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Parallel and Competitive Processes in Hierarchical Analysis: Perceptual Grouping and Encoding of Closure

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The role of perceptual grouping and the encoding of closure of local elements in the processing of hierarchical patterns was studied. Experiments 1 and 2 showed a global advantage over the local level for 2 tasks involving the discrimination of orientation and closure, but there was a local advantage for the closure discrimination task relative to the orientation discrimination task. Experiment 3 showed a local precedence effect for the closure discrimination task when local element grouping was weakened by embedding the stimuli from Experiment 1 in a background made up of cross patterns. Experiments 4A and 4B found that dissimilarity of closure between the local elements of hierarchical stimuli and the background figures could facilitate the grouping of closed local elements and enhanced the perception of global structure. Experiment 5 showed that the advantage for detecting the closure of local elements in hierarchical analysis also held under divided- and selective-attention conditions. Results are consistent with the idea that grouping between local elements takes place in parallel and competes with the computation of closure of local elements in determining the selection between global and local levels of hierarchical patterns for response.

There is now considerable evidence from experimental psychology that the perceptual organization of one's visual world can be determined by gestalt factors, which operate in a rapid and spatially parallel manner in early vision, segmenting the visual scene into separate figural units or objects for further operation by focal attention (Baylis & Driver, 1992; Duncan, 1984; Kahneman & Henik, 1981; Neisser, 1967). Proximity and similarity are two gestalt factors governing perceptual grouping so that spatially close objects and the most similar elements tend to be grouped together (Wertheimer, 1923/1950). Studies have shown that grouping by proximity may occur earlier (Chen, 1986; Han, Humphreys, & Chen, 1999) and be perceived faster (Ben-Av & Sagi, 1995) than grouping by similarity of shapes. The other gestalt factor of interest in the current research, closure, can be detected in parallel across a display of open elements (Elder & Zucker, 1993). Closure discrimination may occur earlier than orientation discrimination (Chen, 1982, 1986; Pomerantz, Sager, & Stoever, 1977). Closure also leads to the grouping together of elements regardless of the number of elements making up the group (Donnelly, Humphreys, & Riddoch, 1991). It also appears that closure is perceived as an emergent property in visual displays, so that it can be detected faster (Treisman & Paterson, 1984) than the component elements (e.g., line orientation) that make up the closed shape.

Other work, however, indicates that perceptual organization is contingent on a hierarchical analysis of patterns, from an initial coding of global shape to subsequent analysis of the local parts. Navon (1977) presented participants with compound large, global letters made up of smaller, local letters. The global and local letters could be either compatible or incompatible with each other. Participants made identification responses to either the global or the local letters. Navon found that participants responded faster to the global relative to local letters and that global letters interfered with responses to local letters when the two levels were incompatible, but not vice versa. These two aspects of performance are termed the *global reaction time (RT) advantage* and *global interference.* On the basis of performance advantage for global letters, Navon (1977) put forward a "global precedence hypothesis," suggesting that "perceptual processes are temporarily organized so that they proceed from global structure towards more and more fine-grained analysis" (p. 354). Note that in this original formulation, it would matter little how local elements

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grouped together (e.g., grouped by proximity or similarity) and whether local elements themselves formed "good" gestalts (e.g., whether local elements were closed).

More recent research, leading on from that of Navon (1977), reveals that there is considerable variability in both the global RT advantage and the global-to-local interference effect. For example, the effects vary as a function of the absolute size of the global shapes (Kinchla & Wolfe, 1979), the density of the local elements (Lagasse, 1993; Martin, 1979; Navon, 1983), the location and spatial uncertainty of the stimuli (Grice, Canham, & Boroughs, 1983; Lamb & Robertson, 1988; Pomerantz, 1983), the exposure duration (Luna, 1993; Paquet & Merikle, 1984), luminance level (Hughes, Layton, Baird, & Lester, 1984), and spatial frequency components contained in the compound stimuli (Badcock, Whitworth, Badcock, & Lovegrove, 1990; Hughes, Fendrich, & Reuter-Lorenz, 1990; Hughes, Nozawa, & Kitterle, 1996; Lamb & Yund, 1993, 1996). Such variability suggests that hierarchical analysis of patterns, from global shape to the encoding of local parts, does not necessarily operate; rather, there may be some flexibility in perceptual organization, with the dominant perceptual structure being determined by the interplay between several factors, including the hierarchical level of stimulus coding (global shape vs. part shape), the relative strength of grouping between local elements (e.g., determined by spacing), and the ease with which local parts themselves are selected and local features are computed for response. For instance, when grouping between local elements is weakened, the perception of global stimuli may be retarded and the ease of selecting individual local elements may be increased. According to this account, perceptual organization is a competitive process involving the computation of alternative perceptual structures across a display. The response speed to global and local stimuli can be determined by whichever organization occurs first.

Evidence for competitive processes operating in perceptual organization comes from neuropsychological studies of patients with brain damage who have impairments in computing some perceptual structures. For example, patients with right-hemisphere lesions, when asked to draw Navon-type stimuli from memory, tend not to produce the global shape but do reproduce local elements; the opposite pattern can occur in patients with left-hemisphere damage (Delis, Robertson, & Efron, 1986). Also, even in non-memory tasks, an unusual pattern of a local rather than a global advantage can be found in patients with right-hemisphere lesions, whereas an abnormally large global advantage is associated with left-hemisphere lesions (Lamb, Robertson, & Knight, 1989, 1990; Rafal & Robertson, 1995; Robertson, Lamb, & Knight, 1988; Robertson, Lamb, & Zaidel, 1993). Consistent with the indications of these neuropsychological findings, the results of research on normal participants measuring event-related potentials (Han, Fan, Chen, & Zhuo, 1999; Heinze, Johannes, Münte, & Magun, 1994; Heinze & Münte, 1993) and regional cerebral blood (Fink et al., 1996) also showed strong activation in the left hemisphere when detecting local targets and strong activation in the right hemisphere when detecting global targets (however, see Han, Fan, Chen, & Zhuo, 1997). Such work suggests that competing perceptual structures may normally be formed that differ in each hemisphere. In addition, the presence of a gestalt property at the local level, such as closure, can bias performance in patients. Humphreys, Riddoch, et al. (1994) reported a single case study of a patient with bilateral parietal lesions in a task requiring the identification of global compound letters. The patient had symptoms of Balint's syndrome (Balint, 1909), being highly impaired at switching attention once he was engaged on one object (see Humphreys, Romani, Olson, Riddoch, & Duncan, 1994, for additional evidence on this). Interestingly, identification of global forms was particularly poor if the local letters were closed rather than open. With closed local elements, the patient reported that he was able to see only the local forms and that it was impossible to detect whether a global shape was formed. This latter finding is consistent with local closure being a strong cue for selection in vision.

In two studies involving healthy participants, the relative roles of gestalt factors and hierarchical pattern coding in perceptual organization were assessed. Kimchi (1994) presented participants with displays composed of closed or oriented elements, which could themselves form closed or oriented global shapes. Participants had to classify the stimuli based on closure or orientation. The response-relevant property could be present at a global or local level in the compound stimulus. Kimchi found that classification based on closure was faster than that based on orientation, particularly for local stimuli. There was a global RT advantage for the orientation discrimination task, but not for the closure discrimination task. Kimchi argued that configural properties (e.g., closure) are salient to the perceptual system, regardless of their level of coding within a hierarchical system. According to this account, only nonconfigural properties (e.g., line orientation) benefit from coding into global forms. Using a visual search paradigm, Enns and Kingstone (1995) had participants search for target feature (e.g., triangle vs. square), which was equally likely to occur at the local, global, or both levels of compound patterns, among distractors that were also compound patterns. They found that search slopes were generally larger for global than for local targets and that manipulations of local element size and spacing had large influences on the search slopes for global targets, but not for local targets. Enns and Kingstone asserted that their results indicate that perception of the global structure in a compound stimulus requires an attention-demanding grouping operation over that needed for the perception of the local elements.

However, some questions about the role of gestalt factors in hierarchical analysis still remain unclear. For instance, why do classification tasks based on closure not show a global RT advantage? Do variations in the global RT advantage simply result from faster RTs for classification based on closure than for classification based on orientation? Are there also differences in the interference effects between classifications based on closure and orientation? In addition to these questions, empirical data are necessary to demonstrate the role of perceptual grouping in hierarchical analysis. To our knowledge, there has been little research on how different gestalt factors (grouping by proximity, similarity, and closure) interact in the perception of hierarchical stimuli. For example, how does the perception of closure of local elements interact with grouping between discrete local elements in determining the relative advantage of global and local processing of compound stimuli? What is the relative importance of grouping by proximity and similarity in the perception of global structure? In the present research, we attempted to answer these questions.

The Present Research

In Experiments 1–4, we used a selective-attention paradigm, in which participants had to select a response to a stimulus coded either at a local or at a global level. In Experiments 1 and 2, we investigated the role of closure in hierarchical (global-to-local) analysis. In Experiment 1, the responses could be contingent on the orientation of the stimuli or determined by whether the stimulus was closed. The global and local levels of these stimuli, unlike those used in Kimchi's (1994) study, could be consistent or conflicted. Therefore, by comparing the RT advantage and the interference effect in the orientation and closure discrimination tasks, we assessed whether the bias for selection based on a local configural property (e.g., closure) would necessarily overrule a bias to select a global rather than a local form. In Experiment 2 we studied whether the local closed shape itself or the perception of closure (the feature used for discrimination) would be responsible for the difference in the global advantage observed in the orientation and closure discrimination tasks in Experiment 1.

Unlike Enns and Kingstone's (1995) search task, in which multiple compound stimuli were used in a display, in Experiments 3 and 4 we studied the role of perceptual grouping between local elements in hierarchical analysis using single compound stimuli, as has been done in most previous research. In Experiment 3, we developed a new paradigm of manipulating perceptual grouping of local elements of compound stimuli. The compound stimuli from Experiment 1 were presented against a background of crosses to attenuate the strength of local element grouping by eliminating proximity grouping and making the similarity of shapes dominate grouping. If local element grouping is crucial for the perception of the global shape of compound patterns, then decreasing the strength of local element grouping by proximity should weaken global advantage and enhance the perception of local stimuli.

In Experiment 4A we further studied how different types of similarity grouping would affect the relative advantage of global and local processing. Global shapes composed of local arrows or triangles were presented against a background of crosses. In this case, global shapes were formed by similarity of closure for closed shape stimuli, but by similarity of orientation for open stimuli. Given that grouping of local elements is crucial for the perception of global structure, there should be a facilitation of global processing when global shapes are formed by similarity of closure rather than when global shapes are formed by similarity of orientation because grouping by similarity of closure is stronger than grouping by similarity of orientation (Chen, 1986). In Experiment 4B we investigated the effect of the nature of background shapes on the relative advantage of global and local levels by presenting the hierarchical stimuli from Experiment 4A against a background of rectangles. This manipulation of the background shapes helped to reveal the different function of the similarity between the local elements of hierarchical stimuli and the dissimilarity between them and the background elements in the perception of global structure.

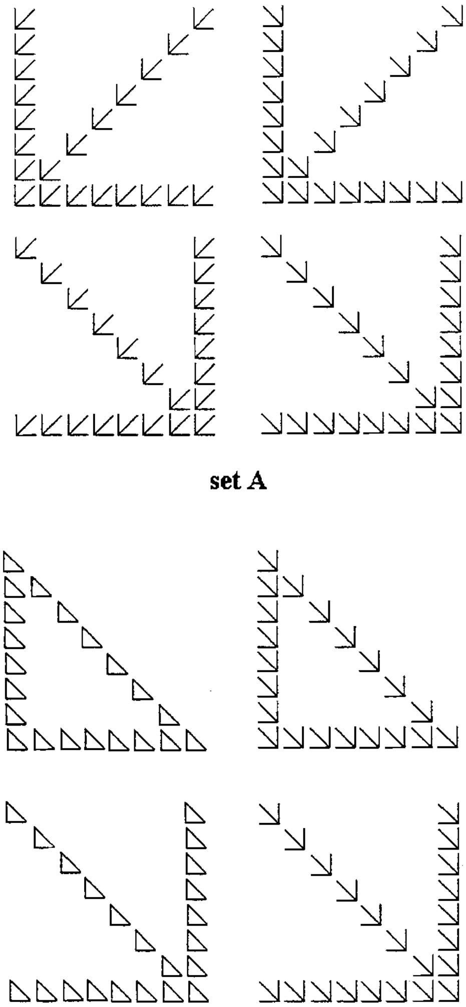
In Experiment 5 we used a divided-attention procedure, in which participants had to respond to either oriented or closed stimuli that could occur at either a local or a global level in a compound stimulus. Under divided-attention conditions, attention does not need to be focused at the local level (see Ward, 1982, for evidence on response-contingent selection of local and global stimuli across trials under divided-attention conditions). Hence, with divided attention, differences in performance attributable to the ease of selecting local elements may be most pronounced and will not be masked by selective attention to local forms. In this case, the advantage for responses contingent on the closure of local elements over those contingent on the orientation of local elements may be increased (when the target is present only at a local level). In addition, the bias toward responding to a global rather than a local shape may increase under divided-attention conditions, but most especially when local closure is absent. The strength of local element grouping was also varied by introducing the background patterns. We wanted to determine whether the role of local element grouping would still be important for the perception of global structure under the divided-attention condition.

Taken together, the present studies provided strong manipulations of the (a) grouping of local elements and (b) selection biases toward configurations of local figures and of the interrelations between these factors in the hierarchical analysis of visual compound stimuli.

Experiment 1: Encoding of Closure and the Global Precedence Effect

The stimuli used in Experiment 1 are shown in Figure 1. In the orientation discrimination task, participants had to respond according to the orientation of the arrow stimuli (see Figure 1, Set A). In one block of trials they responded to the orientation of the global stimuli; in another block they responded to the orientation of the local stimuli. In the closure discrimination task, participants responded according to whether a closed stimulus was present (with the triangles) or absent (with the arrow stimuli; see Figure 1, Set B). Again, discriminations were made to global forms in one trial block and to local forms in a second trial block. To determine the role of local selection in the difference between the orientation discrimination and closure discrimination tasks, we designed a control condition in which participants discriminated the orientation of single local arrows or a single local arrow versus triangle, respectively.

This study extends that of Kimchi (1994), who failed to



set A

set B

Figure 1. Two sets of compound stimuli used in Experiment 1. Set A: Global arrows are composed of local arrows. Set B: Global arrows or triangles are composed of local arrows or triangles.

find a global advantage when responses could be contingent on classification based on closure. In the orientation discrimination task used here, we assessed whether a global advantage would occur with stimuli similar to those used in the closure discrimination task, but in which the elements were not configured to form closed shapes and the discrimination was based on another attribute (orientation). In addition, we tested for the presence of global (local) interference, as well as for any overall global (or local) RT advantage, because responses at the irrelevant level in the stimuli could be compatible or incompatible with those at the relevant level. Response interference effects provide an additional measure of global (or local) precedence in vision (cf. Navon, 1977).

Method

Participants. Twelve graduate students (5 men and 7 women, aged 23–29 years) from the graduate school of the University of Science and Technology of China participated in this experiment as paid volunteers. All had normal or corrected-to-normal vision.

Apparatus. Data collection and stimulus presentation were controlled by a NEC 386 personal computer. Stimuli were presented on a 21-in. (53.3 cm) NEC MultiSync 3-D color monitor at a viewing distance of about 70 cm.

Stimuli. Two sets of compound stimuli were used, as shown in Figure 1; each set comprised black elements on a white background. Each stimulus in Set A consisted of a global arrow made up of local arrows pointing down left or down right. The directions of local arrows were either consistent or inconsistent with that of the global one. Each stimulus in Set B consisted of a global arrow or triangle made up of local arrows or triangles. Shapes at the global and local levels were consistent or inconsistent. The local arrows or triangles were arranged in an 8×8 matrix. The global figure was 3.8×4.4 cm, and the local figure was 0.3×0.4 cm. The global and local figures subtended a visual angle, respectively, of $3.1° \times 3.6°$ and $0.25° \times 0.33°$. The stimulus used in the control condition was only one small arrow or triangle displayed at the center of the screen. The size of the arrow or triangle was the same as those local figures composing the global stimuli.

Procedure. We used a three-factor within-subjects design with the following factors: task (discrimination of arrow directions and discrimination of arrow vs. triangle), globality (discrimination of global or local level), and consistency (the global and local levels are consistent or inconsistent). For Stimulus Set A, participants were required to discriminate the orientation of arrows at the global or local levels. For Stimulus Set B, participants discriminated between arrows and triangles at the global or local levels of the compound stimuli. Each trial began with a 1,000-ms warning beep and the presentation of a fixation cross located at the center of the screen. The fixation cross was 0.4×0.5 cm, subtending $0.33° \times 0.41°$ of visual angle. After another 1,000 ms, the fixation was replaced by the stimulus that was presented at the center of the screen and stayed on until participants responded.

While maintaining fixation, participants were required to discriminate the global or local figures of compound stimuli in separate blocks of trials by pressing one of two keys on a standard keyboard with the right and left middle fingers. Half the participants discriminated the global figures first, and the others discriminated the local figures first. The relationships between the stimuli and the hands of response were counterbalanced across subjects, as was the presentation sequence for the two sets of stimuli. For each stimulus set, there were 16 practice trials followed by 48 trials in each block for the identification of the global or local stimuli. Participants were encouraged to respond as quickly and accurately as possible. In the control condition, participants discriminated the orientations of a small arrow or a small arrow versus a triangle presented at the center of the visual field. There were 60 trials for each task. The first 12 trials were for practice. Stimuli were presented on the screen until participants made a response. Instructions stressed both accuracy and speed.

RTs and error rates were subjected to repeated measure analyses of variance (ANOVAs) with task (discriminating the orientation of arrows or arrows vs. triangles), globality (discriminating the global or local levels), and consistency (figures at the global and local levels are consistent or inconsistent) as the main effects. The error rates were transformed with an arcsine square-root function before the statistical analysis.[1]

[1] Because one of the reviewers was concerned that the interactions between these factors might result from the asymmetrical distribution of skewed reaction times (RTs), we also conducted analyses of variance (ANOVAs) on transformed RTs (log [RT]),

Table 1
Mean Error Rates (%) and Standard Errors for Each Condition in Experiment 1

	Global				Local			
	Consistent		Inconsistent		Consistent		Inconsistent	
Discrimination	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Orientation	3.9	1.2	4.8	2.2	3.3	0.9	5.6	1.6
Closure	2.4	0.9	3.9	1.2	0.4	0.4	5.8	1.6

Results

Errors. The mean percentage of errors for the discrimination of arrow direction and the discrimination between arrows and triangles were 4.4% and 3.1%, respectively. The effects of task, globality, and consistency on error rates were not significant, and none of their interactions was significant ($p > .05$). Comparisons between the error rates and the mean RTs indicated that there was no speed–accuracy trade-off; therefore, the error data are not discussed further. The mean error rates under each condition are given in Table 1.

RTs. The average RTs for correct responses in the two tasks are shown in Figure 2. The analysis for RTs indicated a significant main effect of task, $F(1, 11) = 64.50, p < .0005$, globality, $F(1, 11) = 42.37, p < .0005$, and consistency, $F(1, 11) = 66.16, p < .0005$. Participants responded faster in the closure discrimination task than in the orientation discrimination task. For both tasks, discrimination at the global level was faster than at the local level, and RTs in the consistent condition were faster than in the inconsistent condition.

The Task × Globality interaction was significant, $F(1, 11) = 13.35, p < .004$, reflecting the fact that the global RT advantage was greater for the orientation discrimination task (127 ms) than for the closure discrimination task (47 ms). The Consistency × Task interaction was also significant, $F(1, 11) = 12.86, p < .03$; the interference effect was stronger in the orientation discrimination task (55 ms) than in the closure discrimination task (29 ms). The Globality × Consistency interaction revealed a stronger interference effect on local than on global responses, $F(1, 11) = 40.49$, $p < .0005$, for both tasks. Finally, the Task × Globality × Consistency interaction was significant, $F(1, 11) = 6.05$, $p < .03$; the relative global interference effect was larger for the orientation discrimination task (91 ms) than for the closure discrimination task (49 ms).

Orthogonal planned contrast tests further demonstrated that there were reliable effects for global interference—orientation discrimination task, $F(1, 11) = 58.25, p < .0005$; closure discrimination task, $F(1, 11) = 66.65, p < .0005$—but not local interference—orientation discrimination task, $F(1, 11) = 4.30, p > .05$; closure discrimination task, $F(1, 11) = 3.10, p > .1$. There was no difference between global RTs for the two tasks, $F(1, 11) = 3.29, p > .05$, but local RTs in the orientation discrimination task were slower than in the closure discrimination task, $F(1, 11) = 96.89, p < .0005$. Furthermore, there was no significant difference between global RTs in the orientation discrimination task and local RTs in the closure discrimination task, $F(1, 11) = 1.584$, $p > .2$.

In the closure discrimination task, half the global stimuli were composed of closed local shapes (the triangles), and half were composed of open local figures (the arrows). RTs to the global and local shapes in these conditions were broken down to reflect the type of local form; no reliable difference was found between global RTs to stimuli composed from closed and open local figures ($F < 1$); the same was true for local RTs, $F(1, 11) = 2.59, p > .1$. The mean RTs are shown in Table 2.

In the control condition, RTs were 441 and 444 ms, respectively, for the orientation discrimination task (with 2.8% errors) and the closure discrimination task (with 1.8% errors). Paired *t* tests showed no differences between RTs, $t(11) = 0.35, p > .7$, or between errors, $t(11) = 0.91, p > .3$, for the orientation and closure discrimination tasks.

Discussion

For both sets of stimuli, participants' responses showed a global precedence effect (i.e., global RTs were faster than local RTs), and there was global but not local interference. The global RT advantage and the global interference effect were larger for target discriminations based on orientation than on closure. The variation in the global advantage resulted mainly from differences in local processing; there were no differences in global RTs between the two tasks. Relative to the discrimination of closure of local elements, the discrimination of orientations of local elements was slower and suffered more interference from the global stimuli.

The present finding in the closure discrimination task is different from Kimchi's (1994) finding that classifications based on closure were not affected by globality. It is clear here that RTs were faster to global than to local shapes, suggesting that the global-to-local analysis of patterns may be conducted even when participants discriminated a configural property (closure). The discrepancy between the results of our and Kimchi's experiments may have been caused by the difference in the specific stimuli used. For example, the open stimuli in Kimchi's study had central intersections that did not exist in our stimuli. The central intersection may be an additional feature used for discrimination and thus possibly fasten local RTs. Although the difference exists, our data, consistent with Kimchi's, did indicate that the global advantage was weaker for the closure discrimination task than for the orientation discrimination task, and local RTs for the closure discrimination task were as fast as global RTs for orientation discrimination. Thus, discriminations based on closure were less affected by globality than those based on orientation, even though effects on closure discrimination could be still be observed. Both Kimchi's and our data

which, as the reviewer suggested, may come closer to the assumptions underlying ANOVAs. These ANOVAs showed little difference from those using untransformed RT data. Therefore, here we report the results of ANOVAs on the basis of untransformed RT data.

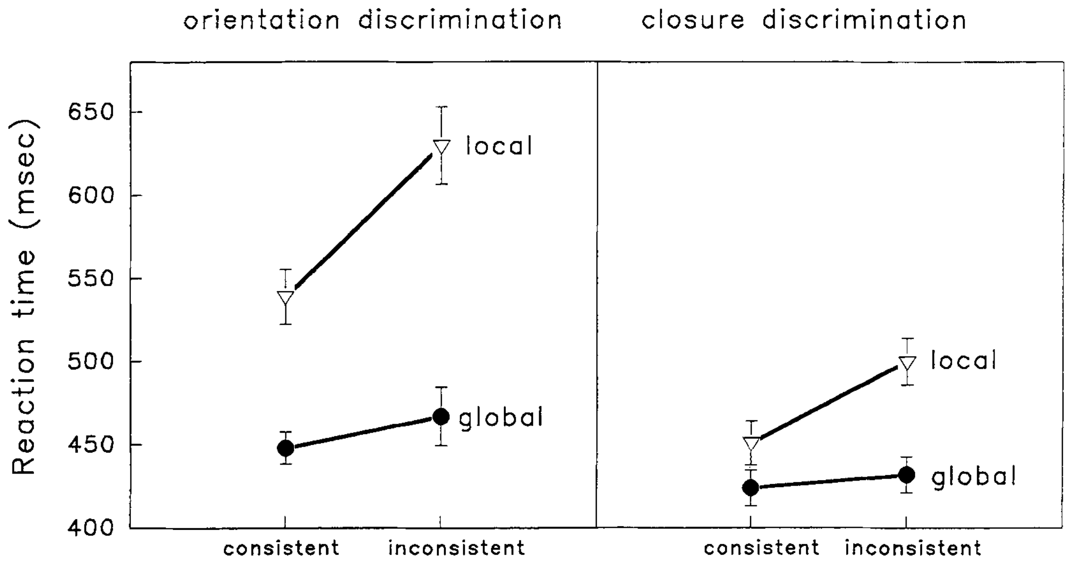


Figure 2. Mean reaction times to global and local levels of compound stimuli in Experiment 1. Data are presented separately for the orientation and closure discrimination tasks.

indicate that both the relative speeds of global and local processing and global-to-local interference effects depend on the features used for the discrimination tasks.

Unlike Kimchi (1994), we examined interference effects as well as overall RTs. Global-to-local, but not local-to-global, interference was found for both discriminations, but interference was larger on the orientation than the closure discrimination task. The pattern of data was consistent with interference being affected by the relative speed of processing the local and global elements. Overall, RTs to local elements were faster in the closure discrimination task than in the orientation discrimination task, and global-to-local interference was also reduced.

Note that there was no difference between closure discrimination and orientation discrimination for global targets or for targets in the control condition, where only one local figure was displayed. We wondered why closure discrimination was faster than orientation discrimination only for local targets in compound stimuli. This effect could not be attributed solely to differences in target discriminability between the global and local levels of compound stimuli because the discrimination of global compound stimuli was only slightly faster than the closure discrimination in the control condition (with a single local stimulus). There was no effect of orientation versus closure discriminations for the control condition either. One main difference between responding to global and local elements of compound stimuli, which has not been discussed much in previous work, is that there is only one target in the field when responses are made to the global stimulus, but there is more than one potential target when responses are made to the local stimuli. This difference also exists between the control task and the task of responding to local parts of global shapes. Hence, it is plausible that, for responses to the local parts, it might be necessary to select one individual local figure from global shapes; this selection process is not required for responses to global shapes or to a single local figure. We propose that the variance in local RTs between the closure discrimination and the orientation discrimination tasks may stem from differences in selection effort, for which two possible mechanisms might be responsible. One is that local closure serves as a strong cue for visual selection (Humphreys, Romani, et al., 1994), enabling local closed elements in a global configuration to be selected relatively easily and thus facilitating responses to local elements. The other possibility is that, relative to the computation of orientation, the computation of closure can be conducted in a more efficient parallel manner, and thus less effort is needed for selection (Chen, 1982, 1986; Han & Chen, 1993; Kimchi, 1994). The first account is based on what local shapes are and predicts that local RTs to stimuli composed from closed local elements (triangles) should be faster than those to stimuli composed from open local elements (arrows). The second account is based on what feature (closure or orientation) is computed for the task and predicts that responses to discriminate closure of local elements should be faster than those to discriminate orientation of local

Table 2
Mean Global and Local RTs (in ms) and Standard Errors in the Closure Discrimination Task for Stimuli Composed of Local Arrows or Triangles in Experiment 1

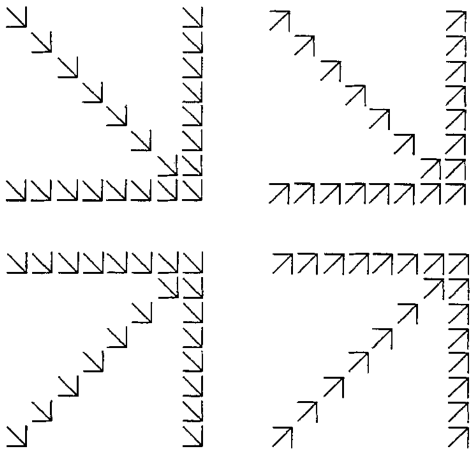
	Arrows				Triangles			
	Consistent		Inconsistent		Consistent		Inconsistent	
RT	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Global	429	9.8	426	13.0	419	11.5	435	10.1
Local	445	14.5	492	12.4	457	13.9	507	16.8

Note. RTs = reaction times.

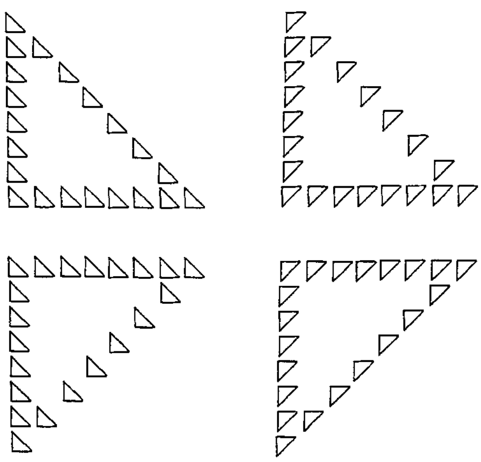
elements, even with open elements present. The fact that in the closure discrimination task local RTs to stimuli composed of local arrows were as fast as those to stimuli composed of local triangles suggests that the second account, rather than the first one, may provide the better interpretation for the difference between the closure and orientation discrimination tasks. This issue was studied further in Experiment 2.

Experiment 2: Orientation Discrimination With Closed and Open Shapes

Which factor, the closed local shape itself or the feature required for the discrimination tasks, was behind the difference in the global advantage between the two tasks in Experiment 1? To test this further, we had participants respond to the orientation of two sets of stimuli (see Figure 3). Each item in Set A was composed of arrows (open shapes), whereas each in Set B was composed of triangles (closed shapes). If the difference in the global advantage observed in Experiment 1 was due to the feature used for discrimination rather than the closed local shape itself, the global advantage for Sets A and B should be comparable because the features for the discrimination task are the same (i.e., orientation). However, if the identity of the local shapes matters, a stronger global advantage should be observed for Set B than for Set A.



set A



set B

Figure 3. Two sets of compound stimuli used in Experiment 2. Set A: Global arrows are composed of local arrows. Set B: Global triangles are composed of local triangles.

Table 3
Mean Error Rates (%) and Standard Errors for Each Condition in Experiment 2

	Global				Local			
	Consistent		Inconsistent		Consistent		Inconsistent	
Stimuli	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Open	2.8	0.9	2.4	0.9	4.5	2.5	10.1	3.4
Closed	5.4	1.8	4.0	2.4	2.7	1.3	6.0	1.5

Method

Participants. Twelve undergraduate students (12 men, aged 20–24 years) from the University of Science and Technology of China participated in this experiment as paid volunteers. All had normal or corrected-to-normal vision.

Apparatus, stimuli, and procedure. These were the same as used in Experiment 1, except that Set A contained large arrows made up of small arrows pointing down right or up right, and Set B contained large triangles composed of small triangles with their right angles pointing down left or up left, illustrated in Figure 3. The orientations of the lines composing the arrows of Set A were the same as those composing the triangles of Set B. Participants were instructed to respond to the orientation of the diagonal line elements in either the global or local shapes on separate trial blocks.

Results

Errors. The mean error rates for Sets A and B were 4.9% and 4.5%, respectively. A three-factor ANOVA indicated that the main effects of task, globality, and consistency were not significant ($p > .2$). The interaction of each pair of factors and the triple interaction of the three factors were also not significant ($p > .2$), except for the interaction between globality and consistency, $F(1, 11) = 7.18, p < .02$. There was interference in the inconsistent condition for local but not for global responses (i.e., there was global-to-local but not local-to-global interference). Table 3 shows the mean error rates in each condition.

RTs. The mean RTs for the open (Set A) and closed stimuli (Set B) are shown in Figure 4. There were significant main effects of consistency, $F(1, 11) = 153.62, p < .0005$, and globality, $F(1, 11) = 108.17, p < .0005$, indicating that responses to the global level were faster than those to the local level and that inconsistency between the two levels slowed responses. The effects of task were not significant, $F(1, 11) = 2.33, p > .15$; there was no difference between RTs for Sets A and B. The Globality × Consistency interaction was reliable, $F(1, 11) = 37.80, p < .002$. This

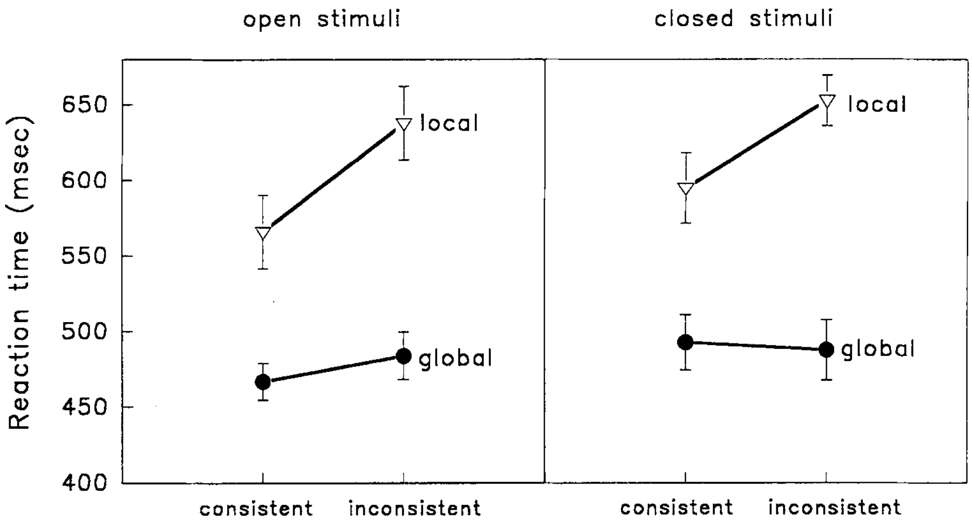


Figure 4. Mean reaction times to global and local levels of compound stimuli in Experiment 2. Data are presented separately for Set A (discriminating orientation of open shapes [arrows]) and Set B (discriminating orientation of closed shapes [triangles]).

occurred because the global level interfered more with responses to local stimuli than the reverse. The Consistency × Task interaction, $F(1, 11) = 7.62$, $p < .02$, also reached significance, indicating that the interference effect was larger for open than for closed shapes. The interactions between task and globality and among the three factors were not significant ($F < 1$). The global RT advantage and the increased global-to-local relative to local-to-global interference held equally for the two sets of stimuli.

Discussion

As in Experiment 1, there was a clear global advantage for both sets of stimuli: Overall, RTs were faster to global shapes, and global-to-local interference was more pronounced than local-to-global interference. The only difference between performance with closed and open shapes was that the interference effect (for both levels of response) was slightly larger on the open stimuli (we discuss this result further after presenting Experiment 4A). Nevertheless, the main result was that the enhanced responses to locally closed stimuli that we observed in Experiment 1 were eliminated; no difference was found between RTs to locally closed and open stimuli. This was consistent with our proposal that the features used for discrimination, rather than local shape itself, determines the magnitude of the global precedence effect. Slow computation of the component orientations of closed shapes (cf. Chen, 1982, 1986; Treisman & Paterson, 1984) here might have been balanced against their faster selection as individual elements within the global shape, equating performance with the closed and open shapes (note that there was a tendency for RTs to be slowed with the locally closed stimuli, but it was not significant).

Overall, the data from Experiments 1 and 2 suggest that one component of the global precedence effect may be the selection effort involved in responding to local parts of compound figures. Less selection effort was needed in the closure discrimination task than in the orientation discrimination task, and this resulted in a weaker global advantage. However, one question was still unanswered: Why did a global advantage still occur even when less selection effort was required in the closure discrimination task? One other factor, perceptual grouping between local elements, as suggested by Enns and Kingstone (1995), may play an important role in the perception of global structure. It is possible that the grouping process competes with the selection of local parts and that local selection is made more difficult if the local elements form a strong group. Differences in grouping may contribute to the variations in the global precedence effect across the tasks. However, there has been little discussion in previous work (however, see Humphreys, Riddoch, & Quinlan, 1985) of how grouping between local elements contributes to the global advantage. The effect of grouping was studied in Experiments 3 and 4.

Experiment 3: Perceptual Grouping and the Global Precedence Effect

In Experiment 3, we presented the stimuli from Experiment 1 against a background of cross elements (see Figure 5). The distance between an individual local arrow or triangle and its surrounding crosses was equivalent to that between two adjacent local arrows or triangles. Under this circumstance, the coding of the global triangle or arrow shape based on proximity grouping between the local elements should have been reduced (i.e., the local elements making up the global triangle or arrow should have been no closer to each other than they were to the surrounding background crosses). The grouping of local elements by similarity of luminance was also weakened because the difference in luminance between local arrows or triangles and the blank screen (in Experiment 1) was greater than that between local arrows or triangles and the background crosses (in Experiment 3). Furthermore, as the local arrows and triangles formed rows and columns with the background crosses, local element grouping by good continuity was reduced in Experiment 3 relative to Experiment 1. Instead, the local elements making up the global triangle or arrow may group by similarity of shape because these elements are identical (and differ from the background crosses). Grouping by similarity of shape may operate at a relatively late stage of perceptual processing relative to grouping by proximity (Ben-Av & Sagi, 1995; Chen, 1986; Han, Humphreys, et al., 1999) and may thus not generate the rapid coding of global shape information necessary to produce the global precedence effect. Evidence that decreasing the saliency of the global shape enhances responses to local stimuli would support the hypothesis that local selection competes with local element grouping in response selection.

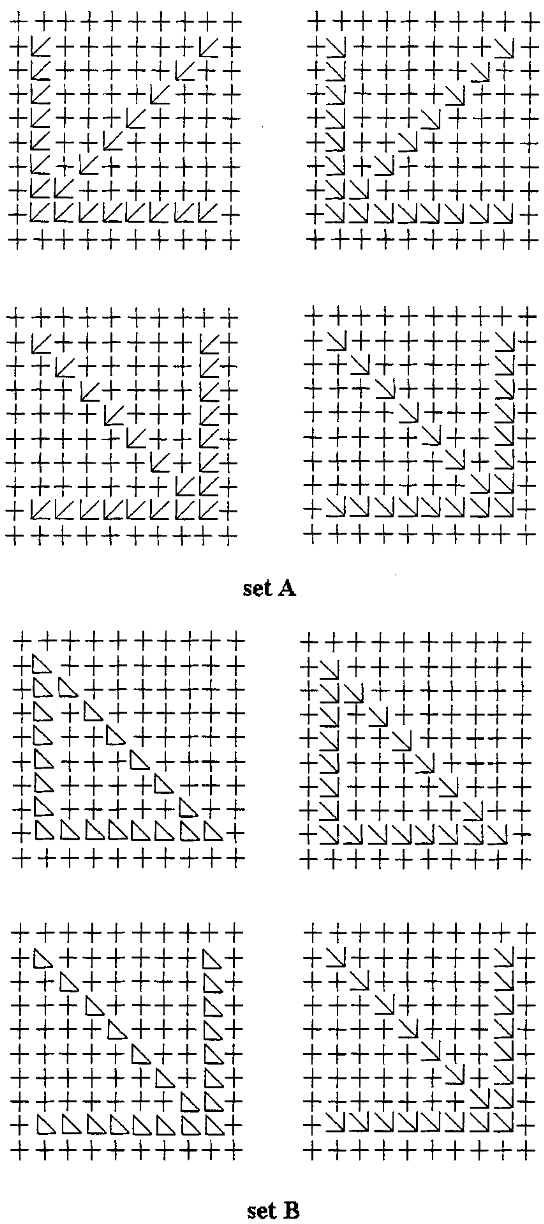


Figure 5. Two sets of compound stimuli used in Experiment 3. The stimuli were made by embedding the stimuli in Experiment 1 in a background of crosses.

Table 4
Mean Error Rates (%) and Standard Errors for Each Condition in Experiment 3

	Global				Local			
	Consistent		Inconsistent		Consistent		Inconsistent	
Discrimination	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Orientation	0.3	0.3	2.5	0.9	1.5	0.7	3.8	0.9
Closure	0.1	0.3	3.1	0.9	2.3	0.6	1.4	0.7

Method

Participants. The same participants as in Experiment 1 participated in this experiment 2 weeks after they took part in Experiment 1.

Apparatus, stimuli, and procedure. All aspects were the same as for Experiment 1, except that the compound stimuli were formed by embedding the compound stimuli from Experiment 1 in a background composed of small distractor crosses, as illustrated in Figure 5. The vertical and horizontal sizes of each of the crosses were the same as those of each of the local arrows or triangles. The distance between adjacent triangles or arrows was equal to that between each triangle or arrow and a neighboring cross. The whole pattern was 4.8 × 5.6 cm, subtending an angle of 3.9° × 4.6°.

Results

Errors. The error rates for the orientation discrimination and closure discrimination tasks are presented in Table 4. The three-factor ANOVA on the error rates indicated a significant main effect of consistency, $F(1, 11) = 11.95, p < .005$, a significant Globality × Consistency interaction, $F(1, 11) = 5.01, p < .05$, and a significant Task × Consistency interaction, $F(1, 11) = 5.52, p < .04$. Participants made more errors when stimuli at global and local levels were inconsistent than when they were consistent. This interference effect was stronger on responses to global relative to local stimuli. Furthermore, the interference effect was larger in the orientation discrimination task than in the closure discrimination task. Separate analyses showed that for the orientation discrimination task, the effect of globality, $F(1, 11) = 9.17, p < .02$, was significant, indicating that participants made more errors in responding to local than to global stimuli. The effect of consistency, $F(1, 11) = 28.29, p < .0005$, was also significant; there were more errors in the inconsistent condition than in the consistent condition. The Globality × Consistency interaction was not significant ($F < 1$). For the closure discrimination task, the effects of globality ($F < 1$) and consistency, $F(1, 11) = 1.02, p > .3$, were not significant. However, the Globality × Consistency interaction, $F(1, 11) = 23.30, p < .001$, was significant,

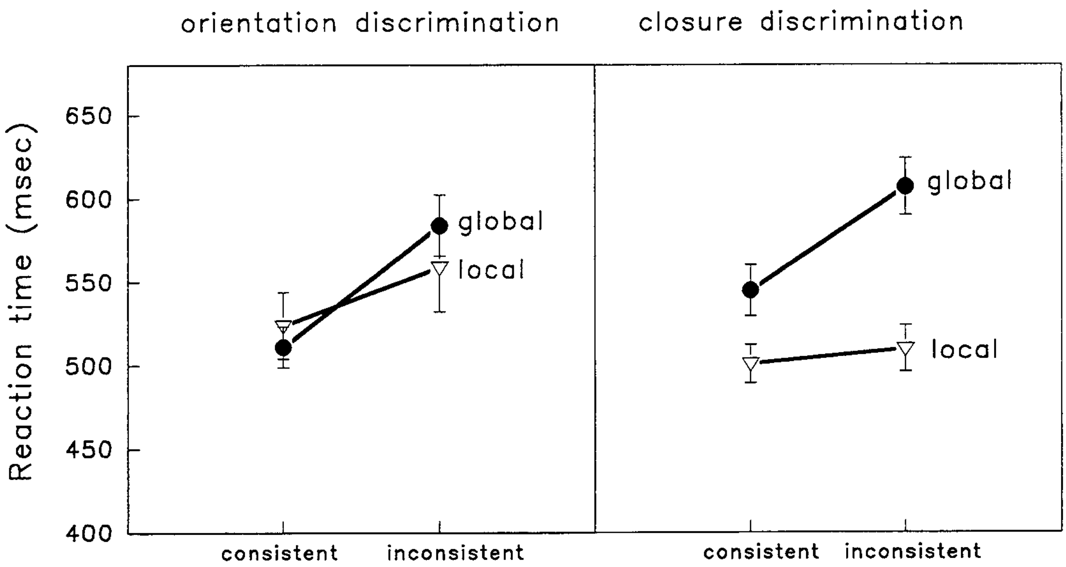


Figure 6. Mean reaction times to global and local levels of compound stimuli in Experiment 3. Data are presented separately for the orientation and closure discrimination tasks.

showing an interference effect on global but not on local responses.

RTs. The mean RTs for the discriminations of orientation and closure are shown in Figure 6. A three-factor ANOVA on the RT data revealed a significant main effect of consistency, $F(1, 11) = 87.26$, $p < .0005$, indicating that RTs in the consistent conditions were faster than those in the inconsistent conditions. The main effects of task ($F < 1$) and globality, $F(1, 11) = 4.09$, $p > 0.6$, were not significant. The Task × Globality interaction was significant, $F(1, 11) = 8.44$, $p < .02$, reflecting the fact that the difference between global and local RTs in the closure discrimination task was larger than in the orientation discrimination task. There was a reliable interaction of Globality × Consistency, $F(1, 11) = 15.33$, $p < .002$; interference was stronger on global than on local responses. The Consistency × Task interaction was also significant, $F(1, 11) = 6.15$, $p < .03$; the interference effect was larger in the orientation discrimination task than in the closure discrimination task. There was no reliable triple interaction among the three factors, $F(1, 11) = 1.70$, $p > .2$.

A separate ANOVA on RTs for the orientation discrimination task showed that there was no significant difference between RTs for the global and local levels ($F < 1$). RTs in the consistent condition were faster than RTs in the inconsistent condition, $F(1, 11) = 50.05$, $p < .0005$, and the local interference on global responses was greater than vice versa, $F(1, 11) = 5.43$, $p < .04$. For the closure discrimination task, there was a complete local advantage. Participants responded faster to the local than to the global stimuli, $F(1, 11) = 14.80$, $p < .003$. RTs in the consistent condition were faster than RTs in the inconsistent condition, $F(1, 11) = 84.78$, $p < .0005$, and local interference was greater than global interference, $F(1, 11) = 41.88$, $p < .0005$. Another orthogonal planned contrast test showed that there was local interference only on global responses, $F(1, 11) = 86.81$, $p < .0005$, but not the reverse, $F(1, 11) = 4.61$, $p > .05$.

As in Experiment 1, RTs to the global and local shapes in the closure discrimination task were broken down further according to whether there were closed or open local shapes, as shown in Table 5. There was a reliable effect of whether the local shapes were closed on global RTs: RTs were faster with closed local shapes, such as triangles, $F(1, 11) = 9.01$, $p < .02$, but there was no significant effect of whether the local shapes were closed on local RTs, $F(1, 11) = 1.23$, $p > .2$.

Discussion

The effect of decreasing the saliency of the global shape (in Experiment 3 relative to Experiment 1) was to facilitate responses to local stimuli. The global advantage in both discrimination tasks observed in Experiment 1 was eliminated in Experiment 3. Global RTs in the orientation discrimination task were no faster than local RTs, and local

Table 5
Mean Global and Local RTs (in ms) and Standard Errors in the Closure Discrimination Task for Stimuli Composed of Local Arrows or Triangles in Experiment 3

	Arrows				Triangles			
	Consistent		Inconsistent		Consistent		Inconsistent	
RT	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Global	553	17.3	614	18.2	537	15.3	599	18.5
Local	502	13.3	519	15.3	498	12.4	505	13.3

Note. RTs = reaction times.

interference was stronger than global interference. For the closure discrimination task, a complete local precedence effect was found. Local RTs were faster than global RTs. There was local interference on responses to global stimuli, but not the reverse. The results indicate that both the global RT advantage and global-to-local interference were eliminated once grouping between local elements was weakened. The results also show that local element grouping to form global shapes competed with the selection of an individual local element for a response. When the grouping process was slowed by making local element group on a late-acting factor (e.g., here, similarity of shapes), local stimuli dominated visual selection. The degree of local dominance depended on the ease of local selection. Selection was easier for the closure relative to the orientation discrimination task here, so the local advantage was more pronounced for closure discrimination. These results are consistent with the hypothesis that the bias toward grouping local elements into a unitary whole parallels and competes with a bias for the selection of individual local elements in determining which—the global or the local level of compound stimuli—is processed first. This competition depends on the presence of gestalt factors at the local level (e.g., closure) and the strength of local element grouping. The bias to select individual local elements can lead to fast local RTs. Nevertheless, a global advantage will emerge when the strong grouping of local elements overcomes the bias to select and compute the properties of local elements. This hypothesis is illustrated in Figure 7.[2]

In Experiment 1, it was likely that several gestalt factors contributed to the grouping of local elements into global shapes, including proximity, similarity of shapes and luminance, continuity, and so on. The gestalt laws of grouping describe the operation of defining regions or contours of perceptual objects at an early, preattentive stage (Rock, 1986) for further focal-attention-involved processes (Kahneman, 1977). Local element grouping by proximity may be

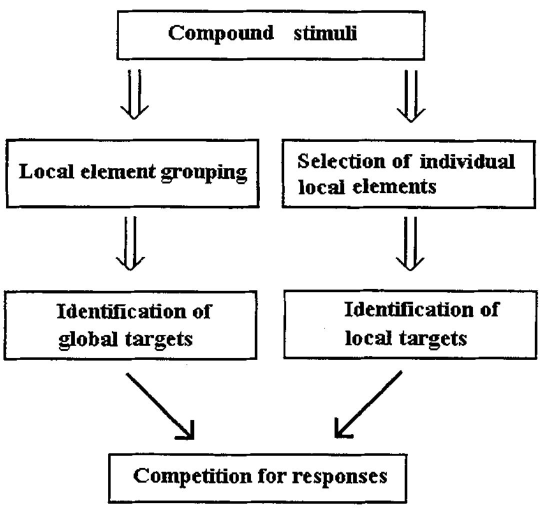


Figure 7. Illustration of a parallel model for the role of perceptual grouping and local selection in hierarchical analysis.

strong enough to overcome the bias to select an individual local element for response even under conditions in which local selection is relatively easy, as in the closure discrimination task, resulting in a global advantage. The paradigm developed in Experiment 3 significantly reduced grouping by proximity by setting the global shapes among a background of similar elements. This manipulation also weakened grouping by similarity of luminance and grouping by good continuity. Under such conditions, grouping by similarity of shapes may strongly determine the segmentation of global shapes from the background crosses. Because grouping by similarity of shape operates later and more slowly than grouping by proximity (Ben-Av & Sagi, 1995; Chen, 1986; Han, Humphreys, et al., 1999), we slowed the segmentation of global figures from their background in Experiment 3 relative to Experiment 1; this resulted in facilitated responses to local shapes.

For the closure discrimination task in Experiment 3, RTs to local arrows were as fast as those to stimuli composed from local triangles. This result provides further evidence that the feature for discrimination, rather than the local shape itself, is the primary determinant of fast local RTs.

One other difference between the results of Experiments 1 and 3 is that the nature of the local elements affected RTs to the global shapes in the closure discrimination task in Experiment 3. Global RTs were faster when the local shapes were closed (triangles) relative to when they were open (arrows; see Table 5). In Experiment 1, the nature of the local elements had little effect (see Table 2). This result may also have stemmed from people's perceptual system being more sensitive to differences in closure than to differences in orientation. In Experiment 1, effects reflecting the ease of grouping by similarity of shape might have been minimized because global shape information may be derived from grouping by proximity, similarity of luminance, and continuity. In Experiment 3, however, the similarity of shape likely dominated grouping. Under this circumstance, it appears that closed shapes group more easily than open shapes among the background crosses (open shapes). In the present study, differences in closure between local triangles and crosses, and differences in orientation between local arrows and crosses, should dominate perceptual grouping for the two kinds of target stimuli. Because grouping based on closure differences occurs earlier than grouping based on orientation differences (Chen, 1986), the grouping of local triangles among the crosses may occur earlier than the grouping of local arrows, thus facilitating responses to global stimuli. This was studied further in Experiment 4.

[2] Note that we do not imply that the two processes (i.e., local element grouping and selection of an individual local element) are isolated, although we did not draw communication between the two processes in this figure. A recent study (Han & Humphreys, 1999) showed that global reaction times (RTs) were slower when local selection was easy than when local selection was difficult and that the effect of easing local selection on local RTs was weaker when local element grouping was strong than when the grouping was weak. These findings suggest that mutual inhibition exists between grouping and local selection.

Table 6
Mean Error Rates (%) and Standard Errors for Each Condition in Experiment 4A

	Global				Local			
	Consistent		Inconsistent		Consistent		Inconsistent	
Stimuli	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Open	1.2	0.8	2.5	0.9	3.5	1.2	2.8	1.1
Closed	0.9	0.6	3.9	1.2	2.0	0.9	3.0	1.4

Experiment 4A: Grouping by Similarity of Shapes and the Global Precedence Effect

In this experiment we examined how different types of similarity grouping would affect global and local stimulus processing. In Experiment 4A, the stimuli used in Experiment 2 were presented against a background of crosses. We thought that this would make similarity of shapes important for grouping of local elements. For Set A, the local arrows were different from the crosses in orientation; global shapes were formed by similarity of orientation. For Set B, the local triangles were different from the crosses in closure; global shapes were formed by similarity of closure. In Experiment 4A we assessed whether the relative RTs to global and local forms would be the same for the two types of stimuli, given that grouping by similarity of closure occurs earlier than grouping by similarity of orientation (Chen, 1986).

Method

Participants. Twelve graduate students (12 men, aged 22–25 years) from the University of Science and Technology of China participated in this experiment as paid volunteers. All had normal or corrected-to-normal vision.

Apparatus, stimuli, and procedure. These were the same as for Experiment 2, except that the compound stimuli were embedded in a background composed of small crosses, as was done in Experiment 3. The vertical and horizontal sizes of each of the crosses were the same as those of each of the local arrows or triangles. The distance between adjacent triangles or arrows was equal to that between each triangle or arrow and a neighboring cross. The whole pattern was 4.8 × 5.6 cm, subtending a visual angle of 3.9° × 4.6°.

Results

Error. The mean error rates for Sets A and B were 2.5% and 2.4%, respectively. There were no effects of task, globality, or consistency ($p > .1$), and only the interaction between globality and consistency reached significance, $F(1, 11) = 7.77$, $p < .02$. There was more local-to-global than global-to-local interference. Table 6 shows the breakdown of the error rates in each condition.

RTs. The mean RTs are shown in Figure 8. There was a significant main effect of consistency, $F(1, 11) = 104.58$, $p < .0005$, and RTs in the consistent condition were faster than in the inconsistent condition. The effects of task, $F(1, 11) = 3.84$, $p > .07$, and globality ($F < 1$) were not significant. There were two reliable interactions: Task × Globality, $F(1, 11) = 12.69$, $p < .004$, and Globality × Consistency, $F(1, 11) = 15.97$, $p < .002$. For Set A, there was a local advantage in overall RTs; for Set B, there was a global advantage. Local-to-global interference was also stronger overall than global-to-local interference. The interactions between consistency and task, $F(1, 11) = 2.37$, $p > .15$, and among the three factors were not significant

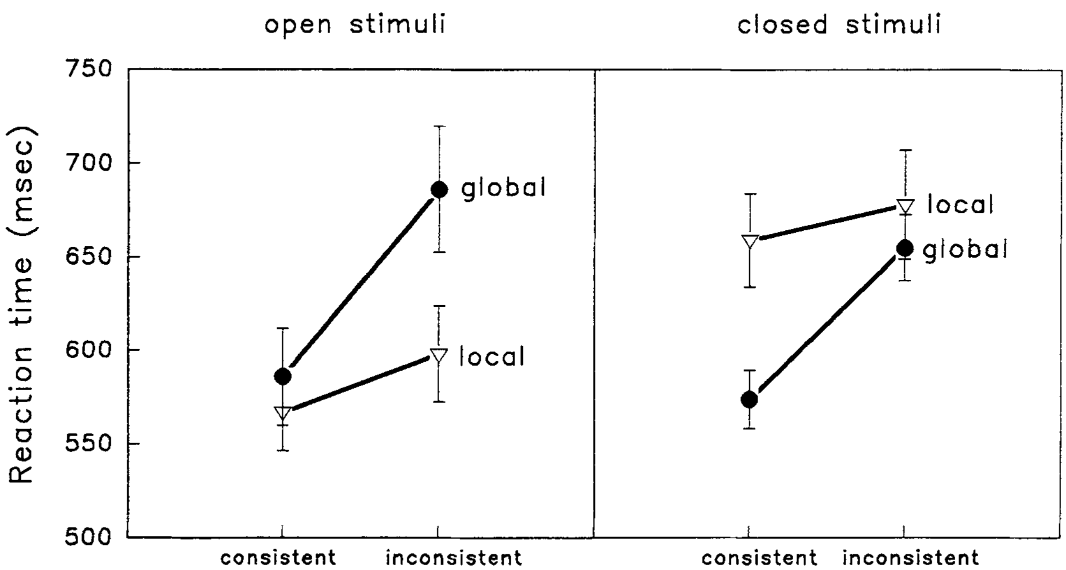


Figure 8. Mean reaction times to global and local levels of compound stimuli in Experiment 4A. Data are presented separately for Set A (discriminating orientation of open shapes [arrows]) and Set B (discriminating orientation of closed shapes [triangles]).

($F < 1$). Additional orthogonal planned contrast tests on RTs demonstrated that local RTs for Set A were faster than those for Set B, $F(1, 11) = 12.75, p < .004$, whereas there was no difference between global RTs for the two types of stimuli, $F(1, 11) = 1.17, p > .3$.

Separate analyses indicated a local advantage for Set A. Global RTs were slower than local RTs, $F(1, 11) = 7.59, p < .02$. The consistency effect was significant, $F(1, 11) = 60.84, p < .0005$, and the Globality × Consistency interaction demonstrated a stronger local-to-global interference than vice versa, $F(1, 11) = 9.00, p < .02$. Orthogonal planned contrast tests showed that there were mutual interference effects on the global, $F(1, 11) = 28.51, p < .0005$, and local, $F(1, 11) = 18.51, p < .001$, levels. For Set B, global RTs were faster than local RTs, $F(1, 11) = 10.68, p < .007$. The consistency effect was significant, $F(1, 11) = 58.15, p < .0005$. The local-to-global interference effect was greater than the global-to-local interference effect, $F(1, 11) = 18.52, p < .001$, and only the former was significant, $F(1, 11) = 137.9, p < .0005$.

Discussion

The results of Experiment 4A are striking. With open stimuli there was a local advantage, both in overall RTs and in the pattern of interference effect (with local-to-global being the larger). This may be expected given that the global shape of the stimuli was made less salient by placing it among a background of cross elements so that similarity of shapes dominated local element grouping. When discrimination of the global shape is made more difficult, responses to local information in the shapes may be initiated relatively more quickly.

In contrast, as far as overall RTs were concerned, the opposite pattern of results occurred for closed shapes. The difference between the closed and open shapes was most apparent for local responses, which were particularly slow with closed shapes. In Experiment 3, we found that when the stimuli were embedded in a background of crosses, computation of the global shape was facilitated by grouping between closed items (grouping by similarity of closure). Thus, with closed shapes, RTs to global shapes could be quicker than those to local shapes. In Experiment 3 there was a local advantage when judgments were based on local closure (Is the local shape an arrow or triangle?). In Experiment 4A we found a global advantage when judgments were based on the orientation of closed shapes (Which direction does the shape point in?). These opposite results were found despite the fact that the global shapes were formed by similarity grouping alone in both instances. The results may be accounted for if the grouping of local elements and the computation of closure of local elements takes place in parallel and competes with each other. Responses to locally closed stimuli will be faster or slower, relative to global stimuli, depending on whether closure can be used for the identification of local elements as well as for grouping local elements to form global shapes. When the task requires orientation judgments, local closed shapes can contribute to grouping (facilitate the perception of global structure) while concurrently impairing judgment of orientation of the local shapes. The result is a global advantage.

One final point concerns the strong local-to-global interference that was found here (especially with closed items). Unfortunately, it was not clear whether this was a genuine effect of response interference or whether it was due to a second factor. In the compatible display, the lines composing the diagonal of each shape were aligned; this was not true for the incompatible display. This alignment of local diagonals may be particularly important for global responses. Hence, it may be that there was a pseudocompatibility effect on global responses attributable to the alignment of local line orientation in this study.

Experiment 4B: The Nature of Background Shapes and the Global Precedence Effect

In Experiment 4B, we further examined how the nature of the background patterns would affect the relative advantage of global and local levels in a hierarchical analysis. When background patterns are introduced, the grouping of local elements is a function of both the similarity between the elements of the hierarchical patterns and the dissimilarity between them and the background elements. Which of the two factors is more important in determining the relative advantage for global and local processing? The compound stimuli used in Experiment 4B were the same as those used in Experiment 4A but were embedded in a background composed of rectangles, as shown in Figure 9. Under this condition, the similarities between the elements of the hierarchical patterns were unchanged in comparison with those in Experiment 4A. However, because the rectangles were closed shapes, the local arrows of the open stimuli (Set A) were different from the background rectangles in closure and thus were grouped based on closure difference. The local triangles of the closed stimuli (Set B) differed from the background rectangles in orientation (both the triangles and rectangles were closed shapes) and thus were grouped based on orientation difference. If grouping based on closure difference is strong and facilitates the perception of global structure, as suggested by the results of Experiment 4A, the background rectangles should weaken the local advantage for the open stimuli observed in Experiment 4A. Similarly, if grouping based on orientation difference is weak and eliminates global processing, the background rectangles should reduce the global advantage for the closed stimuli in Experiment 4A.

Method

Participants. Eighteen graduate students (8 men and 10 women, aged 20–24 years) from the University of Science and Technology of China participated in this experiment as paid volunteers. All had normal or corrected-to-normal vision.

Apparatus, stimuli, and procedure. These were the same as for Experiment 4A, except that the background was composed of small rectangles, as illustrated in Figure 9. The vertical and horizontal sizes of each of the rectangles were the same as those of each of the local arrows or triangles. The distance between adjacent triangles

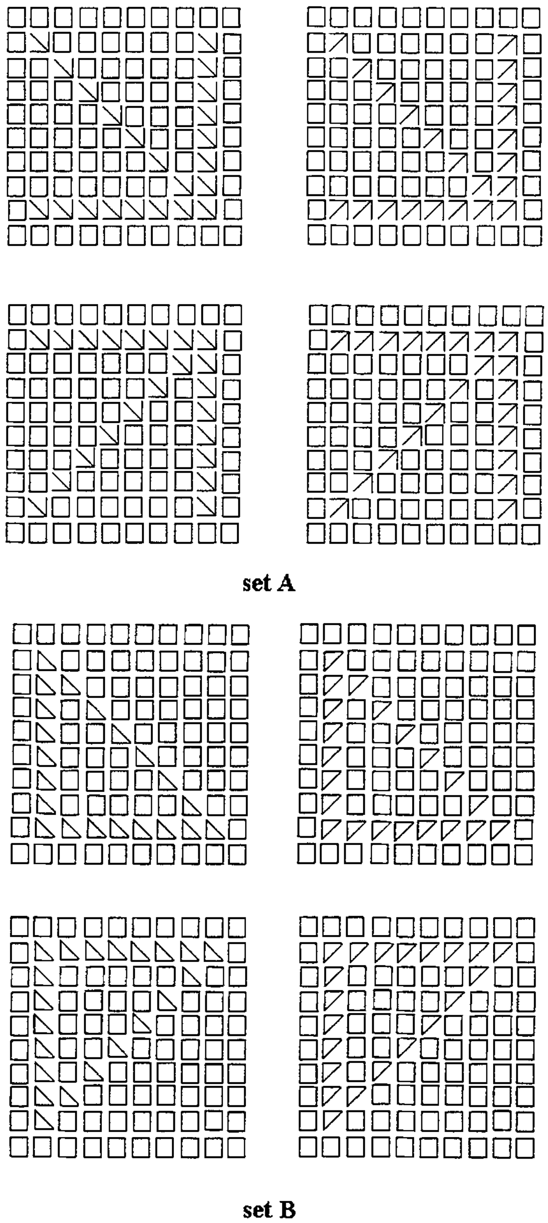


Figure 9. Two sets of compound stimuli used in Experiment 4B. The stimuli were made by embedding the stimuli in Experiment 2 in a background of rectangles.

or arrows was equal to that between each triangle or arrow and a neighboring rectangle.

Results

Error. The mean error rates for Sets A and B were 4.9% and 3.8%, respectively. Only the main effect of consistency was significant, $F(1, 17) = 7.034, p < .02$. Error rates in the consistent conditions were lower than those in the inconsistent conditions. Table 7 shows the breakdown of the error rates in each condition.

RTs. The mean RTs are shown in Figure 10. There was a significant main effect of consistency, $F(1, 17) = 10.723$, $p < .005$, and RTs in the consistent condition were faster than in the inconsistent condition. The Globality × Consistency interaction was also reliable, $F(1, 17) = 8.23, p < .01$. Local-to-global interference was stronger overall than global-to-local interference. There were no significant effects of task and globality or interactions among the factors.

Separate analyses indicated that there was no difference between global and local RTs for Set A, $F(1, 17) = 1.51, p > .2$, or for Set B ($F < 1$). The consistency effect was significant for Set A, $F(1, 17) = 39.37, p < .0005$, but not for Set B, $F(1, 17) = 2.35, p > .1$. RTs were faster in the consistent condition than in the inconsistent condition for the open stimuli. The Globality × Consistency interaction indicated a stronger local-to-global interference than vice versa for Set B, $F(1, 17) = 6.56, p < .02$, but not for Set A, $F(1, 17) = 3.99, p > .05$.

Discussion

The background shapes introduced in Experiment 4B were the same for both the closed and open stimuli. Nevertheless, they produced opposite effects on the two types of stimuli. The background shapes reduced the local advantage for the open stimuli and weakened the global advantage for the closed stimuli observed in Experiment 4A. The similarity between the local elements of the hierarchical patterns was constant across the experiments, whereas dissimilarities between the background figures and the local elements were changed. Therefore, the results of Experiment 4B are consistent with the claim that, when local elements group by shape similarity, the dissimilarity between elements in hierarchical patterns and background shapes is crucial for determining overall global or local advantage. Compared with the results in Experiment 4A, grouping based on closure differences between the local arrows and the background rectangles in Experiment 4B was strong and facilitated the perception of global shape, resulting in a reduction of the local advantage. In contrast, grouping based on orientation differences between closed local triangles and the closed background rectangles was weak and eliminated the perception of global structure, resulting in reduction of the global advantage.

Note that in Experiment 4B, neither the dissimilarity in orientation produced a local advantage for the closed stimuli nor did the dissimilarity of closure produce a global

Table 7
Mean Error Rates (%) and Standard Errors for Each Condition in Experiment 4B

	Global				Local			
	Consistent		Inconsistent		Consistent		Inconsistent	
Stimuli	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*
Open	2.8	1.7	7.7	2.0	4.8	1.2	4.3	1.3
Closed	1.9	0.8	5.0	1.3	3.4	1.0	5.1	1.3

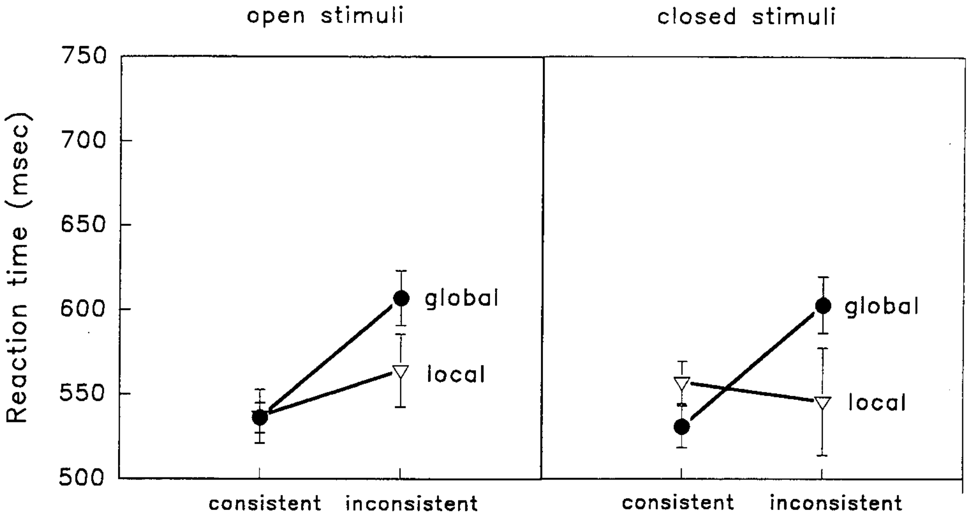
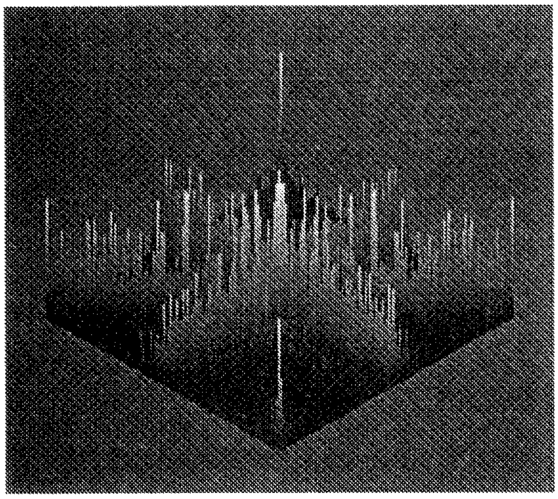


Figure 10. Mean reaction times to global and local levels of compound stimuli in Experiment 4B. Data are presented separately for Set A (discriminating orientation of open shapes [arrows]) and Set B (discriminating orientation of closed shapes [triangles]).

advantage for the open stimuli (as in Experiment 4A). This may have stemmed from differences in local processing between the two tasks. The computation of the component orientations of elements in open shapes might have been faster than the computation of the component orientations in closed shapes (cf. Treisman & Paterson, 1984). It is possible that the fast computation of the component orientation of open figures (local arrows of Set A) competed with the strong grouping of local elements based on the dissimilarity of closure. Similarly, computation of the component orientations of closed figures (local triangles in Set B) might have slowed the local responses, whereas the grouping of local elements based on the dissimilarity of orientation was weak. This difference in the local processing between the two tasks might have resulted in no local advantage for the open stimuli (Set A) or no global advantage for the closed stimuli (Set B).

Although we have discussed the results of Experiments 3 and 4 in terms of the background crosses disrupting grouping, one other account also needs consideration: the background patterns might have reduced the saliency of the global shape by introducing low spatial frequency noise. There has been evidence that low spatial frequency components of images are computed faster than the high spatial frequency components that may be involved in grouping by similarity (Breitmeyer, 1975; Hughes, 1986), and global shapes may be perceived based on the low spatial frequency components in an image (e.g., Hughes et al., 1990, 1996; Lamb & Yund, 1993, 1996; Shulman, Sullivan, Gish, & Sakoda, 1986). In Experiment 3, the background with crosses might have introduced noise into the low spatial frequency components that specified the global triangles or arrows, and the most salient low spatial frequency components might have specified the background square rather than the global arrow or triangle shapes. It may be this masking of the low spatial frequency components that eliminated the global advantage in Experiments 3 and 4.

To assess the contribution of low spatial frequency information, we analyzed the relative amplitude spectra of the Fourier transformations for each of the stimuli used in Experiments 1–4A. The results (illustrated in Figure 11) show that, first, the distribution of the spectra power for stimuli composed from local triangles and local arrows were similar, primarily distributing along three directions (i.e., a vertical, a horizontal, and a diagonal line through the center of the stimulus pattern). Second, the background crosses produced both high- and low-frequency noise (note that there was a general increase in high and low spatial frequency components when background crosses were added). Finally, the noise on the spectra produced by the background crosses was also similar for stimuli composed of local triangles and local arrows in the way that the additional noise distributed along the vertical, horizontal, and diagonal lines through the center of the stimulus. If low spatial frequency information dominated the variations in grouping, the background crosses should have produced similar effects on stimuli composed from local triangles and local arrows, although they grouped by closure and orientation, respectively. In particular, the same stimulus (i.e., the global triangle composed of local triangles) appeared in Set B of Experiment 3 and Set B of Experiment 4A. The spatial frequency components were mathematically the same for this stimulus in the two experiments. Nevertheless, the background crosses produced much different effects on the relative advantage of global and local processing in the two experiments: There was a local advantage in Experiment 3 and a global advantage in Experiment 4A. Furthermore, the same variation in the background patterns from Experiment 4A to Experiment 4B produced opposite effects on the relative advantage of the global and local processing,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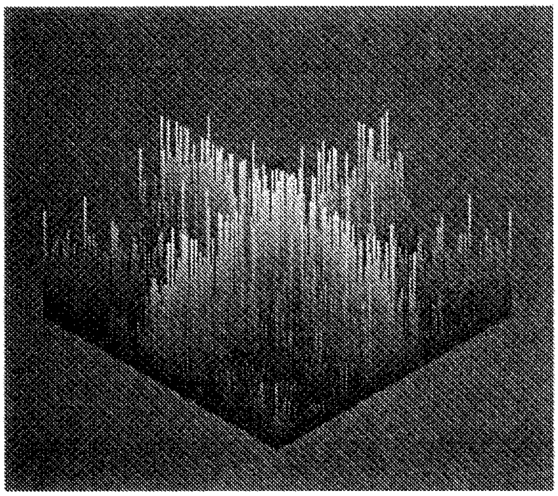
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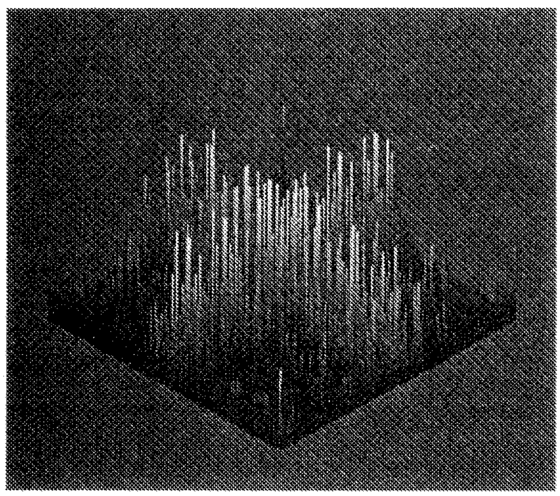
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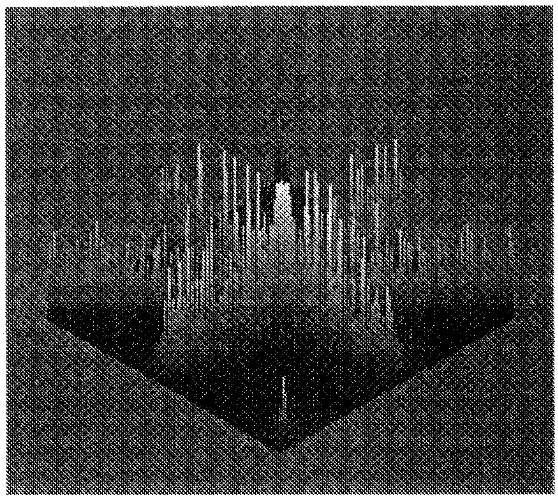
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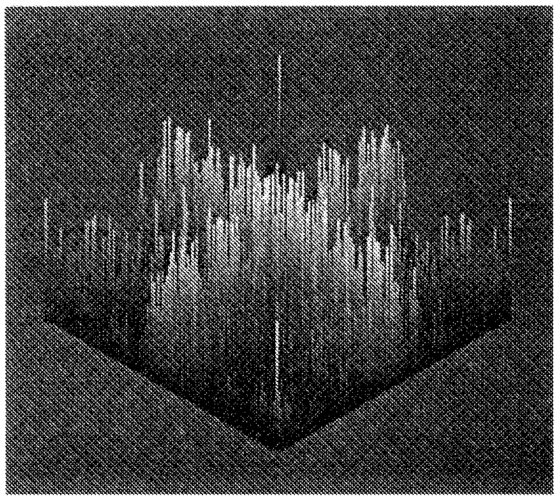
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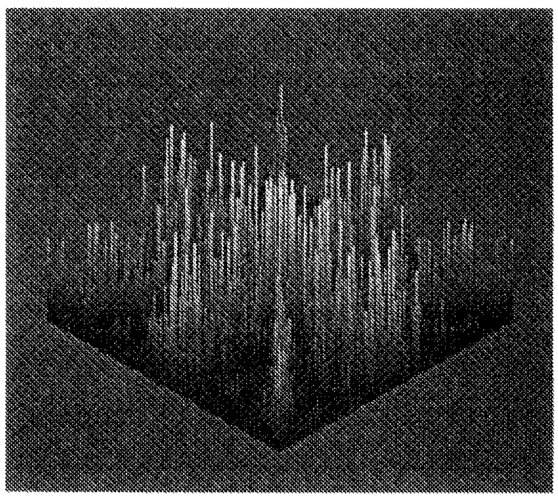
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although the variation of the spatial frequency components induced by the background patterns were the same through the experiments. Together, it seems that the strength of grouping and the features used for discrimination, rather than variance in spatial frequency spectra, were more important for the results in the present set of studies. This argument, against a low spatial frequency account of the global precedence effect, fits with the recent studies in which the global advantage was unaffected by high-pass spatial frequency filtering (Hübner, 1997). In addition, Lamb and Yund's (1993, 1996) research has shown that interference between global and local forms is not affected by eliminating low spatial frequency components in images. However, the background crosses in Experiments 3 and 4A eliminated both the global RT advantage and global-to-local interference. This also suggests that the manipulation of grouping factors affects the relative global or local advantage in a way different from filtering low spatial frequencies.

Experiment 5: Divided Attention

In Experiments 1–4 we used a selective-attention paradigm, in which participants were directed to respond to either a global or local level of a stimulus. Other investigators have examined hierarchical pattern coding using a divided-attention paradigm, in which participants can respond as soon as they detect a target at either the local or global level of stimuli (Hoffman, 1980; Lamb & Robertson, 1989; Miller, 1981; Navon & Norman, 1983). Under this circumstance, there may be less incentive for participants to focus attention at a local rather than at a global level relative to local discrimination task in the selective-attention paradigm, given that it may be more difficult to discriminate local relative to global stimuli. As a result, task-determined biases to select a local form may be weakened because responses may be determined by the global form as well as by the local target form. Consequently, the global advantage may increase. Note that according to our parallel coding account (see Figure 7), local responses in a closure discrimination task should be better able to withstand this increase. Responses based on the closure of local shapes should have a particular advantage over those based on the orientation of local figures because either closure facilitates selection at the local level (Humphreys, Romani, et al., 1994) or the detection of closure occurs earlier (Chen, 1982, 1986; Pomerantz et al., 1977).

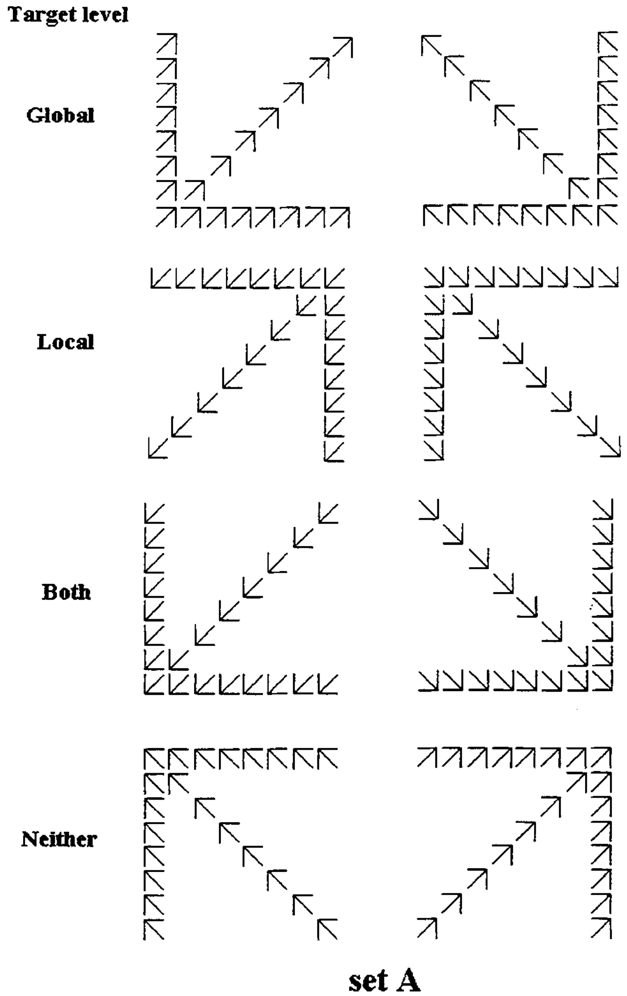

Figure 12. Set A without background crosses used in Experiment 5. The target was the arrows pointing down left or down right appearing at global or local levels.

Method

Participants. Ten undergraduate and graduate students (8 men and 2 women, aged 20–24 years) from the University of Science and Technology of China participated in this experiment as paid volunteers. All had normal or corrected-to-normal vision.

Apparatus, stimuli, and procedure. The apparatus was the same as in Experiment 1. Two sets of compound stimuli were used, as illustrated in Figures 12 and 13. For each set, half the trials were

Figure 11 (opposite). Example of the results of spatial frequency analysis. A: Relative amplitude spectra for the lower left compound pattern in Set A of Figure 3 (global arrows composed of local arrows). B: Relative amplitude spectra for the lower left compound pattern in Set A of Figure 3 embedded against the background of crosses. C: The difference in relative amplitude spectra between Figures 11A and 11B. D: Relative amplitude spectra for the upper right compound pattern in Set B of Figure 3 (global triangles composed of local triangles). E: Relative amplitude spectra for the upper right compound pattern in Set B of Figure 3 embedded against the background crosses. F: The difference in relative amplitude spectra between Figures 11D and 11E.

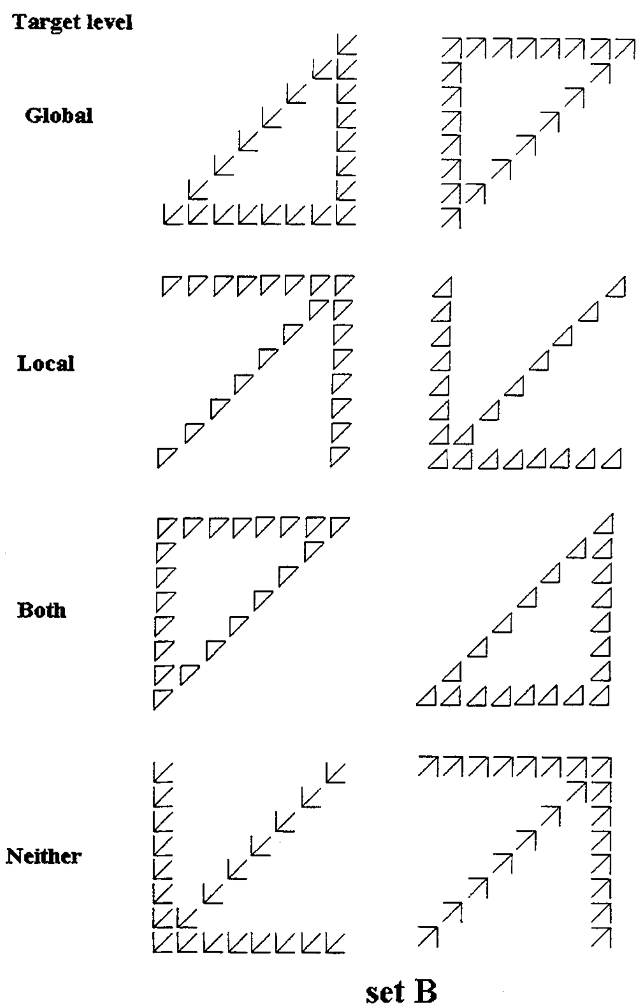

Figure 13. Set B without background crosses used in Experiment 5. The target was the triangles appearing at global or local levels.

presented without background crosses, and for the other half of the trials the compound stimuli were embedded in the background crosses to eliminate the role of proximity in grouping and thus to reduce the salience of the global figure. Set A was composed of global arrows made up of local arrows. The task was to detect the presence of an arrow pointing down left or down right at the global level, the local level, or both. Set B was composed of global triangles or arrows made up of local triangles or arrows. The task was to detect the presence of closed triangles at the global level, the local level, or both. Hence, for Set A, participants detected the presence of targets based on orientation, whereas discriminations were based on closure for Set B. For all the compound stimuli, the local elements were arranged in an 8 × 8 matrix. The size of the global and local figures and the background crosses were the same as those used in Experiment 3.

A yes–no detection task was used. Participants were instructed to identify whether the compound stimulus contained the target figure. They pressed one of the two keys on a keyboard if the target figure appeared at the global level, the local level, or both and pressed another key if the target figure did not appear, using the right and left middle fingers, respectively. Each trial began with a 1,000-ms warning beep and a presentation of the plus-shaped fixation located at the center of the screen. The fixation was presented for 1,000 ms. The stimulus appeared after the offset of the fixation and remained on the screen until the participant made a response. The presentation sequence for the two sets of stimuli was counterbalanced across participants. For each set of stimuli, after 20 practice trials, a total of 320 trials in four blocks were presented. There were no targets on 40% of the trials. The probability of a target appearing on global level, local level, or both was equal (20%). Participants were instructed that both the speed and the accuracy of the response were important.

Results

Errors. Mean error rates were low for both Set A (2.8% for stimuli with a blank background; 1.6% for stimuli with a cross background) and Set B (2.4% for stimuli with a blank background; 1.7% for stimuli with a cross background). There was no indication of a speed–accuracy trade-off; therefore, error data are not discussed further. Table 8 shows the mean percentage of errors in each condition.

RTs. Average RTs to the targets appearing at the global, local, or both, along with the no-target responses, are shown in Figure 14 for the trials with and without the background crosses. RTs for "yes" responses were subjected to a repeated measures ANOVA with task (Set A vs. Set B), background (crosses present or absent), and level (global, local, or both) as within-subjects factors. The main effect of task was significant, $F(1, 9) = 6.67$, $p < .03$, reflecting the fact that RTs in detection of closure (546 ms without and 636 ms with background crosses) were faster than in the detection of orientation (612 ms without and 682 ms with background crosses). The effect of the background was also significant, $F(1, 9) = 52.71$, $p < .0005$. RTs were faster when there was no background present. Furthermore, there was a reliable effect of level, $F(2, 18) = 55.52$, $p < .0005$; responses to targets presented at both levels were faster than those to targets presented at only one level. The Task × Level interaction reached significance, $F(2, 18) = 21.75$, $p < .0005$. For Set A (detection of orientation), the both-level condition was faster than the global-only condition: blank background, $F(1, 9) = 9.13$, $p < .01$; cross background, $F(1, 9) = 27.41$, $p < .001$. This in turn was faster than the local-only condition: blank background, $F(1, 9) = 5.94$, $p < .04$; cross background, $F(1, 9) = 11.77$, $p < .007$, regardless of whether background crosses were present or absent. For Set B (detection of closure), there was an advantage for the both-level condition only when there were no background crosses, $F(2, 18) = 128.1$, $p < .0005$; performance was the same for global and local level stimuli alone ($F < 1$). When there were background crosses, RTs to local targets were faster than to global ones, $F(1, 9) = 6.97$, $p < .03$.

Discussion

Under the divided-attention conditions, participants should have had less incentive to maintain attention at a local level than under selective-attention conditions. If attentional selection is crucial for the perception of local properties, as illustrated in Figure 7, then the global advantage may have

Table 8
Mean Error Rates (%) and Standard Errors for Each Condition in Experiment 5

Condition	Global level *M*	Global level *SE*	Local level *M*	Local level *SE*	Both *M*	Both *SE*	None *M*	None *SE*
Set A with blank background	2.7	1.5	4.2	1.1	0.7	0.7	3.0	0.8
Set A with cross background	0.0	0.0	2.6	1.8	0.7	0.7	3.0	1.0
Set B with blank background	2.1	1.1	3.3	1.8	2.1	1.1	2.3	0.8
Set B with cross background	2.8	1.1	2.0	1.4	0.7	0.7	1.4	1.0

been expected to be stronger in the divided-attention conditions than in the selective-attention conditions. Consistent with this, we found an overall global advantage in the orientation discrimination task, both when there was a blank background and when there was a background of crosses. In the equivalent selective-attention task (Experiments 1 and 3), the global advantage was eradicated when the background of crosses was used and the global shape was made less salient.

However, in the closure discrimination task, we failed to find any evidence of a global advantage, and a local advantage was still observed even when background crosses were used. Again, the results demonstrate the benefit of computing closure for the selection of local elements in compound stimuli. The fast computation of closure of local elements can overcome any bias to respond to outputs derived from the grouping of local shapes to form global shapes, even in a divided-attention paradigm.

Finally, we note that for each task, performance was better when targets were presented at both levels rather than at one level alone. This can be expected if there is overlap in the distributions of RTs to the local and global levels (Miller, 1981).

General Discussion

In the present experiments we investigated the role of perceptual grouping and the computation of closure in the processing of the global and local properties of hierarchical stimuli. Participants were required to discriminate two types of features, orientation and closure, in either selective- or divided-attention conditions. The strength of grouping of

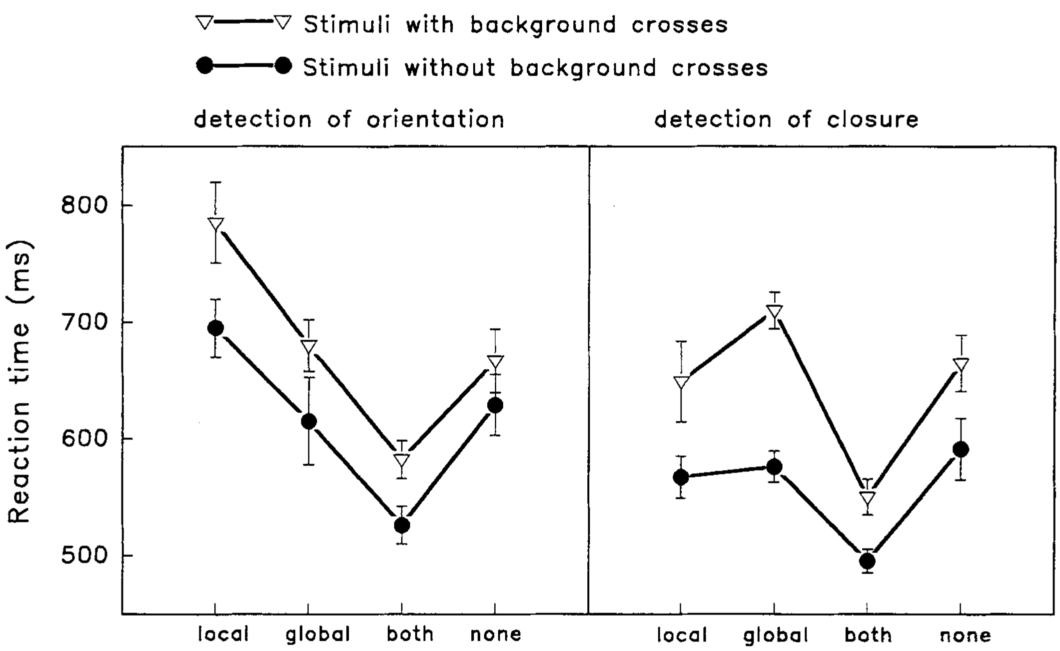

Figure 14. Mean reaction times to global and local levels of compound stimuli in Experiment 5. Data are presented separately for the task of detecting the presence of arrows pointing down left or down right and the detecting of the presence of triangles.

local elements of hierarchical patterns was manipulated by inducing background figures.

In Experiment 1, we found that when local elements grouped strongly into global forms (i.e., when compound stimuli were presented without background crosses), the magnitudes of the global RT advantage and global interference were greater when judgments had to be made on the basis of the orientation of shapes relative to when they were made, on the basis of whether the shapes were closed or open. The differences between the orientation and closure discrimination tasks were found only when responses were made to local stimuli embedded in global shapes, but not when responses were to single small or global stimuli. Within global stimuli, there was an advantage for local responses in closure discrimination tasks. This advantage for closure over orientation discrimination was found even on trials in which open stimuli were presented in the closure discrimination task (i.e., with global arrows or triangles composed of local arrows in Experiment 1). Thus, the effect was due to the stimulus features used to support discrimination rather than to the particular stimulus on a trial; discrimination of closure particularly facilitated the selection of local elements for responses. In Experiment 2, the global advantage was reinstated when participants responded to the orientation of line elements in closed shapes. Again, this iterates that the selection of local stimuli was affected by the judgment required (closure discrimination) rather than by the stimuli presented. We also found, in Experiment 5, that under divided-attention conditions, there was a global advantage for orientation but not for closure discrimination tasks. This is consistent with the results from the selective-attention paradigm, indicating that discrimination of closure facilitates local processing.

We also manipulated the strength of local element grouping by introducing background patterns. When the grouping of local elements was weakened by making shape similarity dominate grouping, the global advantage was generally reduced (Experiments 3–5). Indeed, there was a complete local advantage in terms of both RTs and interference in closure discrimination tasks when local elements grouped by shape similarity (Experiment 3). This local advantage for the closure discrimination task was found under divided- as well as selective-attention conditions (Experiment 5), whereas the local advantage for the orientation discrimination task under the condition that local elements group by similarity of shapes was found only under selective-attention conditions (Experiment 4A). When the task required the discrimination of local line orientation within closed shapes and local elements grouped by similarity of closure, RTs to local shapes were particularly slow and a global RT advantage was observed (Experiment 4A). The variation in the global advantage produced by background patterns could not be attributed solely to effects on the low spatial frequency components in the images. The background crosses added both low and high spatial frequency noises; however, this was equivalent for the stimuli through experiments (Experiments 3 and 4A). Furthermore, the same variation of background patterns could produce opposite effects on the relative advantage of global and local processing depending on the experiment (Experiments 4A and 4B).

The present results fit an account of perceptual organization in which gestalt factors such as grouping by proximity and similarity and computation of closure take place in parallel and compete with each other in determining which level of a compound stimulus dominates visual selection for responses (see Figure 7). By and large, strong grouping between local elements (e.g., grouping by proximity when there were no background patterns in Experiments 1 and 2) facilitated the perception of global structure, and thus there was a global advantage. When detecting closure for the response, there was an easier selection of local elements in compound figures. In this way, the computation of closure of local elements interacted with the effects of grouping between the local elements to form the global figure and assisted the perception of local level of compound stimuli. However, the presence of closure at the local level did not necessarily lead to a local precedence effect. The discrimination of closure reduced the benefit of global shape when the elements grouped strongly (Experiment 1). Only when the grouping was weakened (e.g., when the elements were grouped by similarity of shapes in Experiment 3) did a local precedence effect emerge.

One consequence of participants responding to closure seems to be that the selection of local elements from their more global contexts was eased. Differences between the closure and the orientation discrimination tasks emerged only when the selection of local elements was required, not when single small (local) or large (global) stimuli were presented. This facilitation of selection in the closure discrimination task occurred under divided- as well as selective-attention conditions (Experiment 5), suggesting that it reflects relatively automatic aspects of visual processing.

In Experiment 4A, the advantage for responding to locally closed elements was reversed when the task required responses to a part of the local shapes (to their orientation) and when the elements grouped by the similarity of shapes (when background crosses were present). We suggest that this reversal occurred because grouping by dissimilarity of closure is stronger than that by dissimilarity of orientation (Chen, 1986) when compound patterns are presented against the background crosses, and that grouping between stimuli disrupts responses to local parts within group members.

How do we reconcile this suggestion for strong grouping between closed, local stimuli with the proposal that the selection of such stimuli is facilitated in closure discrimination tasks? One possibility is that when a group is formed, there can be selection of the parts of that group (e.g., the local triangles), but not the parts of these parts (e.g., the line orientation making up the triangles). Thus, there is relative facilitation of selection for locally closed shapes, but not for the orientation of parts of the closed shapes. This may occur if structural descriptions of objects are derived in a hierarchical fashion, in which parts are articulated only with respect to reference frame at the next highest level of representation. For example, hands but not fingers may be represented as parts relative to the body, and fingers may be represented only as parts relative to hands (cf. Marr, 1982). According to this account, grouping may disrupt local orientation judgments even if selection of local stimuli benefits when closure discrimination is required.

In summary, we propose that the relative advantage for global or local coding in hierarchical patterns depends on the parallel processing in perceptual organization: the nature and strength of grouping between the local stimuli, the ease of selecting local stimuli for response, and the presence of configural elements (see Figure 7). This notion can provide a consistent interpretation of some of the previous confused results in the literature. For example, increasing the overall visual angle of compound stimuli (Kinchla & Wolfe, 1979; Lamb & Robertson, 1990; Luna, Marcos-Ruiz, & Merino, 1995) and decreasing the number of local figures while keeping the overall visual angle constant (Martin, 1979; Navon, 1983; Podrouzek, Modigliani, & Lollo, 1992) extend the distance between adjacent local elements and thus weaken the role of proximity in grouping. These manipulations facilitate local processing by weakening local element grouping. On the other hand, presenting the compound stimuli centrally (Grice et al., 1983; Pomerantz, 1983), at a constant location (Lamb & Robertson, 1988), and with a long exposure duration (Paquet & Merikle, 1984) facilitates selection of local elements and so reduces or eliminates the global advantage. In contrast, presenting the local figures peripherally (Luna, 1993; Navon & Norman, 1983), with uncertain locations (Lamb & Robertson, 1988), or with a short duration (Paquet & Merikle, 1984) makes the selection of individual local elements difficult, leading to a strong global precedence effect.

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