

Cognitive Precedence for Local Information in Hierarchical Stimulus Processing by Pigeons

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Four experiments investigated the processing of hierarchical stimuli by pigeons. Using a 4 alternative divided-attention task, 4 pigeons were food-reinforced for accurately identifying letters arranged as either hierarchical global- or local-relevant stimuli or as size-matched filled stimuli. Experiment 1 found that task acquisition was faster with local-relevant than global-relevant stimuli. This difference was not due to letter size. Experiment 2 demonstrated successful transfer to a novel irrelevant letter configuration. Experiments 3 and 4 tested pigeons' responses to *conflict* probe stimuli composed of equally discriminable relevant letters at each level. These tests revealed that all of the pigeons showed a cognitive precedence for local information early in processing, with the pigeons using different cues to initiate the processing of global information. This local advantage contrasts with previously reported results for humans and pigeons but is similar to that reported for nonhuman primates. Alternatives attempting to reconcile these contrasting comparative results are considered.

A key issue in visual cognition is the relation between the processing of the entire object and the processing of its component parts. Of particular interest has been whether animals integrate the whole object from its component parts or instead perceive the whole object prior to the analysis of its parts. One classic approach to this question in humans has involved testing hierarchical stimuli (Navon, 1977, 1981, 1983). Hierarchical stimuli consist of a larger figure configured from smaller component shapes (see letter examples in Figure 1). The *global level* of these stimuli is defined by the larger letter that is formed from the smaller letters, whereas the *local level* is defined by the smaller component letters. In humans, the evidence has suggested that, all things being equal, the overall or global configuration of such stimuli receives greater priority in conscious perception than do local details (Hoffman, 1980; Kinchla & Wolfe, 1979; Martin, 1979; Miller, 1981; Navon, 1977, 1981, 1983; Navon & Norman, 1983).

Do other highly visual animals, such as nonhuman primates and birds, show a similar global advantage in the processing of hierarchical stimuli? For some time, there has been good evidence that both local and global information can exert discriminative control over performance in animals. For instance, we found that pigeons can be easily trained to respond to the global organization of textured hierarchical stimuli (Cook, 1992a, 1992b, 1992c, 1993; Cook, Cavoto, & Cavoto, 1996). In contrast, Cerella (1980) found

that pigeons can be controlled by the local features of a complex visual form. Such findings indicate sensitivity to both levels of organization but do not reveal much about the perceptual and cognitive processes responsible for the interaction between these different types of stimulus control.

Recently, a handful of studies have begun to investigate this type of compound stimulus control in nonhuman animals using hierarchical stimuli similar to those tested with humans. The animals are tested with stimuli in which information relevant to reward is presented at either the local or global level. Figure 1 shows some illustrative examples (although the stimuli and details vary slightly between different experiments). If *T* were the relevant letter, it could be presented as a set of repeated local *T*s arranged to form a global irrelevant *O* (i.e., no discriminative response is appropriate for this letter). This would be an example of a local-relevant display. Likewise, a set of local irrelevant *O*s could be arranged to form a global *T*. This would be an example of a global-relevant display. In both conditions the animals need to make a discriminative response based on the presence of the *T*. An animal's discrimination of this information at each level is then compared using either reaction time (RT) or accuracy measures.

Testing baboons and chimpanzees in a visual search task, Fagot and his colleagues (Deruelle & Fagot, 1998; Fagot & Deruelle, 1997; Fagot & Tomonaga, 1999) found a local advantage (i.e., faster RTs or higher accuracy with local-relevant displays) in the processing of hierarchical stimuli, especially with sparse element arrangements. In contrast, tests with humans revealed the standard global advantage using the same stimuli. This research group argued that nonhuman primates have difficulties with global forms in part because an additional process, present in humans, is needed to integrate spaced elements into a global configuration.

Fremouw, Herbranson, and Shimp (1998) also recently tested pigeons in a hierarchical stimulus processing task. Manipulating the relative probabilities of local-relevant or global-relevant displays within a session, they found faster choice responses to the more frequently tested level. That is, when local displays were

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This research, and its written preparation by Robert G. Cook, was supported by grants from the National Science Foundation. A portion of these data was presented at the 1994 meeting of the Eastern Psychological Association. Additional material and examples of the display types described in this article can be found at Robert G. Cook's website: <http://www.pigeon.psy.tufts.edu/>.

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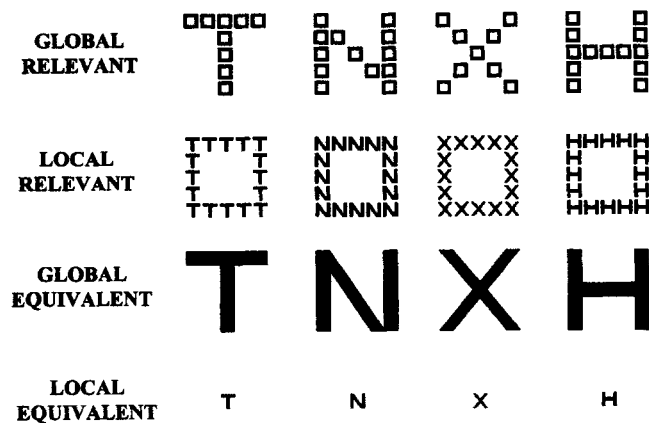


Figure 1. Examples of the four stimulus conditions tested in Experiment 1. Each condition was tested at three different sizes.

more common, the pigeons showed a local advantage in responding faster to the test stimuli on such trials. When global displays were more frequent, they showed a global advantage, responding faster on globally relevant trials. Fremouw et al. suggested these frequency priming data indicate pigeons can flexibly shift attention between the levels of hierarchically arranged stimuli.

The experiments reported in this article also tested pigeons with hierarchical stimuli, with the similar goal of examining how the different levels of hierarchical stimuli are processed. Although they were conducted before the studies described in the two preceding paragraphs (Fulbright-Cavoto, 1994), we think they help to clarify further these recent animal studies because of procedural improvements that help in assessing the interaction between global and local stimulus control.

It is important to note that just because an animal accurately performs a discrimination with globally and locally relevant stimuli, this is no guarantee that the controlling factors are specifically contained within those different levels. Because of its relevance to the current work, consider for the moment the stimuli and testing procedures used by Fremouw et al. (1998). They used only one size of stimuli in their task, and these always appeared at the same location on the computer screen. Because of this, the pigeons could have learned to perform their local discrimination on the basis of element identity (*S* vs. *H*), whereas performing their global discrimination on the basis of the number or separation of the local elements located in a small area of the display (e.g., the bottom line of elements, two separated *T*s or *E*s vs. four grouped *E*s or *T*s; see Fremouw et al.'s Figure 1, p. 281). This raises the possibility that their birds could have been looking at only a local portion of a global-relevant display and still performed accurately. Because of such possibilities, at least two criteria should be met in designing global-local discriminations with animals.

First, every effort should be made to prevent stimulus features other than the relevant ones from controlling performance at each level. We took three actions in the current study to prohibit this problem. One, we concurrently tested our hierarchical stimuli at three different sizes. Two, we presented our stimuli at variable and unpredictable locations on the screen. Three, we used a large number of different relevant letters in forming our hierarchical stimuli. Each of these tactics intuitively reduces the chance that

features extraneous to the required letter discrimination could have come to control our pigeons' choice behavior.

Second, even with the above controls, it is desirable to determine that the same discriminative features are controlling performance at both the global and local levels. Even if an animal is accurately extracting information from both levels it should be demonstrated that it is the same relevant information. Several techniques are available for doing this. One might be to train a discrimination at one level and then examine the degree of transfer to the other level. Another method is to look at the pattern of choice or confusion errors among the relevant letters to be discriminated. If the same features control performance at each level, the pattern of choice errors at each level should mimic one another. Because we used four relevant letters in the current study, we adopted the latter method (see the General Discussion section).

In total, we conducted four experiments examining how pigeons processed hierarchically arranged letter stimuli. Experiment 1 examined in what order pigeons learned to discriminate the global and local levels of hierarchical stimuli. Experiment 2 examined discrimination transfer to stimuli composed of novel irrelevant characters. Experiment 3 tested conflict probe stimuli to assess which level was preferentially processed by the birds. Experiment 4 tested these same conflict probe stimuli at controlled stimulus durations to explore the rate and order at which global and local information became available from these stimuli.

Experiment 1

Experiment 1 focused on three issues. First, could pigeons learn to identify the global and local letters of our hierarchical stimuli? Second, would they learn to identify letters from one level more quickly than the other? Third, how would this acquisition compare with conditions testing small and large letters that had only one level of organization? To address these questions, four relevant letters (*T*, *N*, *X*, and *H*) were used to create four stimulus conditions, two having hierarchical arrangements and two testing size-matched solid forms.

The two types of hierarchical stimuli were composed of a combination of relevant letters and an irrelevant letter. The global-relevant hierarchical stimuli (top row of Figure 1) consisted of a local irrelevant letter (*O* in the first experiment) globally arranged to form the four relevant letters. In these stimuli, only the global level contained information relevant to the subsequent four-alternative choice test. The local-relevant hierarchical stimuli (second row of Figure 1) were composed of the same relevant letters and used the irrelevant letter *O* at the global level. As such, only the local level of these stimuli contained information relevant to the subsequent test. Only one type of organizational level was relevant on any trial with the four relevant letters appearing equally often at both levels.

The other two stimulus conditions tested the same four relevant letters as single solid forms matched in size to the corresponding relevant conditions. The global-equivalent stimuli (third row of Figure 1) were matched to the size of the global-relevant stimuli. The local-equivalent stimuli (bottom row of Figure 1) were simply the local letters used to create the hierarchical stimuli presented as a single letter.

These four conditions were then tested using a four-alternative choice procedure. After the presentation of one of these four

stimulus conditions at a random location within a portion of the computer screen and at one of three size (large, medium, small), four choice stimuli appeared each in a separate corner of the screen. Each choice stimulus was associated with a different relevant letter, and each bird had a different choice stimulus-letter mapping. The pigeons' task was to choose the choice stimulus associated with the relevant letter presented on that trial.

Method

Animals

Four naive male White Carneaux pigeons (*Columba livia*, Palmetto Pigeon Plant, Sumter, SC) were tested. They were maintained at 80% of their free-feeding weights during testing, with free access to water and grit in their home cages.

Apparatus

Testing was conducted in a flat-black Plexiglas chamber (36 cm wide \times 32 cm deep \times 38 cm high). Stimuli were presented on a color computer monitor (NEC Multisync 2A; Wooddale, IL) visible through a 26 \times 18 cm viewing window in the middle of the front panel. The viewing window's bottom edge was 15 cm above the chamber floor. A thin piece of glass mounted in this window protected the monitor. Pecks to the monitor screen were detected by an infrared LED touchscreen (resolution of 80 \times 48 locations; EMS Systems, Champaign, IL) mounted behind a 40-mm-wide Plexiglas ledge that went around the inside edge of the viewing window. A 28V houselight was located in the ceiling and was illuminated at all times, except when an incorrect choice was made. A food hopper was located in the middle of the front panel, its access hole flush to the floor.

A 386-class computer controlled all experimental events. A video card (VGA Wonder; ATI Technologies, Scarborough, Ontario) controlled the monitor in the VGA graphics mode (800 \times 600 pixels). Computer-controlled relays (Metrabyte, Taunton, MA) operated the hopper and houselight. Stimulus and event programming were done with QuickBasic (Microsoft, Redmond, WA) with an attached graphics library (Xgraf, Pittsburgh, PA).

Stimulus Conditions

The two solid (global- and local-equivalent) and two hierarchical (global- and local-relevant) stimulus conditions were magenta in color (SVGA Color #5). Global- and local-relevant stimuli were composed from four relevant letters (*T*, *N*, *X*, and *H*) and the irrelevant letter *O*. Multiple small *O*s forming a larger relevant letter composed each global-relevant stimulus. A larger *O* configuration formed of small relevant letters composed the locally relevant condition. The global letter was 6 times larger than the component local letters. The spacing between the local letters ranged from 0.25 mm to 2 mm depending on the presentation size (see below). The global-equivalent and local-equivalent stimuli consisted of a single filled relevant letter equivalent in size to the global-relevant or local-relevant letters. These four conditions were tested at three different sizes. The global character of the large presentation size was 42 mm², and its local letters were 7 mm² in size. The global character of the medium presentation size was 30 mm², and its local letters were 5 mm² in size. The global character of the small presentation size was 21 mm², and its local letters were 3.5 mm² in size. Altogether, 48 unique stimuli were tested (4 relevant letters \times 3 sizes \times 4 stimulus conditions). From trial to trial during training, these 48 stimuli were presented at a randomized location within an unmarked 9-cm² viewing area of the computer screen.

Each of the four relevant letters was associated with a different choice stimulus. Choice stimuli were consistently located at a different corner of

the viewing area and separated by 9 cm from each other. These choice stimuli were 3-cm² squares and differed from each other in color, fill pattern, and spatial location. Each bird had a different mapping of the relevant letters and choice stimuli. Because there were four choice alternatives on each trial, chance performance in this task was 25% correct.

Procedure

Initial training. The pigeons were autoshaped to peck a 2.5-cm white circular ready signal randomly located within the 9-cm² viewing area. Once pecking at the ready signal was established, the 48 training stimuli were added to the autoshaping sequence. Immediately after a peck to the ready signal, these stimuli were displayed for 20 s or until pigeons emitted one peck at the stimulus. Once the pigeons were consistently pecking at these stimuli, then the correct choice stimulus for that trial's condition was added to this sequence. After pecks to the ready signal and stimulus display, this choice stimulus was illuminated for 20 s or until one peck was directed at the choice stimulus, either of which raised the food hopper. When the pigeons responded to all three events, the peck requirements were gradually increased to the letter stimulus (1–10 pecks per trial determined randomly) and choice stimulus (3 pecks).

Discrimination training: Phase 1. Discrimination training began when all four choice stimuli were illuminated at the time of test. In these sessions, each trial began with a peck to the randomly located ready signal, followed by the presentation of 1 of the 48 training stimuli at a new random location. This training stimulus was pecked 1 to 10 times (randomly determined on each trial), at which point the four choice stimuli appeared. A correct choice, defined by three cumulative pecks to the correct choice stimulus, turned off all stimuli and resulted in 2.5 s of food reinforcement. An incorrect response, defined by three cumulative pecks to any one of the three incorrect choice stimuli, darkened the screen and extinguished the houselight for 10 s. A 5-s inter-trial interval (ITI) separated each trial.

Each daily 144-trial session consisted of three 48 trial blocks. Each block consisted of 12 global-relevant (each relevant letter and size tested once), 12 local-relevant, 12 global-equivalent, and 12 local-equivalent stimuli. The order of testing within each 48-trial block was randomized. During this training, a correction procedure was implemented for two consecutive sessions after any session in which one of the four choice stimuli was selected more than 80% or less than 5% of the time. During correction procedure sessions, incorrect trials were repeated until responded to correctly. Excluding these rare correction procedure sessions, Phase 1 of the experiment lasted 35 sessions.

Discrimination training: Phases 2 and 3. Because initial performance with global-relevant stimuli was mediocre, two additional phases of training were implemented to improve performance. Phase 2 consisted of 26 sessions in which only global or local stimuli were alternatively tested across sessions. The global sessions tested 72 global-relevant and 72 global-equivalent stimuli. The local sessions tested 72 local-relevant and 72 local-equivalent stimuli. After 8 sessions of this phase, a fourth smaller size (10-cm² global letter; 1.5-mm² local letter) was briefly introduced and tested. These smaller stimuli were tested along with the other three sizes for the remaining 18 sessions of Phase 2. As the local letters of this new size proved too hard for the pigeons to discriminate, their testing was discontinued and their data excluded from any analyses.

Phase 3 began immediately after Phase 2. It consisted of a series of three-session blocks. The first two sessions of a block consisted of 120-trial sessions testing only global-relevant stimuli, followed by one 144-trial session testing all four stimulus conditions as in Phase 1. Phase 3 continued until performance on global-relevant stimuli exceeded 65% for three out of four consecutive sessions for each bird. Phases 2 or 3 involved no correction procedures. Immediately after Phase 3, sessions testing only global-relevant stimuli were discontinued and 10 standard 144-trial sessions conducted to evaluate postacquisition performance.

Results

Figure 2 displays the mean percentage of correct choices for the four stimulus conditions across the three training phases. Overall, the pigeons learned to identify the local-relevant stimuli the fastest, followed by the global-equivalent, then the local-equivalent, and last the global-relevant stimulus condition. Analyses comparing acquisition rates among these conditions focused on Phase 1, as it represented the pigeons' initial reaction to the stimuli and equated the number of stimulus presentations both within and across sessions.

Acquisition

A three-way repeated measure analysis of variance (ANOVA; Condition \times Stimulus Size \times 5-Session Block) comparing accuracy in the global-relevant and local-relevant conditions across Phase 1 revealed a significant Condition \times Session interaction, $F(6, 18) = 20.21$ (an alpha level of $p \leq .05$ was used to evaluate all statistical analyses), confirming that the pigeons learned to discriminate the local-relevant condition significantly faster than the global-relevant condition. Stimulus size had little effect on acquisition rate, as this ANOVA found no significant main effect for stimulus size, $F(2, 6) = 3.95$, or its interaction with session block, $F(12, 36) = 1.10$, or condition, $F(2, 6) = 3.89$.

An identical ANOVA compared accuracy in the global-equivalent and local-equivalent conditions. As suggested in Figure 2, no significant difference in accuracy was found between these two conditions. Unlike the hierarchical stimuli, stimulus size did have a significant effect on accuracy with these stimuli, $F(2, 6) = 17.14$, with the smaller size being more difficult than the larger ones (more details provided in the analysis of postacquisition performance).

We next compared accuracy between the global-relevant and global-equivalent conditions and local-relevant and local-equivalent conditions, respectively. These analyses revealed that accuracy was significantly higher in the global-equivalent condition than in the global-relevant condition, $F(1, 3) = 45.7$. In

contrast, the local-relevant condition was discriminated significantly better than the local-equivalent condition, $F(1, 3) = 14.24$.

Postacquisition Testing

The birds steadily improved in all conditions during training Phases 2 and 3, with the global relevant condition benefiting the most because of the extra training it received. Postacquisition performance was evaluated by looking at the 10 sessions conducted upon completion of Phase 3 training. Mean accuracy for the four stimulus conditions over these sessions was global equivalent = 79.6%, local equivalent = 63.9%, global relevant = 68.4%, and local relevant = 80.5%.

A two-way repeated measures ANOVA (Stimulus Condition \times Size) comparing the two local conditions revealed that local-relevant stimuli were discriminated significantly better than local-equivalent stimuli, $F(1, 3) = 14.9$. This is a form of redundancy effect, as these two conditions differed only in element number and arrangement. There was also a main effect of stimulus size, $F(2, 6) = 23.9$, with larger local letters supporting better accuracy than smaller (large = 80.6%, medium = 74.6%, small = 61.4%). There was no significant interaction between condition and size.

An identical ANOVA comparing the two global conditions found that the global-equivalent condition supported significantly higher accuracy than did the global-relevant condition, $F(1, 3) = 10.4$. Unlike the above two local conditions, no significant main effect or interaction with stimulus size was found with size supporting similar levels of performance (large = 74.6%, medium = 74.8%, small = 72.3%). There was again no significant interaction between condition and size.

An identical ANOVA just comparing the global- and local-relevant conditions confirmed that the latter condition's accuracy was still significantly higher, despite the extra training of Phases 2 and 3, $F(1, 3) = 9.7$. There was also a significant interaction between condition and size, $F(2, 6) = 10.6$, as performance with local-relevant stimuli increased with size, whereas performance with the global-relevant stimuli did not vary (compare means reported above).

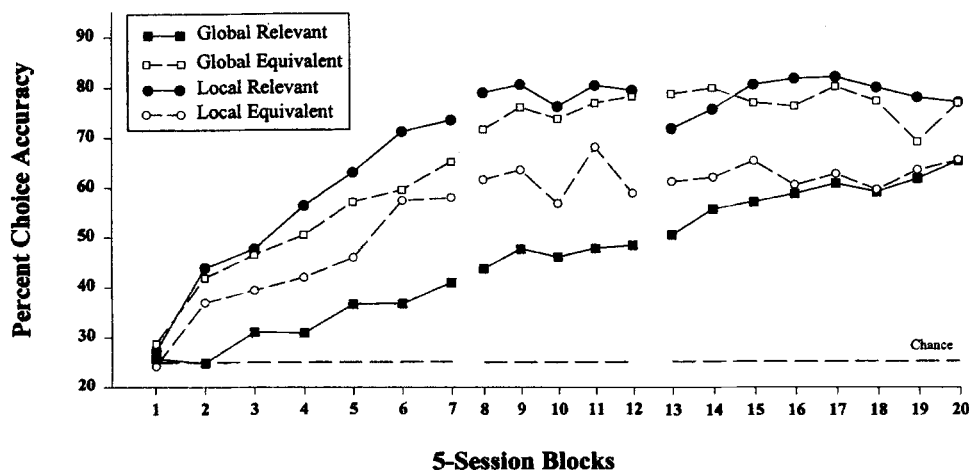


Figure 2. Choice accuracy for the four stimulus conditions conducted during acquisition. Each panel represents slightly different changes in the procedures designed to facilitate learning.

Finally we compared the global- and local-equivalent conditions. This comparison evaluates the simple effect of stimulus size on the letter discrimination. There was no effect of stimulus size for the global-equivalent condition (large = 80.6, medium = 79.4, small = 78.7), but performance did deteriorate with the decreasingly smaller letter sizes tested in the local-equivalent condition (large = 72.6, medium = 64.5, small = 54.5); although they were physically smaller than the global-equivalent condition (see *Method* section), we have kept their labels consistent with their use in the remainder of the article.

We also examined their choice RTs from the onset of the choice stimuli to their first peck at one of them. Between stimulus conditions, we found no significant differences (mean RT: global relevant = 740 ms, local relevant = 807 ms, global equivalent = 771 ms), except for an overall slower RT in the local-equivalent condition (947 ms). There were no significant effects as a function of stimulus size (small = 842 ms, medium = 806 ms, large 801 ms). This pattern held throughout the remaining experiments as these pigeons showed little change in the timing of their choice behavior. This was most likely because the response contingency required to the stimuli put little value in making speeded responses to the choice stimuli.

Discussion

The main finding of Experiment 1 was that pigeons showed a local advantage in accuracy with these hierarchical stimuli. They learned to discriminate the local letters of the hierarchical stimuli faster and to a higher level of accuracy than they did the global letters. We were a little surprised by this, in part because of the variable size and location manipulations we had used. As these manipulations were implemented to ensure that the pigeons had to process the entire stimulus configuration, they would seem to require that some form of global localization occur prior to processing the letters of either level. Such considerations had us originally thinking it might be more difficult to train the local discriminations instead. This was clearly not the case.

Why did the hierarchical conditions differ? The greater difficulty of the global-relevant discrimination cannot be attributed to its larger overall size. The high level of accuracy in the size-matched global-equivalent condition indicates that large solid stimuli readily support accurate letter discrimination. In fact, performance was best with the larger stimulus sizes in such conditions. Rather than a constraint imposed by its size, the poorer performance with global-relevant stimuli might be attributable to a difficulty in processing its overall arrangement. Perhaps the pigeons had trouble integrating the disconnected and separated local elements into a global organization that could be identified as one of the relevant letters. This integration failure hypothesis is similar to the one proposed by Fagot (Deruelle & Fagot, 1998; Fagot & Tomonaga, 1999) for the local advantage found in studies of nonhuman primates. If so, it is a problem that decreases with experience as the birds gradually improved their performance in the global-relevant condition.

Further insight into the local advantage also comes from a previously unreported benefit of element redundancy in the local-relevant condition. This redundancy gain is seen in the superior performance of the local-relevant condition in comparison with the single element local-equivalent condition. The reason for this gain

is not clear, but one possibility is that the repeated letter elements of the local-relevant condition may permit the critical features to remain in view for functionally longer periods of time as the pigeons move their heads about in responding to the display. The greater visual angle of the local-relevant condition may also have been a factor, especially if the pigeons obstructed their own view of the equivalent condition's single element as they responded to it. The slightly slower RTs on these single-element trials offer some support for the latter idea.

Regardless, our pigeons demonstrated a clear local advantage both during learning and at asymptote with these hierarchical stimuli, a finding that contrasts with those previously reported for pigeons by Fremouw et al. (1998). Why do Fremouw et al.'s and our pigeons appear to differ so in a task whose core inspiration is essentially the same? At asymptote, their pigeons performed at equal and high levels of accuracy in both the global- and local-relevant conditions (> 95%). No learning measures are reported, so it is impossible to assess the rate at which this performance was attained for each condition. There are hints in their methods that the training procedures were complex, requiring a number of different manipulations, but there are no indications that the learning of the global and local conditions differed from one another in any significant way. Further speculations about this difference are reserved for the general discussion, but in the meantime the next three experiments explored the local advantage detected in our pigeons.

Experiment 2

Experiment 2 investigated how changes in the nature of the irrelevant letter influenced the global- and local-relevant discriminations. We introduced and transfer tested a novel irrelevant letter, *S*, in forming the two different hierarchical conditions. The purpose of Experiment 2 was to examine whether the pigeons were attending to the generalized letter patterns in these conditions. One possibility is that the pigeons had memorized responses to stimulus-specific features associated with these conditions during Experiment 1, rather than processing the form of the letters as intended. Although the variations in letter size were included to help prevent this, the current test provided a concrete examination of this idea.

Method

Animals and Apparatus

The pigeons and apparatus were the same as in Experiment 1.

Procedure

The same relevant letters were used as in Experiment 1. For this test, two new variations of the global-relevant and local-relevant hierarchical conditions were created. This was done by using a novel irrelevant letter block, *S*, to form each of these conditions at each of the three presentation sizes. These novel irrelevant conditions were tested over 12 test sessions conducted upon completion of Experiment 1. Each of these sessions consisted of 168 trials. The first 48 trials tested the original 48 training stimuli once. The remaining 120 trials consisted of two additional blocks of testing, with the original 48 stimuli randomly intermixed once with the 12 global-relevant *S* and once with the 12 local-relevant *S* transfer trials (each letter

and size tested once). The consequences for correct and incorrect choices on these transfer trials were the same as on baseline trials.

Results and Discussion

The global- and local-relevant conditions formed from a novel irrelevant letter showed clear evidence of transfer. Figure 3 shows accuracy for the global- and local-relevant conditions constructed from the familiar irrelevant letter *O* (filled symbols) and the novel letter *S* (open symbols). A four-way repeated measures ANOVA, Stimulus Condition (global relevant/local relevant) \times Size \times Irrelevant Letter (*O* vs. *S*) \times Sessions, on choice accuracy revealed no significant main effect or other interactions with irrelevant letter (mean *S* accuracy = 74.9%; mean *O* accuracy = 77.3). Similar to Experiment 1, there was a significant difference between local- (87%) and global-relevant accuracy (65.3%), $F(1, 3) = 33.7$. Although it appeared that the global-relevant condition showed reduced accuracy with the new letter on the first day, several different analyses failed to find any statistical support for this. Performance with the two equivalent conditions was essentially identical to that reported for Experiment 1 and is not further described.

Changing the irrelevant letter of these hierarchical stimuli had little effect on choice accuracy. This result indicates that item memorization was not an important factor in performing the current discrimination and is consistent with the idea that the pigeons were attending to the local and global letters as intended. In this regard, our experimental results are consistent with those reported by Fremouw et al. (1998), who conducted a similar experiment, with an identical intent, obtained a comparable outcome, and drew an analogous conclusion.

Experiment 3

The first two experiments found that pigeons can process relevant letter information from both levels of a hierarchically ar-

ranged stimulus. In doing so, however, our pigeons showed a clear local advantage, consistently showing higher accuracy in the local-relevant condition. These results did not, however, provide any concrete information about the order in which the pigeons processed the global and local levels. The next two experiments attempted to do so. We used probe stimuli in which relevant letters were simultaneously present at both levels. By examining the pigeons' reactions to such probe stimuli one can study the competitive and cooperative control between the stimulus information present at each level.

Experiment 3 assessed performance with two such types of probe stimuli. *Conflict* stimuli were made by combining different relevant letters at the global and local levels (e.g., a global *X* formed from the arrangement of local *Ns*). *Consistent* stimuli were made by having the same relevant letter at each of the two processing levels (e.g., global *N* formed from local *Ns*). These stimuli were then tested under conditions in which there was a fixed opportunity to process the relevant information from the probe stimuli.

Assuming that choice behavior is a direct function of the amount of cognitive processing given over to a particular level during its presentation, much as in selective attention research with dimensional compound stimuli (Cook, Riley, & Brown, 1992; Riley & Leith, 1976), three possible outcomes were anticipated. If pigeons, like humans, give greater cognitive emphasis or priority to the global-level information, then the majority of choices after conflict probe stimuli should be directed to the relevant letter presented at that level (global > local). On the other hand, if the local level receives this cognitive emphasis, then the majority of choice responses should be directed to the letter presented at that level (local > global). A third possibility is that cognitive processing is equally distributed between the global and local levels within a trial (or exclusively, but randomly, between levels on a between-trials basis). In this case, one would expect that both the relevant

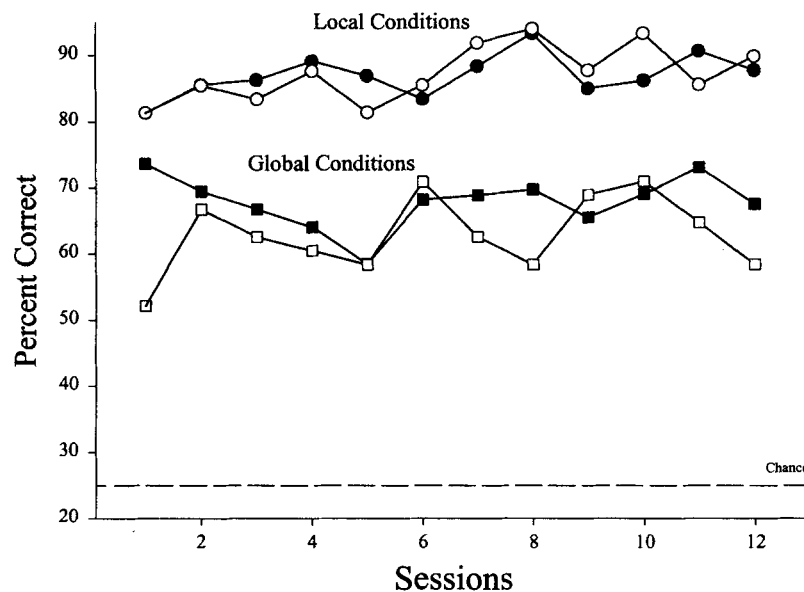


Figure 3. Choice accuracy across sessions during the introduction of a new irrelevant letter *S* in Experiment 2. The filled symbols denote the training conditions using the familiar irrelevant letter *O*. The open symbols denote the transfer condition for the new irrelevant letter.

global and local letters would be chosen equally often during the conflict tests (global = local).

To interpret such a stimulus competition procedure, however, it is critical that the global and local information be equally discriminable. Besides the advantages outlined earlier, an additional benefit of training the pigeons with different sized stimuli was that it allowed us to select stimuli in which the discriminability (as reflected in choice accuracy) of each level was as similar as possible. Toward this end, all probe stimuli were created from sizes selected so that both levels supported equal levels of choice accuracy for a particular bird. For Birds 1H and 3N, this was the medium stimulus size, and for Birds 2R and 4B this was the small size, with the birds correctly discriminating the relevant letters at the global and local levels at 84% and 86.3%, respectively, in sessions collected just prior to the experiment.

Besides the adjustment for size, this equivalence was bought about in part by the pigeons' continued improvement with the global-relevant conditions during the time between Experiments 2 and 3 and an additional change made prior to Experiment 3. Regardless of the individual pigeons' choice mapping, we found after Experiment 2 that the letters *H* and *N* were often confused, especially in the global-relevant condition. Because of this, we replaced the letter *H* with the block letter *P* as one of the relevant letters. For this and the remaining experiment, the relevant letters were now *P*, *N*, *X*, and *T*. After about 40 to 50 sessions in which the *P* replaced the *H*, mean accuracy with this letter across all stimulus conditions was 75.7% and generally improved global-relevant performance relative to the other conditions. With these adjustments, we now felt in position to ask about how processing of the global and local level interacted with one another during the presentation of a single stimulus.

Method

Animals and Apparatus

The pigeons and apparatus were the same as in Experiments 1 and 2.

Stimulus Conditions

The baseline stimuli were identical to those used in Experiments 1 and 2, except that now the relevant letters included a block *P* as an alternative, and the hierarchical conditions were composed equally often from the two irrelevant letters *O* and *S*.

The conflict probe stimuli were composed from two different relevant letters, one presented at the global level and one presented at the local level. Of 12 possible conflict stimuli, four (*P/X*, *X/P*, *N/T*, and *T/N*; first letter denotes global letter, the second denotes the local letter) were selected for testing. The remaining were held in reserve for future tests. Consistent probe stimuli had the same relevant letter present at both the global and local levels, with all four letters being tested (*P/P*, *X/X*, *T/T*, and *N/N*). These probe stimuli were tested at one size selected for each pigeon on the basis of its prior global and local performance. For Birds 2R and 4B, this was the small size, and for Birds 1H and 3N, this was the medium size.

Procedure

The same basic procedure from the previous experiments was used, with two changes made prior to Experiment 3. In preparation for the conflict and consistent probe tests, we first changed from using a simultaneous to zero-delay test procedure, so that the pigeons could no longer (if they did) further process the letter stimuli during the choice test. That is, once the

randomized peck requirement (1–10) was completed, the letter stimulus was turned off and the choice stimuli illuminated. Second, a random 10% of trials within a session had no positive or negative consequences, as these trials were immediately followed by an ITI after a choice. The latter were included to keep responding under stimulus control upon the planned inclusion of the nonreinforced probe test trials in this experiment. Both of these procedural changes were completed 28 sessions prior to the experiment.

A total of 10 test sessions were used to test the conflict and consistent test conditions. Each test session contained 156 trials, 12 of which tested probe stimuli (8 conflict, each combination tested twice, and 4 consistent conditions) without reinforcement, and 144 of which tested the baseline stimuli. Of these latter baseline trials, 8 were conducted without reinforcement and size-matched to the probe stimuli for each pigeon. The conflict and consistent probe trials were randomly intermixed into the last two thirds of each session. The peck requirement for the conflict, consistent, and size-matched nonreinforced baseline stimuli was fixed at six pecks. It took the pigeons an average of 3.6 s to complete this response requirement (1H = 2.5 s, 2R = 3.6 s, 3N = 3.5 s, and 4B = 4.8 s).

Results and Discussion

The outcomes with the conflict probe stimuli offered greater support to the idea that most of the pigeons gave over more processing time or capacity to the information at the local level than at the global level. Figure 4 reveals this most directly. It shows the percentage of times the relevant local or global letter was chosen during the conflict probe tests by the individual pigeons. Of the 4 pigeons, 3 chose the local letter significantly more often than the concurrently presented global letter. To evaluate this, difference scores were derived for each pigeon on the basis of the proportion of global and local responses each made in a session and compared with the expected value for no difference, all one-sample $t(9) > 2.3$. Only Bird 4B showed no significant difference, choosing the local and global letters equally often, $t(9) < 2.3$. These results are consistent with the earlier results, with the pigeons again showing a local advantage, but this time as presented within the same stimulus presentation rather than between stimulus presentations as revealed in Experiments 1 and 2.

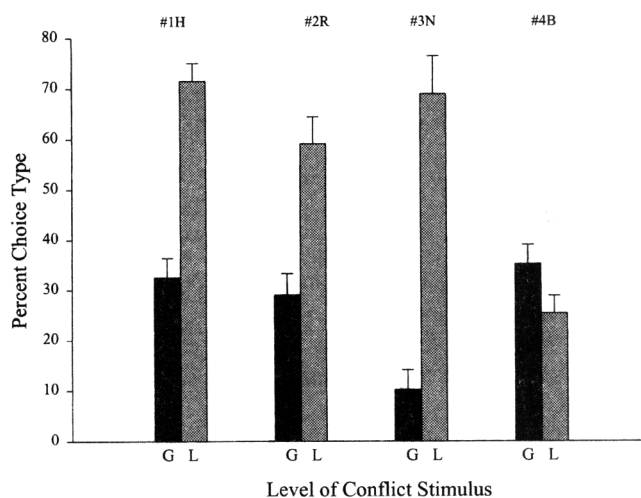


Figure 4. The mean percentage of global (G) and local (L) letter responses for the conflict stimuli for each bird in Experiment 3. Error bars represent the SEM.

With regard to the latter, the continued improvement of the pigeons in the global-relevant condition and the switch to using the P now resulted in a decreased local advantage as measured by the comparison of the local- and global-relevant conditions. Two pigeons, 2R and 4B, showed no significant difference in accuracy between these two conditions, $F_s(1, 10) < 1$, whereas the other 2 pigeons, 1H and 3N, continued to show a small local advantage, $F_s(1, 10) > 5.14$. Table 1 shows individual choice accuracy for these and the other baseline conditions matched for the size to those values tested in the conflict tests.

Was the local advantage in the conflict stimuli simply due to the smaller and larger nature of the letters presented at each level? Once again to answer this question we compared performance between conditions in which only single relevant letters were presented. As in Experiment 1, performance in the global-equivalent condition was significantly greater than in the local-equivalent condition, $F(1, 3) = 17.5$, again indicating that the larger letters were more discriminable than the smaller ones. Keep in mind, however, that the pigeons continued to benefit from element redundancy in the local-relevant condition as compared with the single letter local-equivalent condition, $F(1, 3) = 62.4$. Exactly how much the latter factor might compensate for the smaller size of the local letters is difficult to assess, but in general it appears that larger letters were better discriminated than the smaller ones in the current task.

We were also interested in performance with the probe tests in which the two levels were consistently and redundantly mapped. Table 1 also shows performance for this condition in the right-most column (BTH). This condition is interesting because it helps to reveal how the two levels might cooperate within a single trial. An examination of Table 1 will reveal that 2 birds, 1H and 3N, did not benefit from the redundancy of the consistent probes. In their cases, comparing consistent performance with the local-relevant performance revealed no difference in performance, $F_s(1, 10) < 1$. This outcome, combined with the results from the conflict tests, is most consistent with the idea that their choice behavior was determined primarily by local-level information. The other 2 pigeons, 2R and 4B, showed a slightly different pattern. Recall that these 2 pigeons earlier showed no difference in accuracy between local- and global-relevant conditions. When performance with these two conditions is averaged together and compared with the consistent condition, both pigeons showed a significant benefit from having redundant letter information at each level, $F_s(1,$

$10) > 7.26$. This outcome suggests that these 2 pigeons were processing both global and local information within a single trial. It is interesting that 1 of these pigeons also showed no global-local difference in the conflict tests, a result consistent with this idea.

In summary, this experiment indicates that 3 of the 4 pigeons processed more local information than global information over the approximately 3.5-s presentation of the conflict stimuli. The 4th pigeon processed both levels to an equal degree over this time frame. Assuming that their normal processing was not greatly affected by the simultaneous presentation of relevant letters at each level, it suggests that local advantage revealed in Experiments 1 and 2 was due to the greater processing of local information per unit time from the hierarchical stimuli. These conflict data are consistent with a hypothesis that the birds give cognitive precedence to processing local information. That is, this level is either available first for processing or has a higher priority than global level information from the same stimulus. To properly address this latter claim, however, specific control over the length of time available for processing the stimuli is required.

Experiment 4

Experiment 4 tested the probe stimuli at controlled stimulus durations in order to examine directly the time course of global and local processing from these hierarchical stimuli. Five different stimulus durations (250; 500; 750; 1,750; and 5,000 ms) were tested over a series of 24 sessions. These stimulus durations were tested with the four baseline conditions and the same probe stimuli as used in Experiment 3. Two questions were specifically addressed: To what degree does local or global processing dominate at brief presentation times, and how does this change with increasing stimulus duration?

Method

Animals and Apparatus

The pigeons and apparatus were the same as in Experiment 1.

Procedure

This experiment consisted of 24 test sessions. Each session consisted of 168 trials, with 144 reinforced baseline trials (24 of each type testing all three sizes) and 24 duration test trials. During the first 12 sessions, three durations, 750; 1,750; and 5,000 ms, were tested. During the second 12 sessions, three different durations, 250, 500, and 750 ms, were tested.

Within each session, the 24 duration trials tested two conflict stimuli, two consistent stimuli, and two global-relevant and two local-relevant stimuli at each of that session's three stimulus durations. Two different sets of 24 duration trials were tested in randomized two-session blocks. The first set consisted of the P/X and X/P conflict stimuli, the P/P, X/X consistent stimuli, global-relevant P and X composed of the irrelevant O, and local-relevant P and X composed from the irrelevant O. The second set consisted of the T/N, N/T conflict stimuli, T/T and N/N consistent stimuli, global-relevant T and N composed of the irrelevant O, and local-relevant P and X composed from the irrelevant O stimuli. The size of the probe stimuli was adjusted for each pigeon just as in Experiment 3. The 24 duration trials were randomly scheduled to be tested during the last 120 trials of a session. On the duration trials, a stimulus appeared in a random location in the viewing area for its specified duration, after which it was turned off and immediately followed by the illumination of the four choice stimuli. Choices on duration trials were not reinforced.

Table 1
Percentage Correct for the Hierarchical (GR and LR),
Equivalent (GE and LE), and Consistent (BTH)
Conditions in Experiment 3

Bird	GR	LR	GE	LE	BTH
1H	83.3	93.2	85.2	80.3	95.0
2R	75.0	76.3	81.4	59.2	97.5
3N	73.9	89.6	85.2	67.7	92.5
4B	78.2	76.3	80.3	62.8	92.5
<i>M</i>	77.6	83.8	83.0	67.5	94.3

Note. GR = global relevant; LR = local relevant; GE = global equivalent; LE = local equivalent.

Results

We first considered performance with the conflict probe stimuli. As expected, increasing the presentation duration significantly increased the percentage of correct choice responses (global + local choices) on conflict trials (250 ms = 65.6%; 500 ms = 77.1%, 750 ms = 74.1%, 1,500 ms = 76.0%, and 5,000 ms = 74.0%) $F(4, 12) = 3.4$. Newman-Keuls post hoc comparisons revealed that the 250-ms condition supported significantly poorer choice accuracy than did the other four durations.

As in Experiment 3, the dependent variable of most interest was not accuracy but the proportion of choices made to the choice stimuli associated with different relevant letters presented simultaneously at the global and local levels in the conflict stimuli. Figure 5 shows the mean and individual choice behavior of the birds for these conflict stimuli as a function of stimulus duration. The top panel shows mean proportion of these two choice types averaged across all 4 pigeons. This panel shows there was a strong preference by the pigeons to choose the local letter over the global letter at all durations. This crude level of analysis, however, prevents one from seeing some revealing individual differences in choice behavior.

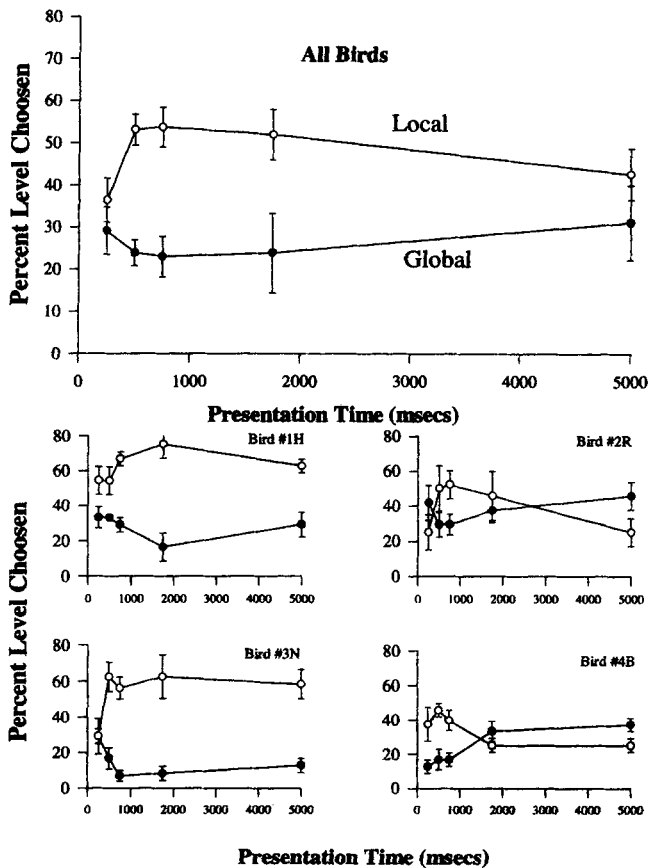


Figure 5. The top panel shows mean percentage of global and local letter responses of conflict stimuli as a function of stimulus duration in Experiment 4. The bottom four panels show the same function for each of the individual pigeons. Error bars represent the SEM.

The lower four panels of Figure 5 show these individual data for each pigeon. Two pigeons (1H and 3N, the left two panels) consistently identified the local letter of the conflict stimuli more often across all stimulus durations, although this was reduced at the shortest durations. The other 2 pigeons (2R and 4B, the right two panels) showed instead systematic changes in the proportion of global and local choices as a function of duration. At the short durations, these pigeons reported the local letter more often, whereas at the longer durations the global letter was reported more often. Because of the statistical dependence between global and local choices, these values were compared by using difference scores between the proportion of local responses and global responses within blocks of three sessions. Repeated measures ANOVAs for each bird using these difference scores for durations tested within the same sessions (750; 1,500; and 5,000 ms, or 250, 500, and 750 ms) revealed the following. There were significant effects of duration on the difference between global and local choices for the durations 750; 1,500; and 5,000 ms for Birds 2R, $F(2, 6) = 5.7$, and 4B, $F(2, 6) = 6.4$. This effect was due to the changing proportion of global and local choices across duration, as more local choices were made at 750 ms and more global choices were made at 5,000 ms. An identical ANOVA revealed no change in proportion of local and global choices for Birds 1H and 3N across these three durations, as local choices clearly dominated. The same analyses for those sessions testing the shortest durations found no significant changes in the proportion of global and local choices at these brief durations, during which local choices dominated for each bird (see Figure 5).

Figure 6 shows mean and individual accuracy for the global-relevant, local-relevant, and consistent conditions as a function of time. Among these conditions, differences were quite small and somewhat dependent on the individual pigeons. On the basis of the average data, a repeated measures ANOVA, Stimulus Condition \times Duration, found that accuracy significantly improved with increasing viewing time, $F(4, 12) = 3.58$. It also revealed a main effect for condition, $F(2, 6) = 5.9$, although this did not significantly interact with duration. This main effect of stimulus condition appeared to be due to the slightly higher accuracy in the consistent and local-relevant conditions at some values, although subsequent pairwise comparisons found only marginally significant differences among certain conditions: Consistent versus global-relevant, $F(1, 3) = 7.7, p = .07$; local-relevant versus global-relevant, $F(1, 3) = 7.0, p = .08$; and local-relevant versus consistent $F(1, 3) = 1.32, p > .05$.

The data for the individual pigeons are consistent with the patterns detected above and those in Experiment 3. Bird 1H continued to show a tendency to perform better with stimuli that relied on local letter discrimination, showing superior performance across all durations for the local-relevant and consistent conditions. Bird 2R increased its performance with time, showing little difference among conditions except at the longest duration where the consistent and global-equivalent conditions were slightly better. Bird 3N appeared to be little affected by duration or condition. Bird 4B increased its performance with time, showing little difference among conditions except at the longest duration where the consistent and local-equivalent conditions were slightly better.

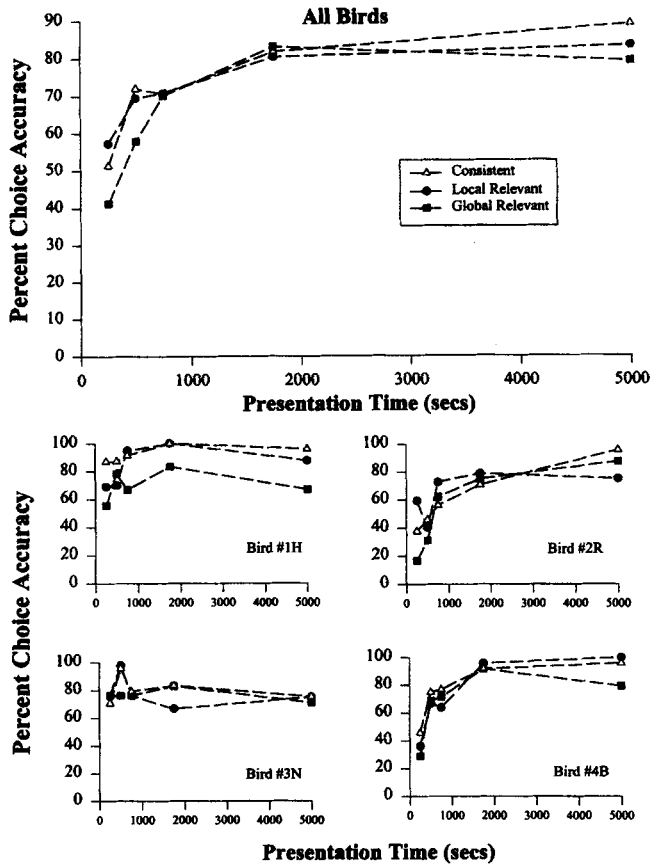


Figure 6. The top panel shows mean percentage of accurate letter responses for consistent, global-relevant, and local-relevant conditions as a function of stimulus duration in Experiment 4. The bottom four panels show the same functions for each of the individual pigeons.

Discussion

The results of Experiment 4 revealed that the local advantage found in the previous three experiments existed at stimulus presentation durations as short as 500 ms. For 2 pigeons, this local advantage remained present across all durations tested, whereas the other 2 pigeons shifted to showing a global advantage at the longest duration. Determining the nature of stimulus control at the shortest duration (250 ms) was more problematic. As in other sample duration experiments with compound stimuli (Cook et al., 1992; Lamb & Riley, 1981; Maki & Leith, 1973), accuracy was markedly reduced at this duration. As such, there is a greater contribution of behavioral processes that are not under stimulus control at this value (i.e., guessing). Given the generally poorer performance and the mixed nature of pigeons' responding, it is probably safest to conclude that neither level controlled choice at this shortest duration.

Previous animal studies have relied on RT to measure the processing of hierarchical stimuli. We think that the use of experimenter-controlled presentation times is a technique better suited for revealing the temporal dynamics of processing in such settings. Controlled manipulations of stimulus presentation time allow one to better study these processing dynamics by looking

instead at variations in choice accuracy as a function of time. Because terminal RT is a strictly subject-controlled measure, there is no comparable way to examine or control what information is present at different points in the sequence of processes leading to a response. Essentially similar arguments have been made in advocating the use of speed-accuracy trade-off techniques over RT in studying the details of human cognitive processing (Pachella, 1974).

On the basis of this assumption, for stimulus presentation values of between 500–750 ms, and by interpolation values close to 1,000 ms as well, all 4 pigeons showed a clear local advantage. This indicates that local information has cognitive precedence early in their processing of these hierarchical stimuli. Depending upon the pigeon, this initial local advantage changed in interesting ways as a function of time. Two pigeons continued to make a large proportion of local choices at the longest durations, and 2 switched to making more global choices. This pattern suggests that the pigeons had different but consistent behavior patterns or strategies for initiating processing of the global level of these hierarchical stimuli. Although the apparent cognitive precedence of local information is reflected in the strong local advantage documented over these four experiments, the contingencies and procedures of the baseline global relevant condition did require the pigeons to process the global level on a large percentage of the trials. What Experiment 4 seems to reveal is that they accomplished this in different ways. Two pigeons, 2R and 4B, seemed to use a time-based strategy. In their case, as time passed within a trial, stimulus control shifted from the smaller to the larger spatial scale of the hierarchical stimuli. This was especially revealed by the conflict tests, but is also consistent with the redundant advantage both of these birds showed in the consistent conditions in Experiment 3 (but not so strongly in Experiment 4). The other 2 pigeons, 1H and 3N, seem to have adopted a different strategy. Time appears not to be a factor, as these pigeons showed a local advantage across all durations. For these pigeons, the cue to begin processing global-level information was likely the presence of the irrelevant local letters *O* and *S*. A dependence on these cues would easily explain why these 2 pigeons always chose the local letter in the conflict condition and showed little redundant facilitation in the consistent condition. In both cases, a relevant letter was immediately present at the local level, preempting the subsequent detection of any global information.

General Discussion

All four experiments found in different ways that pigeons showed a strong local advantage in processing these hierarchical stimuli. This was manifested most clearly in the faster acquisition of the local-relevant condition in Experiment 1 and in the conflict results of Experiments 3 and 4. The latter experiment revealed that the origins of this local advantage stemmed from a dominance of local information early (500 to 1,000 ms) in the processing of these stimuli. After that, depending on the pigeon, different cues seemed to increase subsequent control by the global level of the stimuli.

The marked tendency to make choices based on local information at short presentation times suggests this level is available first for processing or has a higher priority over global-level information in these stimuli. That is, there seems to be a cognitive precedence effect for local information displayed by our pigeons in

the current situation. Why is this? In general, there are two general classes of explanations for such precedence effects. The first class attributes the effect directly to stimulus factors, such as stimulus size or arrangement, whereas the second attributes it to cognitive factors, such as differences in attention or memory processing.

Consider first the class of explanations that would suggest that this outcome is due to stimulus factors. As mentioned, the original global advantage reported for humans turned out to be more complex than we first thought, with several stimulus-related factors influencing the relative degree of global and local control, such as visual angle or size (Kinchla & Wolfe, 1979; Lamb & Robertson, 1990; Navon & Norman, 1983), stimulus location (Grice, Canham, & Boroughs, 1983; Lamb & Robertson, 1988), sparsity (Martin, 1979; Navon, 1981), and quality of the stimulus (Hoffman, 1980). One might therefore argue that the local letters in the current procedures were more salient than the global letters because of the different visual angles subtended by each. Although it is plausible, we do not think stimulus size is directly responsible for the observed effects. First, we consistently found that the larger, solid letters supported higher accuracy than smaller letters in both Experiments 1 and 2. Second, we attempted to control for the discriminability of such stimulus factors by selecting the size of the different levels to make global- and local-relevant performance as equal as possible in Experiments 3 and 4. Despite this equivalence, all 4 of the pigeons showed a local advantage effect over the first second of stimulus processing. These considerations suggest that visual angle per se was not the critical factor.

Another possibility is that the pigeons had a specific problem in grouping the disconnected elements of the global-relevant stimuli. Recall that in Experiment 1 and 2, the pigeons were generally better with the solid global-equivalent condition than the global-relevant condition. This finding suggests that a limiting capacity in joining the separated elements of the global condition into complex configural gestalts may be a factor. This would suggest that these effects may reflect more of a global disadvantage in some sense. This factor has been empirically identified as an important contributor to the local advantage reported in nonhuman primates (Deruelle & Fagot, 1998; Fagot & Deruelle, 1997; Fagot & Tomonaga, 1999; see also the object inferiority effect reported by Donis & Heinemann, 1993, for pigeons). The major argument against such an explanation in the current test is that we equated the global and local levels in the critical conflict stimuli, so that whatever effect the separation of the elements had, if any, it was at least compensated by other factors that allowed performance to be equivalent to that with the local level. Furthermore, by Experiment 4 the accuracy difference between the global-relevant and global-equivalent conditions had greatly diminished, suggesting that with experience the birds could cope with the separated elements of the global letters. These considerations suggest that the local advantage in the conflict test was not directly due to figural integration failure, although this is a potentially very important factor that merits serious further investigation.

If stimulus factors alone do not explain the effects, as is the case with humans (Kimchi, 1988; Kinchla, Solis-Macias, & Hoffman, 1983; Miller, 1981; Paquet & Merikle, 1988; Venturino & Gagnon, 1992; Ward, 1982), then one might begin looking at the properties of different cognitive mechanisms that might be responsible. Two sources seem most likely. The first is that local-level features have perceptual or attentional priority for the animals.

That is, local information is perceived or attended to prior to global information. This is essentially the complement of Navon's (1977) original explanation for the human global precedence effect. Although the strong form of Navon's sequential hypothesis is generally not accepted, others have continued to speculate that the global perceptual channels are processed faster or become available sooner in humans, perhaps because of their lower spatial frequencies or the organization of the different brain regions responsible for separately processing these different levels (Delis, Robertson, & Efron, 1986; Robertson & Lamb, 1991; see also Ivry & Robertson, 1998). One intriguing comparative reason why pigeons might have shown a perceptual- or attentional-related local advantage may stem from the structure of their visual system. Pigeons have two specialized areas or foveae in their eyes that may serve different functions (Bloch & Martinoya, 1982; Catania, 1964; Jager & Zeigler, 1991; see also Zeigler & Bischoff, 1993). One area is specialized for binocular perception of the visual space immediately in front of the pigeon. This frontal visual field has presumably evolved for myopic foraging for food on the ground. The second area is specialized for wide field monocular perception of the visual area around and lateral to each side of the pigeon. This lateral visual field has presumably evolved for predator detection and flight control. Because of the proximity and location of our stimuli, it is highly likely they were viewed with the frontal field. If so, its near-sighted acuity or potentially specialized capacity for examining fine stimulus details may be responsible for the local advantage observed here. Because of the perceptual and navigational demands of flight, it will be interesting to see if pigeons show a global advantage to identical stimuli presented to the lateral visual fields. It is interesting that research with humans has found that retinal location may similarly influence processing, finding a local precedence with centrally located stimuli and a global precedence with peripherally located stimuli (Lamb & Robertson, 1988).

A second possibility is that global and local information are processed in parallel at the perceptual level, but local information becomes available more quickly. Another possibility is that global information is processed first, followed by local information, but that it is the stronger trace strength of the more recently processed information that comes to control choice behavior. With the current data, there is no real way to decide between these different alternative processing mechanisms in accounting for the cognitive precedence of local information revealed by these experiments.

Regardless of the exact mechanism, the present local advantage contrasts with the global advantage effect most typically found in humans. It should be noted that this global advantage with hierarchical stimuli is just one of a class of effects in humans that has suggested that global information has a greater degree of cognitive priority over local information, including work on change blindness (Rensink, O'Regan, & Clark, 1997), the word superiority effect (Reicher, 1969), the object superiority effect (Weisstein & Harris, 1974), and the configural orientation effect (Palmer & Bucher, 1981). Whereas humans regularly make excellent use of global or configural information, increasing evidence from animal studies with hierarchical stimuli of the current type suggest this might not be the case for nonhumans. As outlined in the introduction, baboons and chimpanzees show a consistent local advantage effect, at least with sparse stimuli, or no advantage for either level (Deruelle & Fagot, 1998; Fagot & Deruelle, 1997; Fagot & To-

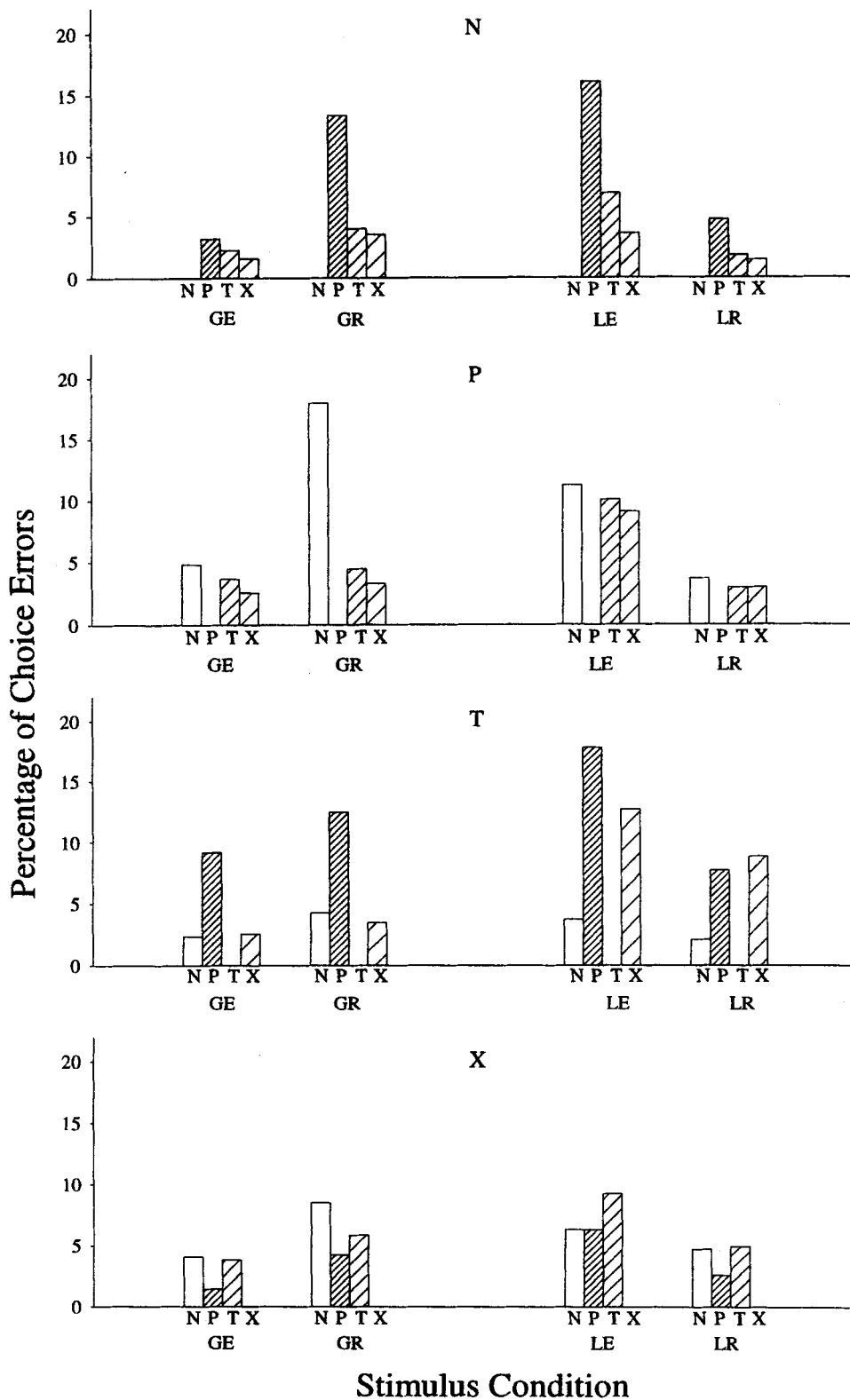


Figure 7. The misclassification errors made to each relevant letter in the hierarchical and equivalence conditions. These data are from the last 62 sessions of testing. Each panel shows a different relevant letter and the percentage of times the other letters were reported in error to it. GE = global equivalent; GR = global relevant; LE = local equivalent; LR = local relevant.

monaga, 1999; Hopkins, 1997). Our results are essentially in agreement with these nonhuman primate findings.

More problematic is that our results contradict those recently reported by Fremouw et al. (1998) for pigeons. Recall that these authors interpreted their findings as suggesting that pigeons can flexibly shift processing back and forth between the local and global levels of hierarchical stimuli. We found no evidence that our pigeons initially processed global information under any circumstance, even though it was just as relevant as the local information. The main issue is how to reconcile these two sets of findings with pigeons from nominally identical testing procedures. Two options are apparent.

One possibility is that the same processes were used by the pigeons in both studies, but because of the nature of the manipulations, each experiment captured a different aspect of these processes. Assume for the moment that both sets of findings are correct: That is, pigeons give cognitive precedence to local information (Experiment 4) but that this processing can be changed by the frequency of testing each level (Fremouw et al., 1998). One possibility is that each experiment measured a different portion of the same sequence of processes. For instance, the current results captured the general disposition to shift perceptual or attentional focus from local to global information, whereas Fremouw et al.'s session-wide frequency manipulation may have changed, for instance, the relative accessibility of the different memory representations required for the task. Another possibility, following up on one of the speculations raised above, is that their frequency manipulation may have allowed their pigeons to more effectively shift their observing behaviors back and forth between their frontal and lateral visual fields, whereas in our task the pigeons tended to look only with their frontal field.

Another approach to resolving these contradictory results is to suggest that each experiment measured different behaviors, such as differences in what or how the pigeons learned to solve each discrimination. As mentioned previously, it is critical that the same stimulus features control the pigeons' choice behavior at each level. Because of our improvements in using variably sized and located stimuli, responding to the same features of each letter should be enhanced in the current setting. To empirically examine this question, we investigated the misclassification errors made by the pigeons to each of the relevant letters in the different baseline conditions. For this we analyzed the last 62 sessions of this experimental series (the 24 sessions of Experiment 4 and 38 subsequent sessions). Figure 7 shows the misclassification errors made for each relevant letter in the hierarchical and equivalence conditions (we have averaged across bird and size because these factors had little effect). Each panel shows the percentage of times each letter was chosen incorrectly for each condition. Although accuracy varies, the ordinal pattern of errors for each letter is similar across conditions. That is, the pigeons make the same letter confusions regardless of level of organization or stimulus configuration. These comparable patterns of misclassification errors suggest that the same stimulus features controlled behavior at both the global and local levels. Collectively, the increased number of relevant letters to choose among, their variable sizes and locations, and the similar pattern of letter choice errors at both the global and local level strengthen the case that our pigeons were processing these hierarchical stimuli in the manner intended, with the pigeons

searching for the same discriminative information at two distinct levels of organization within a single hierarchical stimulus.

It is more difficult to evaluate this essential property for the Fremouw et al. (1998) study. As pointed out early in this article, their use of stimuli of fixed size and location raises the prospect that their pigeons could have used an exclusively local solution for both their local and global conditions. As a result, the shifts in attention between levels proposed to explain their RT data may reflect only a change in the relative importance of different stimulus features within the same level. It is because of such possibilities that we think evidence documenting the use of the same set of features at each level is critical in properly evaluating animal studies of hierarchical stimulus processing.

In conclusion, these experiments revealed strong evidence for the cognitive precedence of local information in hierarchical stimulus processing by pigeons. Although the conditions and contexts over which this conclusion holds need to be far more thoroughly investigated, perhaps it is the exceptional human ability to readily see, process, and subsequently define such hierarchical and abstract concepts as forests that is in some way critical to our species' advanced intellectual capacities.

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Received February 8, 2000

Revision received May 23, 2000

Accepted May 25, 2000 ■