Attentional selection in the processing of hierarchical patterns: an ERP study

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Abstract

The current study aimed to investigate the effect of attentional selection of distinctive local elements on the processing of hierarchically organized patterns. Event-related brain potentials (ERPs) were recorded from subjects during identifications of global or local shapes of hierarchical patterns where either all local elements were identical (homogeneous stimulus) or a local element closest to fixation was distinguished by color from others (pop-out stimulus). One group of subjects was presented with the homogeneous stimuli and required to identify global or local shapes in separate blocks of trials. The other group was presented with the pop-out stimuli and asked to attend to the unique local item in the local task. A global precedence effect was observed in behavioral data. ERPs showed enlarged posterior P1 and N2 amplitudes in the local relative to global conditions. Top-down attention to the pop-out item resulted in increased frontal/central N2 amplitudes in the local condition but eliminated the temporal/occipital N2 enhancement in the local relative to global conditions. Top-down attention to the pop-out item also increased local-to-global interference in reaction times and frontal N2 latencies. The results suggest that a frontal mechanism is involved in directing top-down attention to a specific local item whereas a temporal/occipital mechanism is engaged in an attentional filtering process in the identification of local shapes in hierarchical analysis. © 2001 Elsevier Science B.V. All rights reserved.

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1. Introduction

The processing of visual scenes often proceeds from a global level to a more local level. For example, compound stimuli constructed from smaller repeating elements usually show a global precedence effect, the reaction times (RTs) to identify the global structure are faster than RTs to identify the composing local elements, and the global structure interferes with responses to local elements but not vice versa (Navon, 1977). However, RTs may show a local precedence effect where visual angles (Kinchla and Wolfe, 1979), density of local elements (Martin, 1979), stimulus positions in the visual field (Pomerantz, 1983), spatial frequency components of compound stimuli (Badcock et al., 1990; Hughes et al., 1990; Lamb and Yund, 1993, 1996), or strength of perceptual grouping (Han and Humphreys, 1999; Han et al., 1999b) have been manipulated.

Studies have shown that processing of global or local levels of Navon-type compound stimuli modulates event-related brain potentials (ERPs). For instance, Heinze and Münte (1993) recorded ERPs to targets that could appear on either global or local levels in the same block of trials (a divided attention procedure). They found that a temporal/occipital N2 component exhibited an earlier onset and higher amplitude to local than to global targets when RTs showed a local advantage. Han et al. (1997) asked subjects to identify global or local shapes in separate blocks of trials (a selective attention procedure). Behavioral performance showed a global RT advantage and a one-way global interference. ERPs showed enlarged posterior P1 and N2 components in the local relative to global conditions. The latencies of the frontal/central N2 were longer in the local than global conditions and were further delayed by the incongruency between global and local shapes. The P3 latencies mirrored the behavioral data, showing a global advantage and a one-way global interference. Similar modulations of the posterior P1 and N2 by hierarchical processing were confirmed in studies using compound letters and a selective attention procedure (Han and Chen, 1996; Han et al., 1999a) and using compound shapes and a divided-attention procedure (Han et al., 2000).

Long-latency endogenous components (such as the P3) may be parts of the electrophysiological substrates of the late phases of the global precedence effect observed in RTs since the P3 latency is thought to reflect the final stage of stimulus evaluation and classification (Donchin, 1977; McCarthy and Donchin, 1981). The modulation of shorter-latency ERP components (i.e. the posterior P1) suggests that attention to local elements may enhance processing in occipital cortical regions. These results are consistent with the results of positron emission topography (PET) study (Fink et al., 1996; Heinze et al., 1998), which showed increased regional cerebral blood flow (rCBF) in visual cortical areas during selective attention to global and local targets. However, the functional role of the temporal/occipital N2 enhancement in local relative to global processing of hierarchical patterns is still unclear. Recent behavioral studies (Han and Humphreys, 1999; Han et al., 1999b) suggest that one component of the global precedence effect may be an additional filtering (or selection) process required for local processing relative to global processing. The filtering process operates because there are many potential targets

at the local level in the local task (i.e. all local elements are task relevant) whereas there is only one potential target at the global level in the global task (i.e. only one global pattern is task relevant). Therefore, identification of local shapes requires selection of one local element from multiple identical objects that are presented simultaneously in the visual field. The objective of the present study was to examine to what extent the N2 enhancement in local relative to global conditions can be attributed to the filtering process in a local task.

ERP indices of attentional filtering have been studied using visual search tasks. Luck et al. (Luck et al., 1993; Luck and Hillyard, 1994a,b; Girelli and Luck, 1997) asked subjects to detect the presence of an item that differed from distractors in color, orientation, or motion. One finding was that stimulus arrays that contained a pop-out item elicited an enhanced frontal N2 wave when subjects were required to detect pop-out targets. However, the frontal N2 enhancement was eliminated when subjects were not required to detect pop-outs but attended to features of distractors. Luck et al. suggested that the frontal N2 enhancement reflects a top-down controlled process of attention rather than an automatic stimulus-driven process of attention during the pop-out detection. Another finding was that stimulus arrays with a pop-out item elicited a contralateral N2pc subcomponent (i.e. N2-posterior-contralateral) over the occipital cortex, which was prominent for target stimuli or nontarget stimuli that needed to be carefully examined to be distinguished from target stimuli. However, the N2pc was absent for nontarget stimuli that could be rejected on the basis of simple features. In addition, the N2pc was observed when a target item was surrounded by competing distractor items but was eliminated when a target was presented alone or multiple identical targets were displayed simultaneously. Luck et al. suggested that the temporal/occipital N2pc reflects an attentional filtering process that depends on a feature-based stimulus analysis. Eimer (1996) extended the assumption by showing that the N2pc is also evident when a target is presented together with just one non-target item, and suggested that the N2pc may reflect the attentional selection of task relevant stimuli.

The ERP results of visual search studies suggest that an attentional filtering process operates when there is a pop-out target in stimulus arrays. However, it is unknown whether or not a filtering process is engaged when processing shapes of multiple identical items in a stimulus array. It is difficult to address this issue using

homogeneous stimuli) or a local element closest to fixation point was distinguished by color (i.e. a red item among white local elements, pop-out stimuli). A selective attention procedure was used in which subjects were asked to identify global and local shapes in separate blocks of trials. One group of subjects was presented with the homogeneous stimuli whereas the other group with the pop-out stimuli. The global task was the same for the two groups of subjects. The local task, however, differed between the two groups in that subjects were instructed to identify the shape of the local element with unique color for the pop-out stimuli whereas no specific local element was emphasized for the homogeneous stimuli. This manipulation made local processing different between the pop-out and homogeneous stimuli in two aspects. First, the red local item, like Pashler (1988) 'feature singleton', may pop out from surrounding items and capture attention in a stimulus-driven fashion (Bravo and Nakayama, 1992; Nothdurft, 1993). As a result, it should be easier to select the red item and filter the others relative to selecting an individual element from the homogeneous stimuli because multiple identical items would compete for selection in the latter condition. If the temporal/occipital N2 enhancement in local relative to global conditions observed in earlier studies (Heinze and Münte, 1993; Han and Chen, 1996; Han et al., 1997, 1999a; Heinze, et al., 1998) reflected the filtering process in the local task, it should be smaller for the pop-out stimuli relative to the homogeneous stimuli. Secondly, when identifying the local shapes of the homogeneous stimuli, no specific local element in stimuli displays is emphasized. Therefore, top-down controlled attention would not be directed to a specific local item. For the pop-out stimuli, however, subjects would have to direct their attention to a specific local figure because they are instructed to identify the red local item near the fixation. Consequently, a top-down controlled attention is preset before stimulus onset and more top-down attentional effort engaged during the local processing of pop-out relative to homogeneous stimuli. If the frontal/central N2 elicited by hierarchical stimuli is related to top-down controlled attentional process as has been observed in visual search tasks (Luck and Hillyard, 1994a), we would expect enlarged frontal/central N2 to identifications of local shapes of the pop-out stimuli compared with the homogeneous stimuli.

2. Methods

2.1. Subjects

Fourteen healthy college students (all males; aged between 19 and 24 years) were presented with homogeneous stimuli. Twenty healthy college students (15 female, five male; aged between 20 and 27 years) were presented with pop-out stimuli. Consent forms were obtained from all subjects. All subjects were right handed. All had normal or corrected-to-normal vision and reported no color blindness.

2.2. Stimuli

Compound stimuli were presented on a computer-controlled video monitor 60 cm from the subject's eyes, as illustrated in Fig. 1. Each of global arrows was made up of identical local arrows pointing to a direction either consistent or inconsistent with directions of the global arrow. The local arrows were arranged in an 8×8 matrix. The global and local arrows subtended an angle of $4.1 \times 4.8°$ and $0.38 \times 0.48°$, respectively. The homogeneous stimuli were white on a black background. Pop-out stimuli were different from homogeneous stimuli in that a local element closest to the fixation was red. The background had a luminance of 0.02 cd/m^2. Each of the hierarchical patterns of homogeneous and pop-out stimuli had a luminance of 0.68 cd/m^2 (with CIE coordinates of $0.237/0.285$) and 0.66 cd/m^2 (with CIE coordinates of $0.228/0.219$), respectively.

2.3. Procedure

Trials began with a centrally located white cross as fixation, which subtended $0.2 \times 0.2°$ of visual angle, and was overlapped by the stimulus display, which was presented for a duration of 400 ms. The fixation was presented throughout the interstimulus interval, which varied randomly between 600 and 1000 ms. While maintaining fixation, the first group of subjects was requested to indicate global or local arrow directions of homogeneous stimuli in separate blocks of trials by
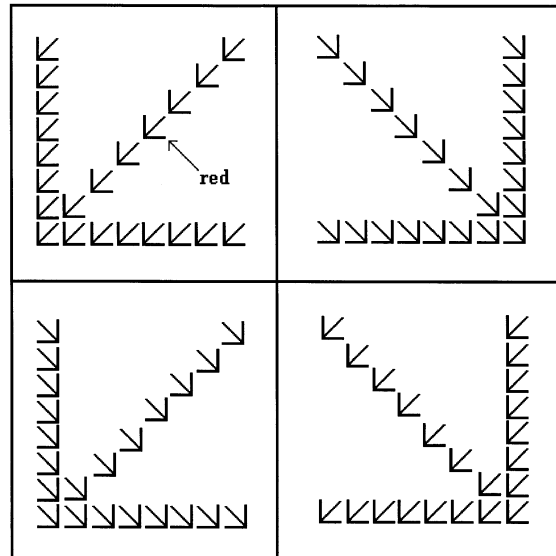

Fig. 1. Illustrations of compound stimuli used in the current experiment. Homogeneous stimuli consisted of identical local elements (white on a black ground) whereas pop-out stimuli contained a red local arrow closest to fixation.

pressing one of two keys with the right or the left thumb. Instructions placed a slight emphasis on accuracy. After 40 practice trials, a total of 800 trials in 10 blocks were presented, respectively, in the global and local conditions. The global and local arrows were consistent in 400 trials, and were inconsistent in the remaining 400 trials. The second group of subjects was presented with pop-out stimuli. The only difference between the two groups of subjects was that the second group of subjects was requested to indicate directions of the red local item in the local task. The order of global and local tasks and the relation between directions of arrows and responding thumb were counterbalanced across subjects.

2.4. ERP recording and analysis

EEG activity was recorded from International 10/20 system sites FP1, FP2, F3, F4, F7, F8, T3, T4, C3, C4, T5, T6, P3, P4, O1, O2, Fz, Cz, Pz, and from 10 sites in the expanded 10/20 system. These were FC1/2 located halfway between Cz and F3/4, CP1/2 located halfway between Pz and C3/4. Additional electrodes were placed at TO1 located halfway between O1 and the midpoint between P3 and T5, and a homologous placement TO2 over the right hemisphere; left (IN3) and right (IN4) occipital sites located at the edge of the cap, equidistant from O1 and T5 and from O2 and T6, respectively; middle occipital sites posterior INz located at the posterior edge of the cap and anterior IPz located halfway between Pz and INz. The distance between INz and Pz was about 12.0 cm, and the distance between IN3 (or IN4) and the midpoint of distance connecting O1 (or O2) and T5 (or T6) was about 4.0 cm. The electrode impedances were maintained below 5 kΩ.

The computed average of the left and right mastoids was used as reference. The EEG was amplified by using a band pass of 0.1–40 Hz (1/2 amplitude cutoffs) and digitized at 250 Hz per channel. Eye blinks were monitored with an electrode located below the right eye. The horizontal electro-oculogram (EOG) was recorded from electrodes placed 1.5 cm lateral to the left and right external canthi. ERPs were averaged off-line using a computer program that extracted epochs of EEG beginning 200 ms before stimulus onset and continuing for 1000 ms. Trials containing eye blinks, eye movement deflections exceeding ± 80 μv at any electrode, or incorrect behavioral responses were excluded from the ERP averages. The baseline for ERP measurements was the mean voltage of a 200 ms prestimulus interval and the latency was measured relative to the stimulus onset.

RTs and error rates were subjected to a repeated measure analyses of variance (ANOVA) with Globality (identify directions of global or local arrows) and Consistency (directions of global and local arrows were consistent or inconsistent) as within subject factors, and Stimulus Set (homogeneous versus pop-out stimuli) as between subject factors. ERP measures were subjected to ANOVA with Globality, Consistency, Stimulus Set, and Hemisphere (electrodes on the left or right hemispheres) as factors. The ERP measurement windows are shown in Table 1.

Table 1
ERP component measurement windows and electrode locations

	Peak latency search window (ms)	Mean amplitude integration window (ms)	Measurement electrode
P1	80–140	90–130	T5, T6, P3, P4, TO1, TO2, O1, O2, IN3, IN4
N1	130–210	150–200	T5, T6, P3, P4, TO1, TO2, O1, O2, IN3, IN4
P2	160–220	170–210	F3, F4, FC1, FC2, C3, C4
Frontal/central N2	220–360	240–340	F3, F4, FC1, FC2, C3, C4
Temporal/occipital N2			T5, T6, P3, P4, TO1, TO2, O1, O2, IN3, IN4
Homogeneous stimuli	200–350	250–320	
Pop-out stimuli	200–350	230–300	
P3			C3, C4, P3, P4, T5, T6, O1, O2
Homogeneous stimuli			
Global condition	300–700	310–430	
Local condition	300–700	380–500	
Pop-out stimuli			
Global condition	300–700	310–430	
Local condition	300–700	370–490	

Table 2
Reaction times (ms) and error rates (%) in the global and local conditions

	Global		Local	
	Consistent	Inconsistent	Consistent	Inconsistent
Homogeneous stimuli (n = 14)				
RT	377	379	425	459
Error rates	6.5	6.3	8.9	16.8
Pop-out stimuli (n = 20)				
RT	375	384	440	465
Error rates	1.2	1.8	1.5	2.6

3. Results

3.1. Behavioral performance

RTs and error rates in each condition are shown in Table 2. RTs were faster in the global than local conditions [$F(1,32) = 123.7$, $P < 0.0005$]. Incongruency between directions of global and local arrows slowed RTs [$F(1,32) = 140.9$, $P < 0.0005$], with greater interference for responses to local than global targets [$F(1,32) = 32.0$, $P < 0.0005$]. The main effect of Stimulus Set was not significant [$F < 1$]. However, the triple interaction of Globality × Consistency × Stimulus Set was significant [$F(1,32) = 3.93$, $P < 0.05$], suggesting that the global advantage in the interference effect was smaller for pop-out than homogenous stimuli. Planned comparisons confirmed that, for homogeneous stimuli, the interference effect was significant in the local condition [$F(1,13) = 70.4$, $P < 0.0005$] but not in the global condition [$F(1,13) = 1.25$, $P > 0.2$]. For pop-out stimuli, however, interference effects were reliable in both local and global conditions [$F(1,19) = 5.73$, $P < 0.0005$, ($F(1,19) = 3.72$, $P < 0.002$, respectively].

Error rates were higher in the local (6.5%) than global (3.5%) conditions [$F(1,32) = 141.0$, $P < 0.0005$], with more errors for the inconsistent than consistent displays [$F(1,32) = 35.2$, $P < 0.0005$]. There were more errors for homogeneous than pop-out stimuli [$F(1,32) = 126.7$, $P < 0.0005$]. The interaction of Globality × Consistency was significant [$F(1,32) = 12.3$, $P < 0.002$], indicating that the interference effect was larger for local than global responses. There was a reliable interaction of Stimulus Set × Globality [$F(1,32) = 13.6$, $P < 0.001$], reflecting the fact that the global advantage in error rates was reduced for pop-out displays. The interaction of Globality × Consistency × Stimulus Set was also significant [$F(1,32) = 8.96$, $P < 0.005$]. Separate ANOVA on error rates for each set of stimuli showed that, for homogeneous stimuli, the interference effect was larger for local than global responses [$F(1,13) = 20.4$, $P < 0.0005$]. For pop-out stimuli, however, the effect of incongruency on global and local responses was not different [$F < 1$].

3.2. Electrophysiological data

ERP waveforms were computed separately for global consistent, global inconsistent, local consistent, and local inconsistent conditions of each set of stimuli. The grand average ERPs for each condition are illustrated in Figs. 2 and 3. For both sets of stimuli, ERPs over posterior scalp sites contained a P1 between 80 and 140 ms, a negative N1 between 130 and 200 ms, a negative going N2 between 200 and 350 ms. At frontal/central sites, ERPs were characterized by a positivity P2 between 160 and 260 ms, a negative going N2 between 220 and 360. A positive P3 between 300 and 700 ms showed a broad distribution with a parietal maximum.

3.2.1. P1 and N1

The main effect of Globality was significant at occipital, temporal, and parietal electrodes [T5–T6: $F(1,32) = 15.40$, $P < 0.0005$; TO1–TO2: $F(1,32) = 15.28$, $P <$
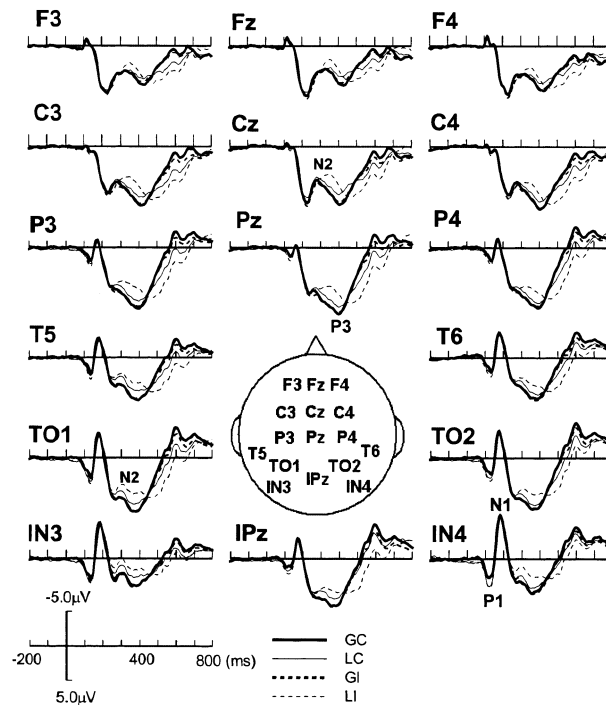
Fig. 2. Grand average ERPs to identifications of global and local shapes of the homogeneous stimuli. GC, global consistent; GI, global inconsistent, LC, local consistent, LI, local inconsistent.

0.0005; IN3–IN4: $F(1,32) = 19.25$, $P < 0.0005$; P3–P4 ($F(1,32) = 10.56$, $P < 0.003$]. The P1 was of greater amplitude in the local relative to global conditions[1]. The main effect of Stimulus Set and Consistency, and the interaction including these factors were not significant [$P > 0.05$]. The ANOVA did not show any significant effects on N1 amplitudes and latencies.

3.2.2. Frontal/central N2

The amplitudes of the frontal/central N2 were higher in the local relative to global conditions [F3–F4: $F(1,32) = 18.16$, $P < 0.001$; FC1–FC2: $F(1,32) = 32.13$, $P < 0.001$; C3–C4: $F(1,32) = 36.68$, $P < 0.001$]. In addition, there were reliable interactions of Stimulus Set × Globality ([F3–F4: $F(1,32) = 8.13$, $P < 0.007$; FC1–FC2: $F(1,32) = 8.66$, $P < 0.006$; C3–C4: $F(1,32) = 8.77$, $P < 0.006$], reflecting the fact that the frontal/central N2 enhancement was more salient for pop-out than homogeneous stimuli. Separate analysis showed that the amplitudes of the frontal/

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[1] Separate analysis confirmed that modulations of the P1 amplitudes by global/local processing were significant for the homogeneous group ($P < 0.03$) but not for the pop-out group ($P > 0.1$), even though similar trend was observed for both groups. However, as the interaction between globality and stimulus set was not significant, it cannot be concluded that the P1 effect was different between the two groups of subjects.

central N2 did not differ between global and local conditions for homogeneous stimuli [$P > 0.1$], but were greater in the local relative to global conditions for pop-out stimuli [F3–F4: $F(1,19) = 27.92$, $P < 0.001$; FC1–FC2: $F(1,19) = 43.76$, $P < 0.001$; C3–C4: $F(1,19) = 41.12$, $P < 0.001$]. The incongruency between global and local patterns produced a stronger effect (making the N2 amplitudes more negative) in the local than global conditions, resulting in significant interactions of Globality × Consistency [F3–F4: $F(1,32) = 8.43$, $P < 0.007$; FC1–FC2: $F(1,32) = 10.75$, $P < 0.003$; C3–C4: $F(1,32) = 9.96$, $P < 0.004$]. The incongruency between global and local levels also retarded the N2 peak latencies [F3–F4: $F(1,32) = 8.15$, $P < 0.007$; FC1–FC2: $F(1,32) = 4.58$, $P < 0.04$; C3–C4: $F(1,32) = 7.69$, $P < 0.009$]. This interference effect was larger in the local relative to global conditions, resulting in reliable interactions of Globality × Consistency [FC1–FC2: $F(1,32) = 4.19$, $P < 0.05$; C3–C4: $F(1,32) = 4.70$, $P < 0.05$]. The N2 latencies showed a larger global advantage for homogeneous than pop-out stimuli, reflected in a reliable interaction of Stimulus Set × Globality [F3–F4: $F(1,32) = 6.06$, $P < 0.02$]. The triple interaction of Stimulus Set × Globality × Consistency was also significant at F3–F4 [$F(1,32) = 7.24$, $P < 0.01$], indicating that the global interference advantage was stronger for homogeneous than pop-out stimuli.
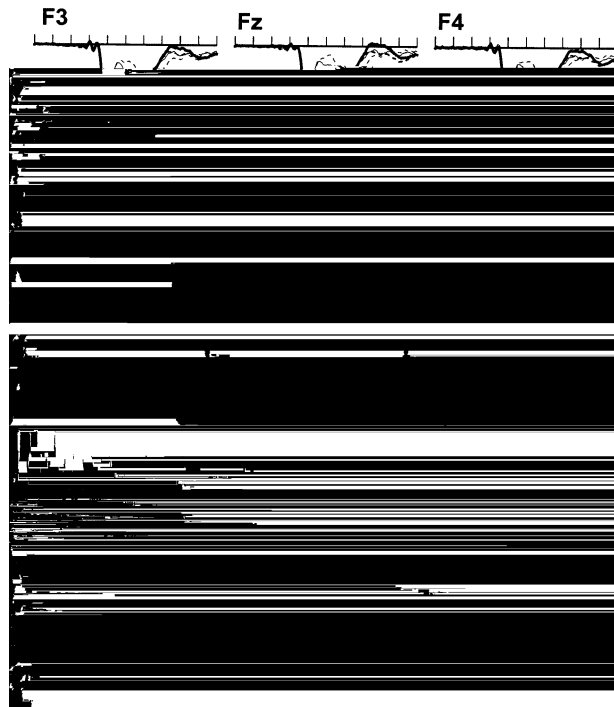

Fig. 3. Grand average ERPs to identifications of global and local shapes of the pop-out stimuli. GC, global consistent; GI, global inconsistent, LC, local consistent, LI, local inconsistent.
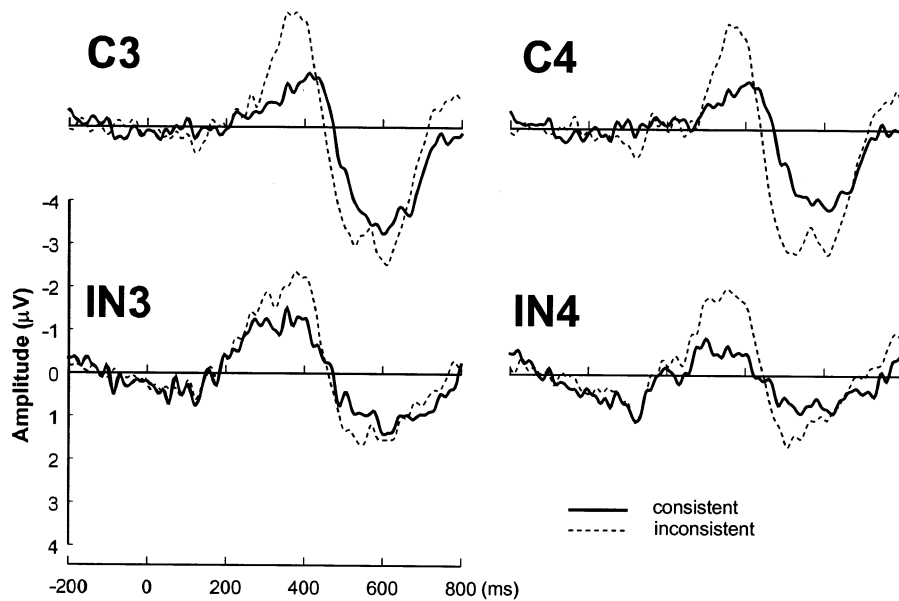
Fig. 4. Difference waves obtained by subtracting ERPs generated in the global condition from ERPs in the local condition of the homogeneous stimulus set at central and lateral occipital sites. The difference waves in the consistent and inconsistent conditions were presented with solid and dashed lines separately.

3.2.3. Temporal/occipital N2

The temporal/occipital N2 was of larger amplitude at electrodes over the left than right hemispheres [T5–T6: $F(1,32) = 17.05$, $P < 0.001$; TO1–TO2: $F(1,32) = 7.43$, $P < 0.01$; IN3–IN4: $F(1,32) = 5.08$, $P < 0.03$]. The temporal/occipital N2 also showed larger amplitudes in the local relative to global conditions [T5–T6: $F(1,32) = 12.63$, $P < 0.002$; TO1–TO2: $F(1,32) = 4.64$, $P < 0.04$]. The incongruency between global and local patterns increased the temporal/occipital N2 amplitudes [T5–T6: $F(1,32) = 26.63$, $P < 0.001$; TO1–TO2: $F(1,32) = 28.45$, $P < 0.001$; O1–O2: $F(1,32) = 31.46$, $P < 0.001$; IN3–IN4: $F(1,32) = 48.89$, $P < 0.001$]. This interference effect was larger in the local than global conditions, resulting in significant interactions of Globality × Consistency [T5–T6: $F(1,32) = 4.94$, $P < 0.03$; TO1–TO2: $F(1,32) = 5.07$, $P < 0.03$]. Interestingly, there was a significant interaction of Stimulus Set × Globality at IN3–IN4 [$F(1,32) = 4.39$, $P < 0.04$;], reflecting that fact that the enhancement of the temporal/occipital N2 in the local relative to global conditions was reduced for pop-out stimuli compared with homogeneous stimuli. The temporal/occipital N2 latencies were longer for homogeneous than pop-out stimuli [T5–T6: $F(1,32) = 11.64$, $P < 0.002$; IN3–IN4: $F(1,32) = 6.42$, $P < 0.02$].

To illustrate the increased frontal/central N2 and decreased temporal/occipital N2 in the local relative global conditions elicited by the pop-out stimuli, difference waves were obtained by subtracting ERPs elicited during the global task from

ERPs during the local task for each set of stimuli (Figs. 4 and 5). Fig. 6 illustrates the topography maps of the difference waves in the N2 time window. Note that, for the homogeneous stimuli, the difference waves in the N2 time window focused over the temporal/occipital areas (slightly larger over the left hemisphere, but did not reach significance). For the pop-out stimuli, however, the amplitudes of the difference wave in the N2 time window were decreased over temporal/occipital areas but increased over the central area.

3.2.4. P2 and P3

The P2 enhancement in the global relative to local conditions was evident at frontal electrodes [F3–F4: $F(1,32) = 8.02$, $P < 0.008$; FC1–FC2: $F(1,32) = 4.57$, $P < 0.04$]. The results of ANOVAs of P3 amplitudes and latencies are shown in Table 3. P3 amplitudes were enlarged in the global relative to local conditions. The interference effect was stronger for the local than for the global tasks, resulting in a significant interaction of Globality × Consistency. P3 latencies were longer for the local relative to global tasks and were slowed by the incongruency between the two levels of compound stimuli. The interaction of Globality × Consistency was reliable, suggesting that the interference effects on P3 latencies were larger in the local than global conditions. The effect of Stimulus Set and its interaction with other factors were not significant.
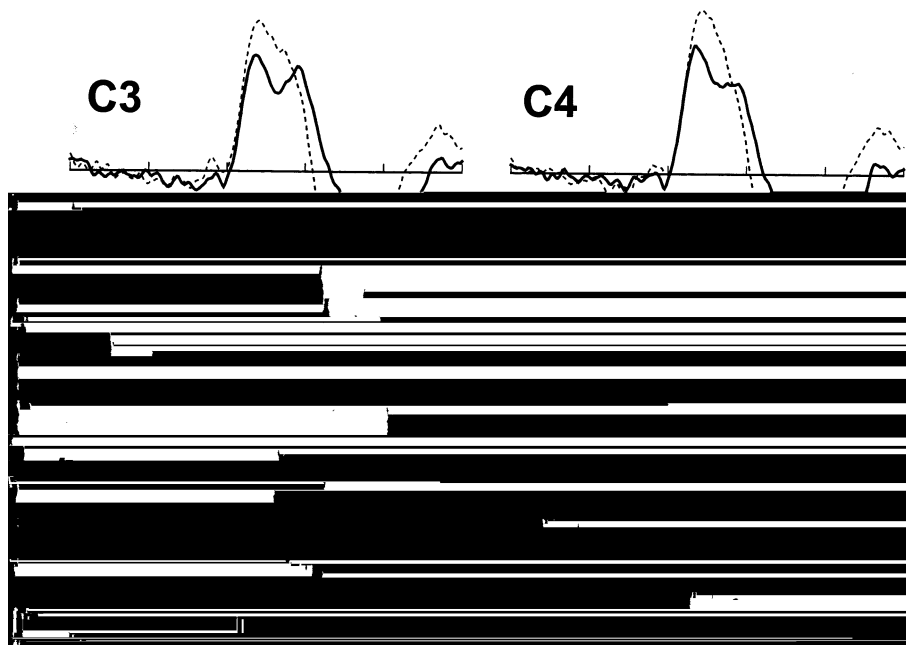

Fig. 5. Difference waves obtained by subtracting ERPs generated in the global condition from ERPs in the local condition of the pop-out stimulus set at central and lateral occipital sites. The difference waves in the consistent and inconsistent conditions were presented with solid and dashed lines separately.
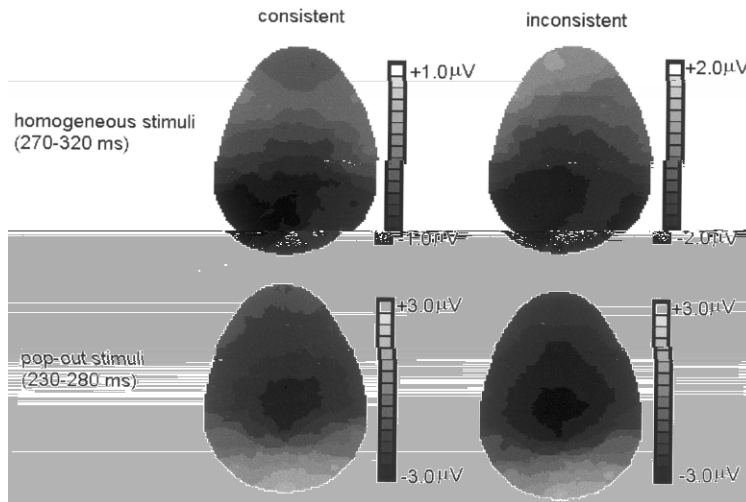
Fig. 6. Topography maps of the difference waves showing locations of maximum difference between local and global conditions during the frontal/central and temporal/occipital N2 time window.

4. Discussion

The present study investigated ERP correlates of an attentional selection process involved in hierarchical analysis. Subjects identified global and local shapes of hierarchical patterns in separate blocks of trials. The ease of the attentional filtering process in the local task was manipulated by introducing a pop-out local element in the hierarchical stimuli.

The behavioral data showed a global precedence effect. Subjects responded faster with fewer errors to global relative to local levels of compound stimuli. Global-to-local interference was stronger than vice versa. The ERP data showed that the

Table 3
Summary of ANOVAs for P3 components at frontal/central and occipital-temporal sites[a]

	G	C	G × C
P3 amplitudes			
C3–C4	0.002	n.s.	0.003
P3–P4	0.001	n.s.	0.003
T5–T6	0.001	n.s.	0.017
O1–O2	0.001	n.s.	0.002
P3 latencies			
C3–C4	0.001	0.001	0.001
P3–P4	0.001	0.002	0.001
T5–T6	0.001	0.001	0.001
O1–O2	0.001	0.001	0.001

[a] G, Globality; C, Consistency; G × C, Globality × Consistency.

processing of global and local levels of hierarchically organized patterns resulted in both short-latency and long-latency modulations of ERPs. The posterior P1 and N2 components were enhanced in the local relative to global conditions. The P3 to the local task showed longer latencies and smaller amplitudes compared with that to the global task. It was unlikely that the P3 effects were due to the overlapping N2 since the negative going limb of the P3 showed genuine delay in the local relative to global conditions. The incongruency between global and local shapes increased temporal/occipital N2 amplitudes and slowed frontal/central N2 and P3 latencies. This interference effect was larger in the local relative to global conditions. Consistent with earlier studies (Heinze and Münte, 1993; Han and Chen, 1996; Han et al., 1997; Heinze, et al., 1998; Proverbio et al., 1998; Han et al., 1999a, 2000), the present results give neurophysiological evidence that the global precedence effect observed in behavioral performance has neural substrates over a broad time range from sensory-perceptual processing to later stimulus recognition and identification.

More interestingly, we found that top-down attention to the pop-out local item produced effects on both behavioral performances and ERPs. The main effect on behavioral responses was to increase local-to-global interference. When all local elements were identical, incongruency between global and local levels of compound stimuli only slowed local responses. However, local-to-global interference was

The effect of top-down attention to the pop-out local item was also reflected in variations of the frontal/central and temporal/occipital N2 amplitudes. The frontal/central N2 amplitudes did not differ between global and local conditions for homogenous compound stimuli. However, top-down attention to the pop-out local element significantly enhanced the frontal/central N2 in the local condition. Our recent work also showed that a pop-out local item in a compound stimulus did not produce the frontal/central N2 enhancement if subjects were not asked to attend to the pop-out item (Han et al., 2001). The frontal/central N2 enhancement observed here was similar to that in visual search studies (Luck and Hillyard, 1994a,b; Girelli and Luck, 1997) in that it was present when attention was directed to a specific local element in stimulus arrays (pop-out stimuli) but absent when attention was not directed to the pop-out item or when there was no pop-out item to direct allocation of attention (homogeneous stimuli). Therefore, similar to that in visual search tasks, the frontal/central N2 enhancement in the local relative to global conditions may reflect a stronger effort with which to direct top-down attention to a specific local element for the pop-out stimuli than for the homogeneous stimuli.

However, modulation of the temporal/occipital N2 by top-down attention to the pop-out local element showed a contrasting pattern. The temporal/occipital N2 was enlarged in the local relative to global conditions when all local elements in a hierarchical stimulus were identical. This N2 enhancement was diminished when subjects were presented with hierarchical patterns containing a pop-out local element and were instructed to discriminate the pop-out item in the local task. The temporal/occipital N2 enhancement in local relative to global condition was different from the N2pc observed in visual search tasks by Luck and Hillyard (1994a,b). The N2pc is prominent only for a stimulus array containing a pop-out local item but absent for a stimulus array consisting of identical target items. In addition, the N2pc locates contralaterally to the hemifield where a pop-out target is displayed, whereas the temporal/occipital N2 enhancement in the local task has been shown to be larger over the left hemisphere regardless of the hemifields where compound stimuli are presented (Han et al., 1999a).

We suggest that the temporal/occipital N2 enhancement to local relative to global conditions may reflect a specific filtering process involved in the local task. Since recognition of multiple identical local shapes in a global structure may not be accomplished efficiently in the visual field, it is necessary to select one local element from multiple identical elements. The selected item is then input into the later stage of shape analysis whereas other local items are filtered from further processing. This filtering process was relatively difficult for the homogeneous stimuli because all items were identical and competed for selection. This resulted in the temporal/occipital N2 enhancement in the local condition. When subjects were informed in advance of the unique local element at a location closest to fixation, this filtering process was easier because this unique local element defined by a distinctive feature popped out from the global structure, and resulted in elimination of the temporal/occipital N2 enhancement in local relative to global conditions. Accordingly, the temporal/occipital N2 enhancement could be an electrophysiological correlate of the filtering process required for recognition of multiple identical objects that are displayed simultaneously in the visual field.

Earlier behavioral studies suggest that selection between global and local levels of hierarchical stimuli may be based on spatial frequency information in compound stimuli. For example, researchers have shown that the global RT advantage is decreased when subjects respond to compound stimuli devoid of low spatial frequency components (Badcock et al., 1990; Hughes et al., 1990; Lamb and Yund, 1993, 1996though see Hubner, 1997). It has been argued that the analysis of global and local shapes may depend on the difference in spatial frequency contents between global and local levels (Shulman and Wilson, 1987; Ivry and Robertson, 1999). Information at the local level is carried in relatively high spatial frequency channels, whereas information at the global level is carried in relatively low spatial frequency channels. Guided by these assumptions, it may be suggested that, when local elements of hierarchical patterns are identical, the temporal/occipital N2 enhancement in local relative to global conditions may reflect a local selection process based on spatial frequency information. Top-down attention to a pop-out local element may allow local selection mediated by other features[2] (such as color) rather than spatial frequencies, and lead to elimination of the temporal/occipital N2 enhancement.

Note that the early P1 enhancement in local relative to global conditions was not influenced by top-down attention to the pop-out local element in the current experiment. It is possible that the P1 enhancement related to local processing is mediated by mechanisms different from that underlying the temporal/occipital N2 enhancement.

In summary, the present study found that brain activities in the N2 time window were modulated by top-down attention to a unique local element in hierarchical stimuli and the modulations showed contrasting patterns in the anterior and posterior areas. The frontal/central activity was increased whereas the temporal/occipital activity was decreased in local relative to global tasks. These results suggest that distinct mechanism over the anterior and posterior brain areas are involved in the processing of local features of hierarchical stimuli.

Acknowledgements

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[2] Our recent work (Han and He, 2001) showed that top-down attention to a pop-out item defined by brightness produced similar results as in the present study, suggesting that the effect of top-down attention to a pop-out local item on hierarchical processing is not color specific.

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