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

Shihui Han
University of Science and Technology of China

Glyn W. Humphreys
University of Birmingham

Lin Chen
University of Science and Technology of China

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

other gestalt factor of interest in the current research, closure, can be detected in parallel across a display of open 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

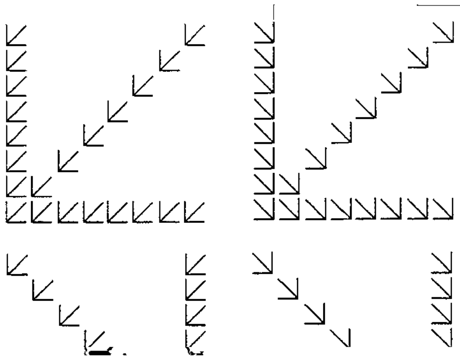
targets (however, see Han, Fan, Chen, & Zhuo, 1997). Such work suggests that competing perceptual structures may normally be formed that differ in each hemisphere. In addition, the presence of a gestalt property at the local level, sis. To our knowledge, there has been little research on how different 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

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



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

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

	Global				Local			
	Consistent		Inconsistent		Consistent		Inconsistent	
Discrimination	*M*	*SE*	*M*	*SE*	*M*	*SE*	*M*	*SE*

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

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, $F(1, 11) = 1.584$,

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 differ-

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

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

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.

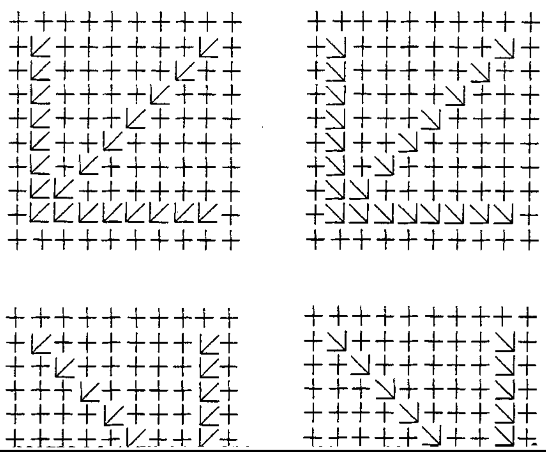


Table 4
Mean Error Rates (%) and Standard Errors for Each Condition in Experiment 3

	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

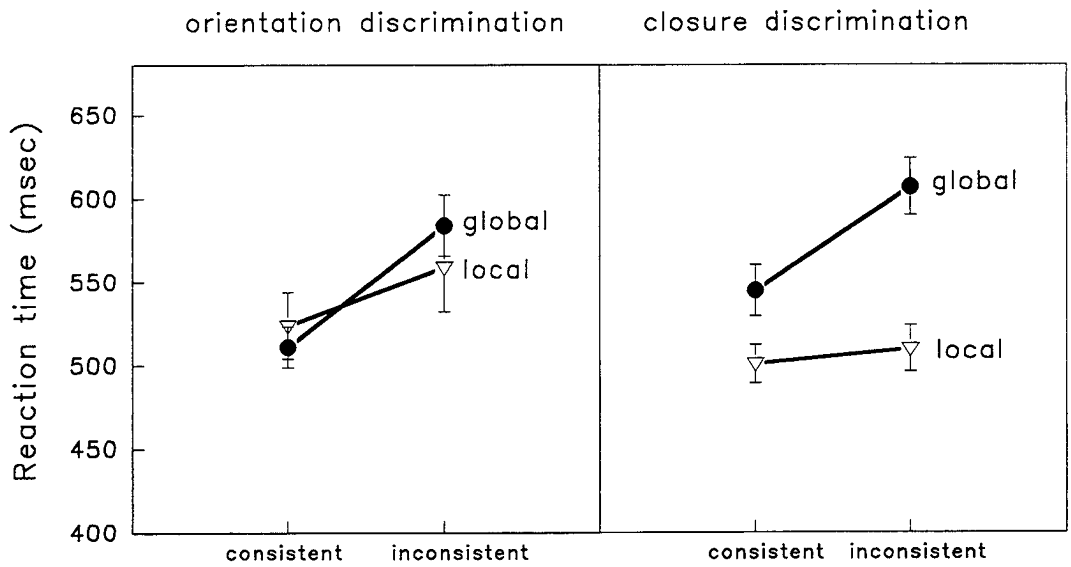


Figure 6. Mean reaction times to global and local levels of compound stimuli in Experiment 3. Data are presented separately for the orientation and closure discrimination tasks.

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

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 group-

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

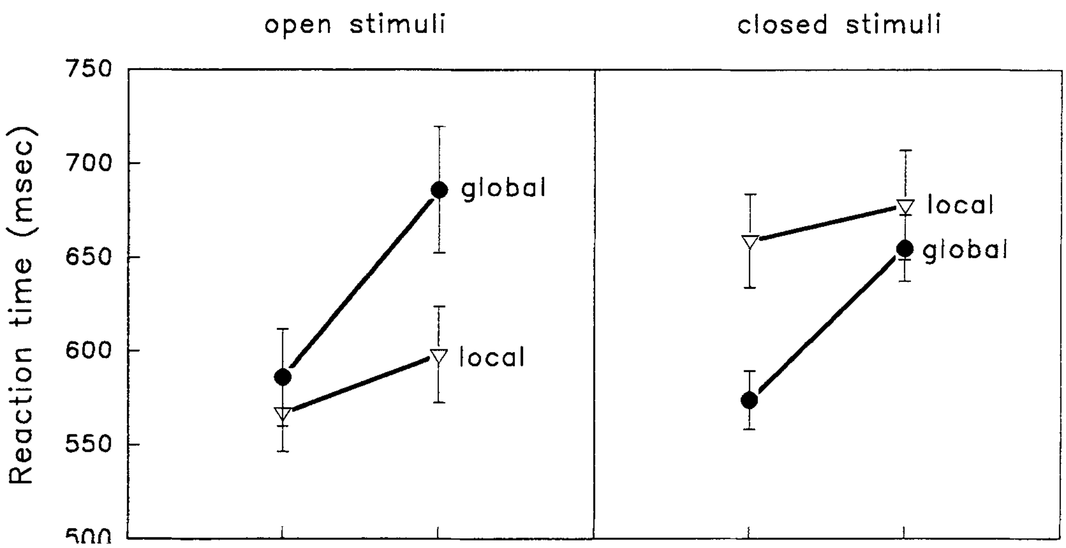
Participants. Twelve graduate students (12 men, aged 22–25 years) from the University of Science and Technology of China participated in this experiment as paid volunteers. All had normal or corrected-to-normal vision.

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



($F < 1$). Additional orthogonal planned contrast tests on RTs

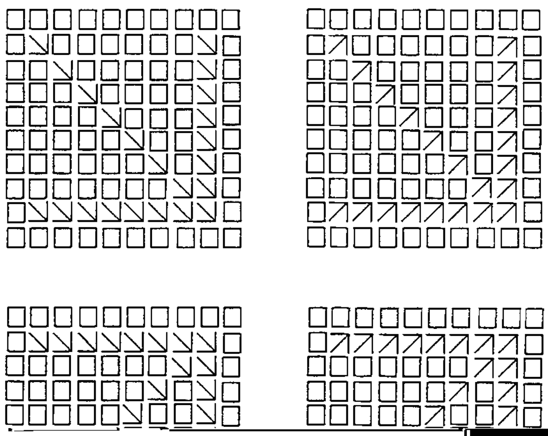
for Set B, $F(1, 11) = 12.75$, $p < .004$, whereas there was no difference between global RTs for the two types of stimuli, $F(1, 11) = 1.17$, $p > .3$.

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

structure) while concurrently impairing judgment of orienta-

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



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

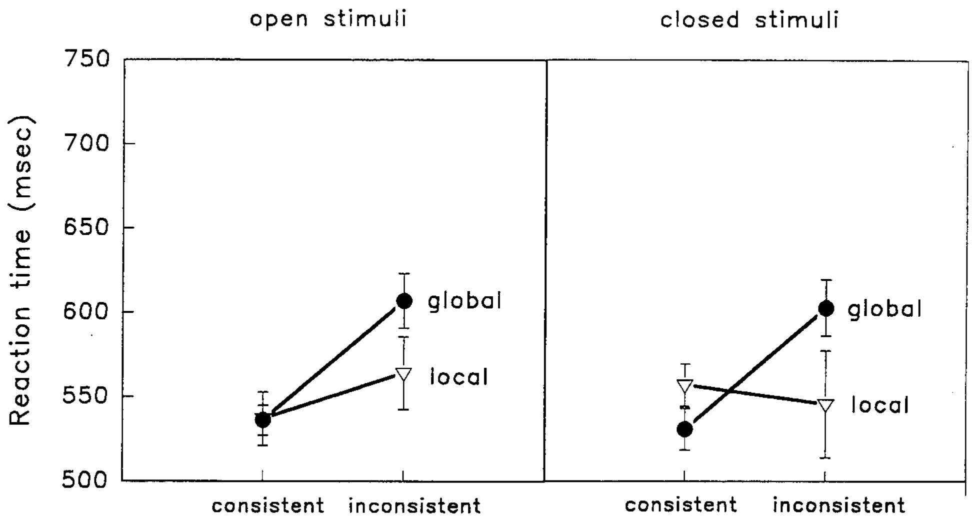


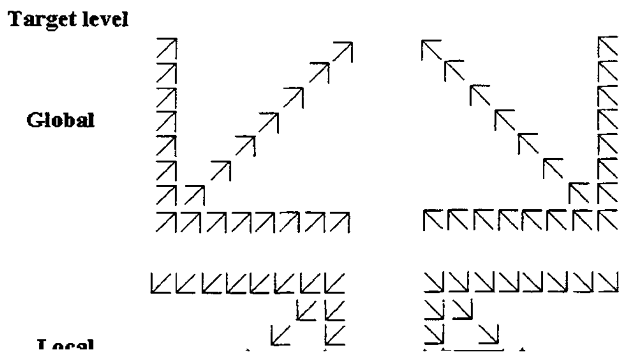
Figure 10. Mean reaction times to global and local levels of compound stimuli in Experiment 4B. Data are presented separately for Set A (discriminating orientation of open shapes [arrows]) and Set

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 orienta-

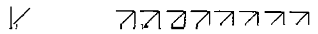
masking of the low spatial frequency components that eliminated the global advantage in Experiments 3 and 4.

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

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



Target level



fixation located at the center of the screen. The fixation was presented for 1,000 ms. The stimulus appeared after the offset of

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

Condition	Global level		Local level		Both		None	
	M	*SE*	*M*	*SE*	*M*	*SE*	*M*	*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

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

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 discrimina-

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 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;

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