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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

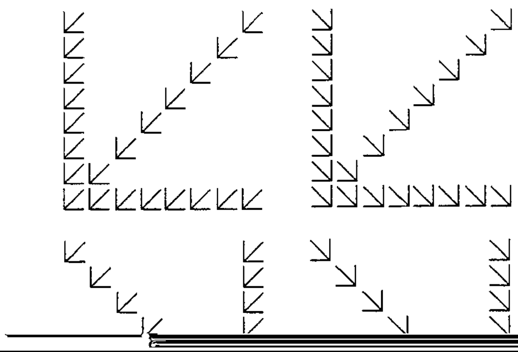
background figures could facilitate the grouping of closed local elements and enhanced the perception of global structure. Experiment 5 showed that the advantage for detecting the closure of local elements in hierarchical analysis also held under divided- and selective-

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

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 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

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



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 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 discrimi-

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 com-

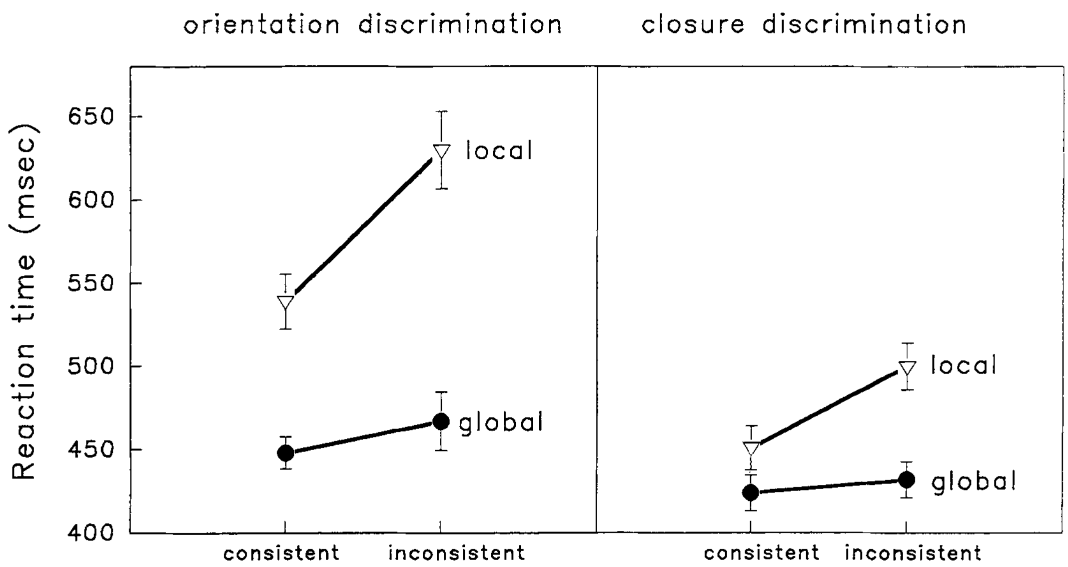


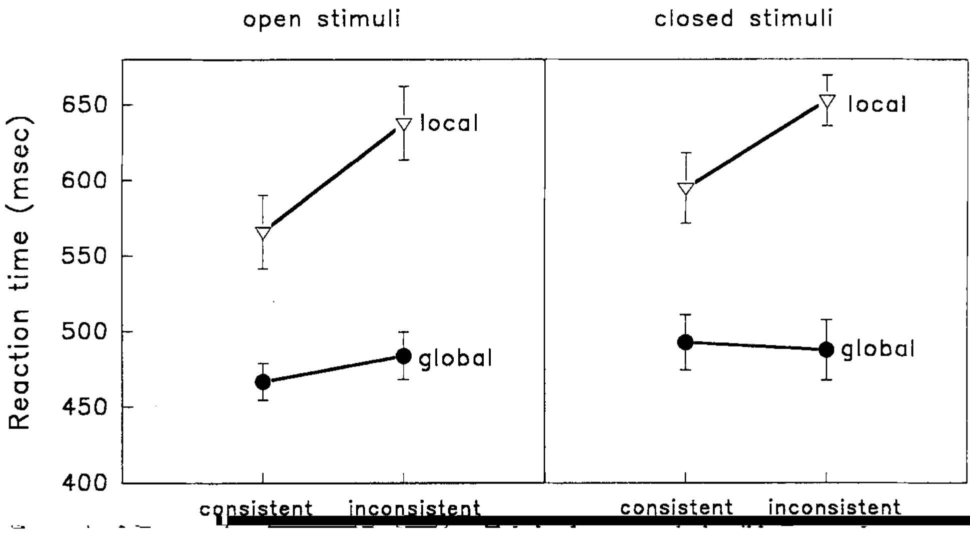
Figure 2. Mean reaction times to global and local levels of compound stimuli in Experiment 1. Data are presented separately for the orientation and closure discrimination tasks.

indicate that both the relative speeds of global and local [redacted] 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

only slightly faster than the closure discrimination in the [redacted] 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 elements, even with open elements present. The fact that in

Table 3



are presented separately for Set A (discriminating orientation of open shapes [arrows]) and Set B (discriminating orientation of closed shapes [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.

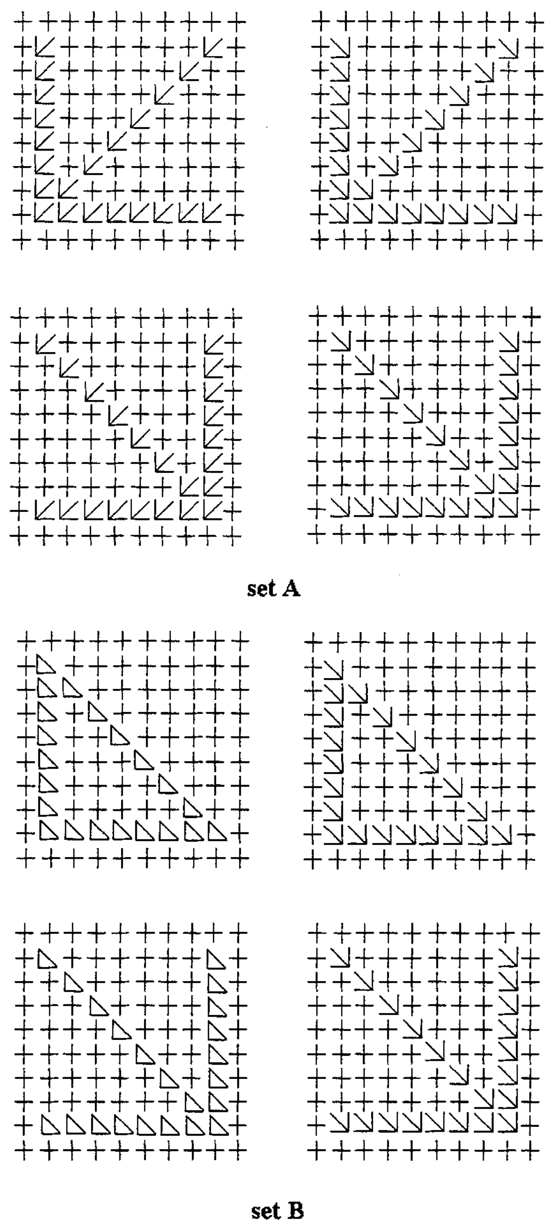


Figure 5. Two sets of compound stimuli used in Experiment 3. The stimuli were made by embedding the stimuli in Experiment 1 in a background of crosses.

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

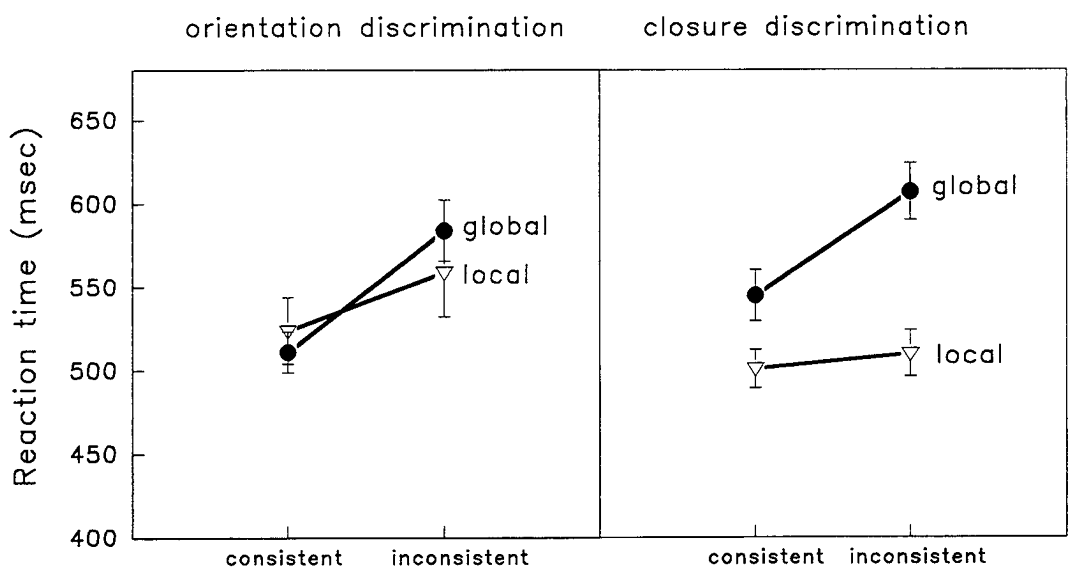
Method

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,



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 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, 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

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 similar-

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

	Global				Local			
	Consistent		Inconsistent		Consistent		Inconsistent	
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

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

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

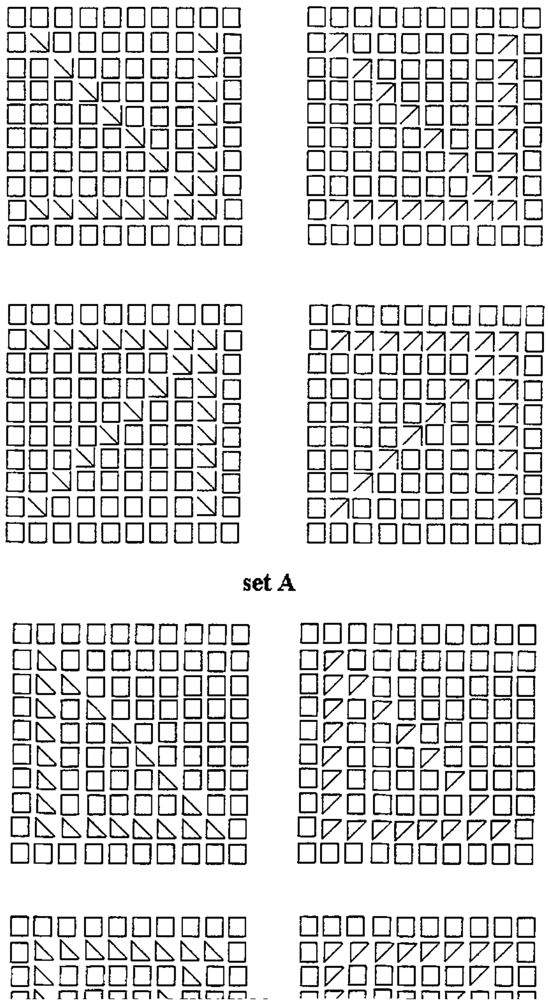
Error. The mean error rates for Sets A and B were 2.5% and 2.4%, respectively. There were no effects of task, globality, or consistency ($p > .1$), and only the interaction between globality and consistency reached significance,

($F < 1$). 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, $F(1, 11) = 1.17, p > .3$.

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



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

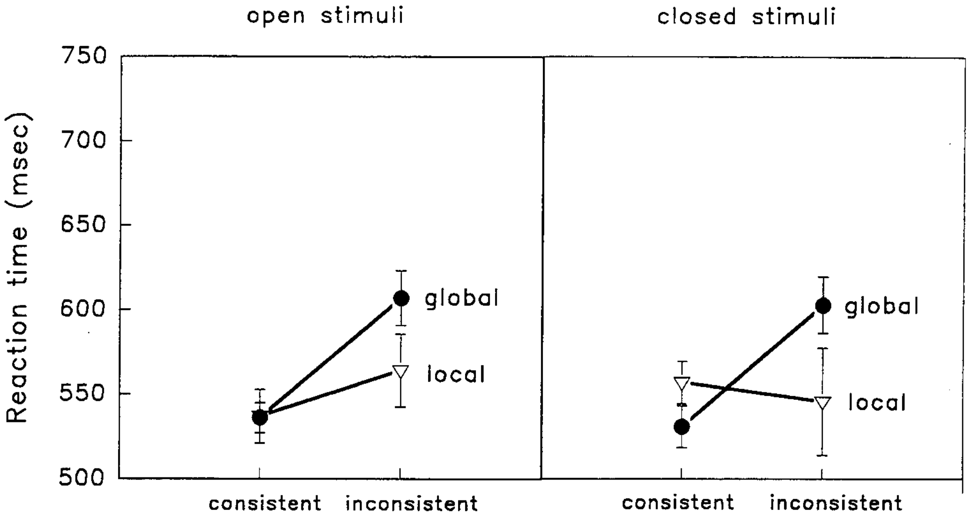


Figure 10. Mean reaction times to global and local levels of compound stimuli in Experiment 4B. Data are presented separately for Set A (discriminating orientation of open shapes [arrows]) and Set B (discriminating orientation of closed shapes [triangles]).

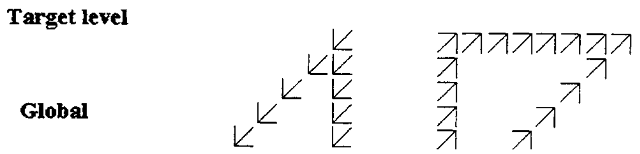
advantage for the open stimuli (as in Experiment 4A). This may have stemmed from differences in local processing between the two tasks. The computation of the component orientations of elements in open shapes might have been faster than the computation of the component orientations in closed shapes (cf. 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,

although the variation of the spatial frequency components induced by the background patterns were the same through

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 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

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

	Global level		Local level		Both		None	
Condition	*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 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

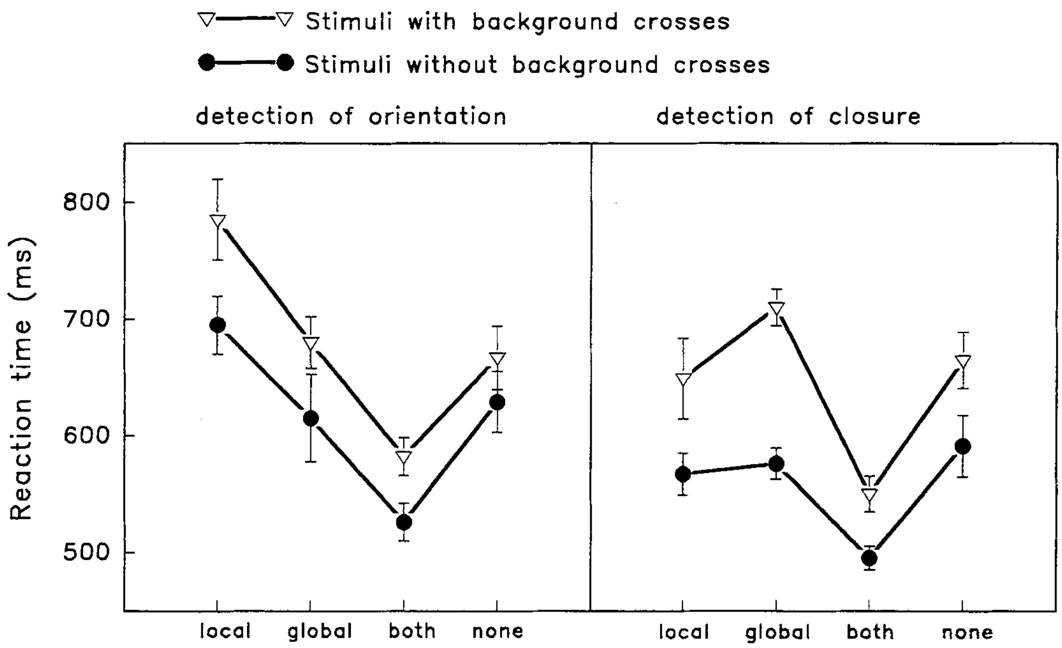


Figure 14. Mean reaction times to global and local levels of compound stimuli in Experiment 5. Data are presented separately for the task of detecting the presence of arrows pointing down left or down right and the detecting of the presence of triangles.

local elements of hierarchical patterns was manipulated by

relative advantage of global and local processing depending 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

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