study of sequential priming in pigeons, and is related to classic Gestalt positions. It assigns a role to the establishment and retrieval of memory representations in the form of expectations, that is, memory processes are involved even in this account that otherwise emphasizes attention. Similarly, Shimp and Friedrich (1993) showed how several properties of spatial attention can be explained purely in terms of dynamic interactions among memory processes.

The distinction between purely attentional and purely memory processes is fuzzy, and in general we agree with Navon (1977) that "perceptual processing must be both input-driven and concept-driven" (p. 356). We therefore expect the mechanisms underlying local–global attention ultimately to be found to involve several dynamic interacting processes (McClelland, 1993), just as repetition or identity priming is often interpreted as the outcome of interactions between various bottom-up (attentional) and top-down (memory) processes (Desimone, Miller, Chelazzi, & Lueschow, 1995; Johnston, Hawley, & Farnham, 1993; Johnston & Schwarting, 1996; Tipper & Milliken, 1996).

The human literature on local–global attentional shifts suggests a variety of such processes, including (a) shifts in attention to different spatial frequencies, where lower and higher spatial frequencies may facilitate global and local attention, respectively (Shulman & Wilson, 1987), and/or (b) shifts in spatial properties of an attentional spotlight, where broader and narrower spatial patterns of attention presumably would facilitate global and local attention, respectively (Lamb & Robertson, 1988). We hope investigators will now exploit the opportunity to search for these and other possible mechanisms responsible for local–global attentional shifts in nonhuman animals.

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