

positron emission tomography (PET). Fink et al. (1996) measured regional cerebral blood flow (rCBF) of normal subjects when they named compound letters. Increases in relative rCBF in the right lingual gyrus was observed when subjects named global letters of visual compound stimuli, whereas increases in relative rCBF in the left inferior occipital cortex was found when subjects named local letters. The results of lesion and PET studies suggest that a subsystem composed of occipital, temporal and parietal lobes in the right hemisphere dominates global processing whereas a subsystem of the homologous areas in the left hemisphere dominates local processing. However, since patients' results exhibit final output of impaired cognitive process, and measures of rCBF show integration over several seconds (Kim et al. 1997; Kwong 1995), it is difficult for these studies to provide information about accurate time course of neural activities between the onset of stimuli and subject's responses (usually several hundred milliseconds).

The character of high temporal resolution makes the measurement of event related brain potentials (ERPs) particularly useful for studying time courses of cognitive processes. ERPs have been employed to investigate differences in brain activities associated with hierarchical processing. For example, Heinze and Münte (1993) re-

found that the amplitude of an early occipital P1 component was modulated by attention to the global and local levels of compound stimuli, being larger in the local condition than in the global condition. ERPs have been also used to compare the prevalence of the global or the local level at the perceptual or the later stages (Proverbio et al. 1998; Ridderinkhof and van der Molen 1995) and to reveal the mechanisms of attentional shift between global and local level of compound stimuli (Kotchoubey et al. 1997).

The first objective of this study was to confirm Han et al.'s (1997) finding that the early occipital P1 component was modulated by attention to global or local levels of compound stimuli, but using compound letters this time. Previous studies using divided attention paradigm (Heinze and Münte 1993; Heinze et al. 1994) did not show any difference in P1 amplitudes evoked by global and local stimuli. They employed hierarchical stimuli made up of global letters whereas non-linguistic stimuli were used in Han et al.'s (1997) work. Is the modulation of P1 amplitude a special effect for non-linguistic compound stimuli or a general effect for all sorts of compound stimuli including compound letters? In addition, compound stimuli were displayed in the centre of the visual field in the previous studies (Han et al. 1997; Heinze and Münte 1993; Heinze et al. 1994). In the current study, however, compound

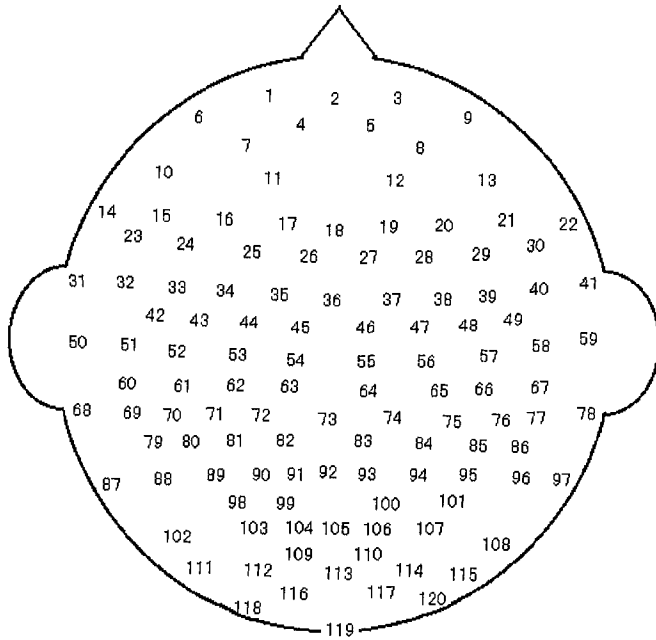


Figure 2. The diagram of 120-channel scalp montage used in the present study.

position of the probe tip with respect to a magnetic field source in the head support.

The average of the left and right earlobes was used as reference. Eye blinks were monitored with electrodes located below the left and right eyes. The horizontal electro-oculogram (EOG) was recorded from electrodes placed about 1.5 cm lateral to the left and right external canthi to measure eye movements. EEG was amplified with a gain of 15000 times by using a band pass of 0.1-40 Hz (1/2 amplitude cutoffs) digitized on-line at a sampling rate of 256 samples per second and stored on a hard disk. The ERPs to targets and standard stimuli were

the global and local levels were consistent or inconsistent), and hemifield (stimuli were presented in the LVF or the RVF) as independent variables. The peak latencies and amplitudes of ERP components were subjected to ANOVAs with globality, consistency, hemifield, and electrode position (on the left or right hemisphere) as independent variables.

To obtain information about cortical distributions of the ERP components and the difference between the ERPs in global and local conditions, topographic maps of the distribution of voltage over the scalp were constructed. The present work also calculated tomography of current source density with the average of all electrodes as a reference. The LORETA algorithm computes first an inverse operator based on the assumptions of maximal smoothness on a fixed lattice with input of the positions of each electrode and averaged ERPs at each electrode. The resolution of this 3D grid was set as 0.01m in the present study. After the calculation of inverse operators was complete, tomographic images during a specific time range were drawn to exhibit sharp foci at parallel horizontal brain slices viewed from the top of the head. A three shell spherical head model was adopted for the LORETA analysis, in which the ratio (inner skull radius)/(outer skull radius / (head radius) was fixed at 0.87/0.92/1.0 (Rush and Driscoll 1986). The coordinate system for presenting LORETA images was defined as follows. The origin was at the midpoint of the left and right preauricular points. The +X-axis is defined by the directed line from the origin through the nasion. The +Y-axis is defined by the directed line from the origin through the left preauricular. The +Z-axis is defined as the directed line from the origin towards the top of the head perpendicular to the XY plane. The program for calculating tomography of current density was provided by a software called EMSE (ElectroMagnetic Source Estimation) written by Greenblatt (1995).

Table II. Latencies and amplitudes of the P1, N1, P2 and posterior N2 evoked by standard stimuli (n=10).

Stimulus position Electrode	left visual field		right visual field	
	left	right	left	right
P1 latencies (ms)				
global	128	103	101	118
local	129	102	103	118
P1 amplitudes (μ V)				
global	2.96	1.86	2.61	1.25
local	3.33	1.93	3.50	1.83
N1 latencies (ms)				
global	190	166	171	177
local	192	167	167	178
N1 amplitudes (μ V)				
global	-3.58	-6.18	-8.66	-4.34
local	-4.20	-7.07	-9.15	-3.96
Posterior N2 latencies (ms)				
global	265	294	286	264
local	275	287	288	273
Posterior N2 amplitudes (μ V)				
global	-0.75	-0.77	-1.42	-0.49
local	-2.28	-1.64	-2.66	-0.92
P2 latencies (ms)				
global	220	214	211	227
local	227	205	207	232
P2 amplitudes (μ V)				
global	3.66	3.82	3.17	4.23
local	5.18	3.23	2.46	4.97

posterior N2 latencies were shorter at the ipsilateral than at the contralateral electrodes ($F(1, 9)=5.05, p<0.05$). This posterior N2 was enhanced in the local condition relative to the global condition ($F(1, 9)=12.6, p<0.006$). This difference was stronger at the left than at the right hemisphere

Table III shows latencies and amplitudes of the anterior N2 elicited by standard stimuli. The anterior N2 showed shorter latencies at the contralateral than at the ipsilateral side ($F(1, 9)=6.60, p<0.03$). The latencies of this N2 component were longer when the global and local

Table III. Latencies and amplitudes of the anterior N2 elicited by standard stimuli (n=10).

Stimulus position	left visual field		right visual field	
	left	right	left	right
Latencies (ms)				
GC	314	312	290	311
GI	314	313	318	316
LC	315	309	307	316
LI	318	317	319	322
Amplitudes (μ V)				
GC	1.23	1.24	1.02	1.50
GI	1.29	1.41	1.30	1.56
LC	0.96	0.02	0.55	1.16
LI	0.40	-0.57	-0.17	0.93

note: GC = global consistent; GI = global inconsistent; LC = local consistent; LI = local inconsistent

whereas reduced the amplitudes to global stimuli.

Table IV shows the mean peak latencies and amplitudes of the P3 component elicited by targets. There was no significant difference in the P3 amplitudes between global and local conditions. However, the P3 latencies elicited by global targets were shorter than those elicited

consistent and inconsistent stimuli in global and local conditions, the P1 component emerged first over the contralateral occipital region, its focus then shifted to the ipsilateral hemisphere. The N1 component was focused over the contralateral occipital-temporal sites. The frontal P2 in the local condition was focused over the ipsilateral side whereas the P2 in the global condition was

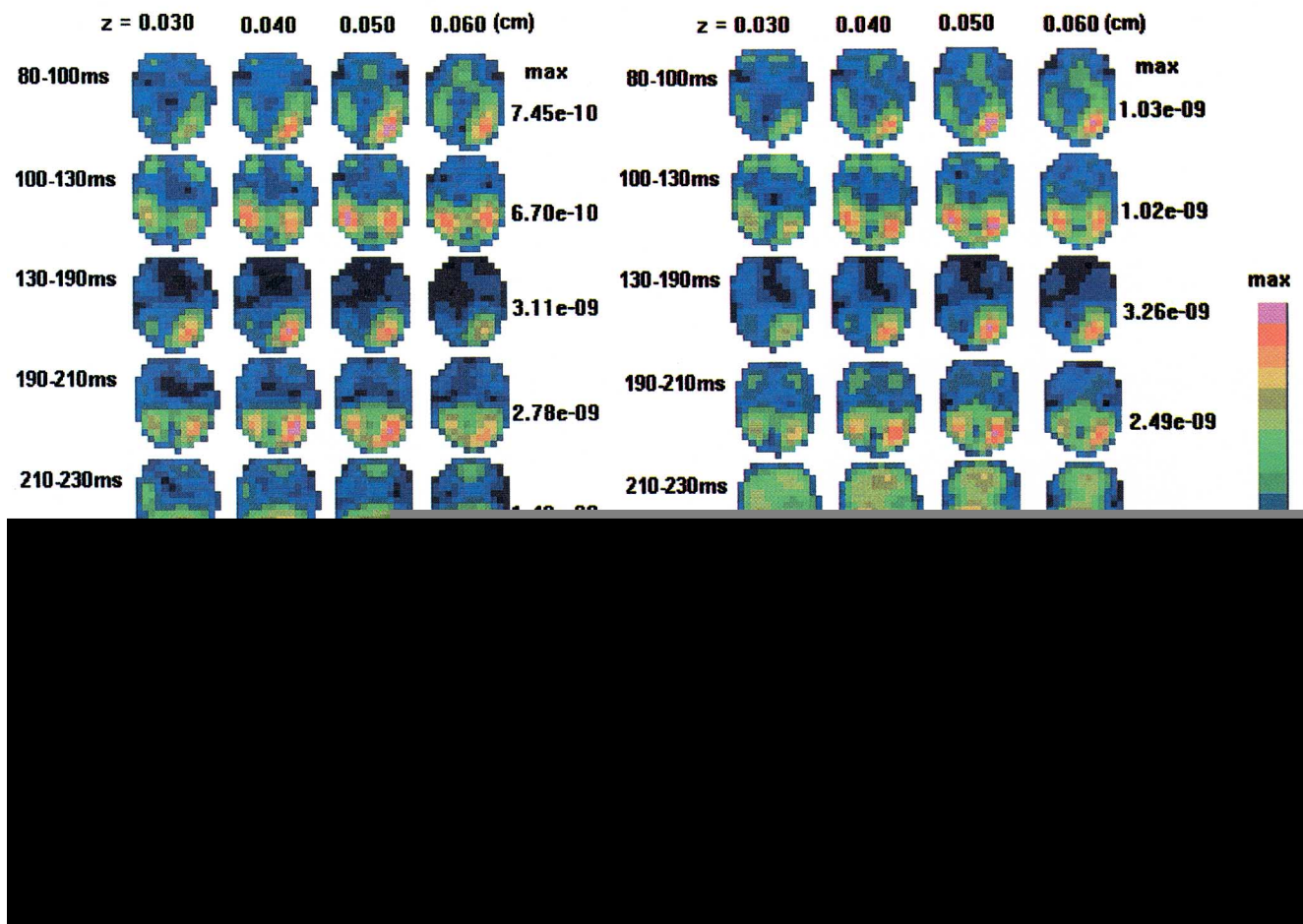


Figure 8. Tomographic maps showing distributions of current source density in relation to consistent stimuli presented in the LVF in global and local conditions. The pictures shown include images in four slices in which strong activities are clear (i.e., $z=0.03, 0.04, 0.05, 0.06$ m).

LVF, two frontal foci at the left and right hemispheres appeared simultaneously at about 230 ms. The ipsilateral one decreased and disappeared at about 340 ms. The contralateral one also declined from 230 ms, but began to enhance at about 300 ms, and lasted over 400 ms. When stimuli were presented in the RVF, an ipsilateral frontal focus emerged at about 250 ms, decreased, and disappeared at about 340 ms. At about 300 ms a contralateral frontal focus became visible and lasted over 400 ms. The ipsilateral focus located slightly posteriorly relative to the contralateral one. In the global condition, however, there was only one contralateral focus, which emerged at about 330 ms and lasted over 400 ms for both consistent and inconsistent stimuli presented in the LVF or the RVF.

Discussion

This study investigated how hierarchical attention modulates brain potentials by recording high-density

ERPs and computing 3-D distribution of current density in association with global or local processing of hierarchical stimuli. The pattern of behavioural data, similar to Navon's (1977) results, showed a global precedence effect. In line with the findings of the previous studies (Martin 1979; Sergent 1982), the present experiment also observed an asymmetry of the global RT advantage, being stronger for stimuli presented in the LVF than for those presented in the RVF.

The ERP data corroborated Han et al.'s (1997) findings that the amplitude of the occipital P1 was enhanced during local processing in comparison with that during global processing. Together with the previous research, the present study demonstrated that the attentional modulation of the P1 component in hierarchical processing is independent of the types of compound stimuli (linguistic or non-linguistic) and the stimulus positions (in the central or peripheral visual fields). As research has disclosed that the occipital P1 evoked by visual stimuli is

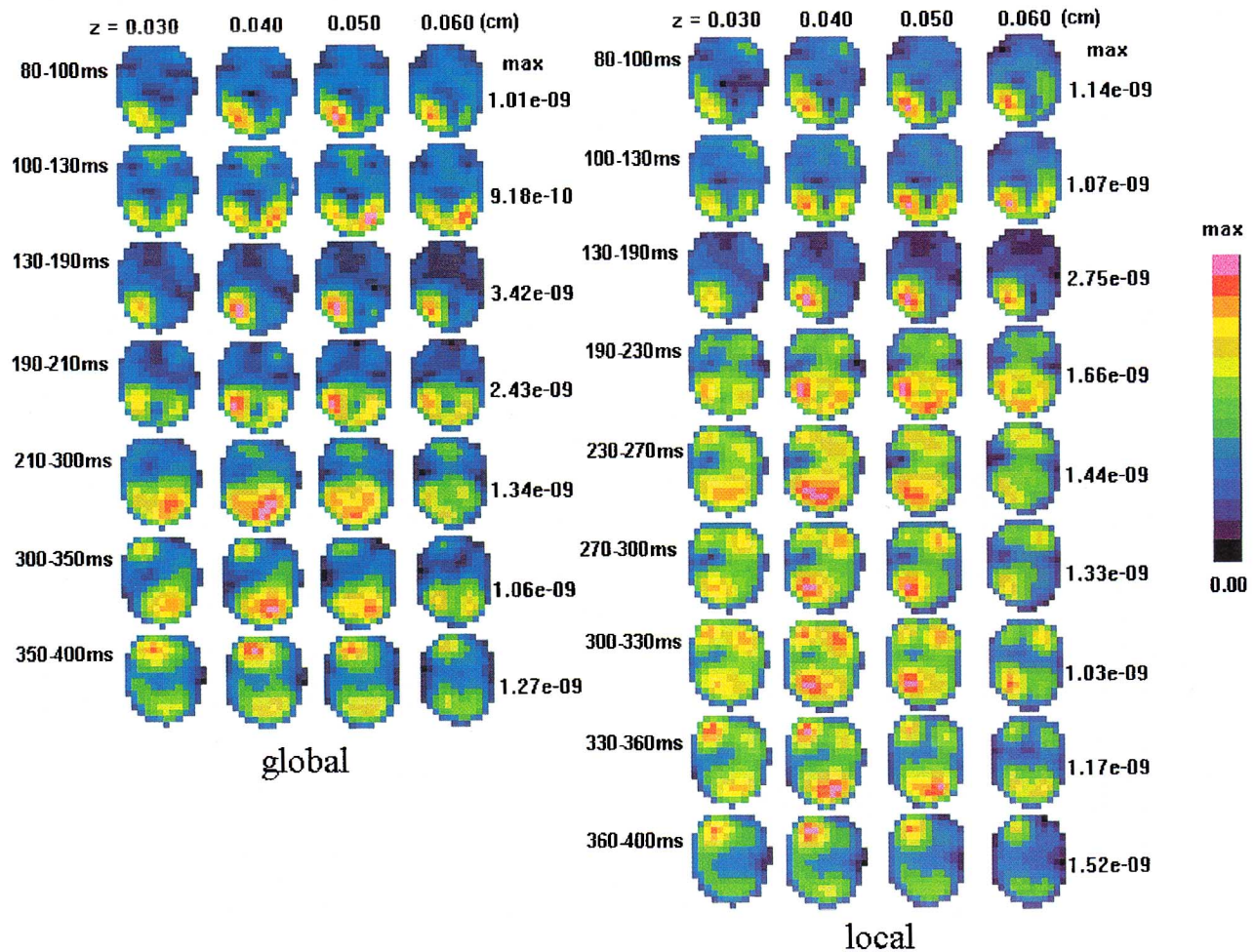


Figure 9. Tomographic maps showing distributions of current source density in relation to consistent stimuli presented in the RVF in global and local conditions. The pictures shown include images in four slices in which strong activities are clear (i.e., $z=0.03, 0.04, 0.05, 0.06$ m).

generated in the extrastriate cortex (Gomez et al. 1994; Heinze and Mangun et al. 1994; Hillyard et al. 1997; Mangun et al. 1993), the P1 effect observed in this study indicates that selective attention to specific levels of hierarchical patterns can modulate neural activities in the early stage of visual processing in the occipital cortex. Consistent with the results of PET study (Fink et al. 1996), these ERP results strongly suggest that the differences in behavioural performance between global and local conditions is mediated, at least partially, by neural substrates at the level of sensory processing. Previous research has shown that, when other non-spatial features (such as color, shape, motion or spatial frequency) are attended to, the typical response to attended stimuli includes a broad selection negativity which usually peaks between 150 to 300 ms post-stimulus (Anllo-Vento and Hillyard 1996; Eimer 1997; Harter et al. 1982; Kenemans et al. 1993; Previc and Harter 1982; Wijers et al. 1989). In comparison

with these non-spatial attentional ERP effects, the current findings indicate that, similar to spatial selective attention, hierarchical attention can modulate neural activities at a stage earlier than that at which other non-spatial attentions operate.

The asymmetrical activities of the two hemispheres during hierarchical processing appeared at about 270 ms after sensory stimulation, indexed by the posterior N2. The N2 enhancement in the local condition relative to the global condition was larger over the left than over the right occipital-temporal regions. This is consistent with the results of other ERP studies employing the divided attention paradigm (Heinze et al. 1994; Johannes et al. 1996). The present study demonstrated further that the asymmetry of the N2 effect is independent of stimulus positions, being similar for stimuli presented in both the LVF and the RVF. The topographic maps showed additional asymmetrical activities over the parietal and tem-

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