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Electrophysiological evidence of a perceptual precedence of global vs. local visual information

Alice Mado Proverbio a,*, Alessia Minniti a, Alberto Zani b

a Cognitive Electrophysiology Laboratory, Department of Psychology, University of Trieste, Via dell’Università 7, 34123 Trieste, Italy
b Cognitive Electrophysiology Laboratory, Istituto di Psicologia, Consiglio Nazionale delle Ricerche, Viale Marx, 00137 Rome, Italy

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Abstract

Aim of the present study was to investigate the mechanisms of attentional selection of hierarchically organized visual patterns (compound letter stimuli), while subjects were engaged in target selection at either the global or local level. Event-related brain potentials (ERPs) were recorded using a high density electrode montage. Reaction times (RTs) to target stimuli were also recorded. RT data indicated the interference effect of global incongruent information with the local one. ERP data were consistent with behavioral data. In fact, the early sensory N115 component recorded at the primary visual areas exhibited smaller responses to locally attended elements when the global configuration was incongruent rather than congruent, suggesting an interference effect of the global with the local level. Conversely, no interference effect was found for globally attended configurations. These results strongly support the view of a perceptual advantage of globally conveyed information, very likely mediated by low spatial frequency channels. At later processing levels, N1 and P3 components were faster and larger when attention was paid to the global configuration. The difference between target and nontarget responses, indexing the attentional target selection, yielded a broad occipital-temporal negativity focused onto the left hemisphere in the attend-local, and over the right hemisphere in the attend-global condition. The present findings indicate a hemispheric asymmetry in cerebral activation during local/global processing. In addition, they provide robust evidence of a sensory precedence of global information. © 1998 Elsevier Science B.V.

Keywords: Compound stimuli; Global and local visual information; Attentional selection; ERPs; N115; Selection negativity; Global advantage; Hemispheric asymmetry

1. Introduction

An interesting issue in current literature concerns how the brain generates visual unitary percepts. The question has been arisen whether different perceptual mechanisms are involved in the construction of a unitary figure (for example, a ‘keyboard’) by organizing local elements as well as in the segmentation of different elements of a configuration (a single ‘key’). Using reaction time (RT) measures, Navon [16] showed that visual information is processed in a top–down order. The analysis of the global configuration had an advantage on the analysis of local elements. The author adopted hierarchically structured stimuli, consisting in large (global) configurations, either geometrical or linguistic, composed of smaller (local) elements to allow the selection of either the global or local level of information. Typically, when a subject is asked to identify a target stimulus at either the global or local level, the results are that global patterns are identified faster than local ones, and that when the global configuration is incongruent with the local element it interferes with the identification of the latter, leading to slower response times. These data have been interpreted as an index of a general advantage of global vs. local visual information. Some neuropsychological and electrophysiological studies have questioned that the global advantage and the interference effects are expression of the same phenomenon: the perceptual advantage of the global information. For example, Lamb and Robertson [13] in a divided attention task carried out with normal subjects found a RT advantage for local stimuli subtending large visual angles, along with a global interference effect independent of visual angle. This pattern of results made them conclude that the RT advantage and interference are dissociable effects, and do not necessarily reflect a perceptual precedence of global vs.
local information. Rather, it would be founded on post-perceptual attentional mechanisms. More recently, the psychophysical study by Hughes et al. [9] have provided strong evidence that global precedence may actually be perceptual in nature, it being conveyed by low spatial frequency channels. According to the authors, low spatial frequency content would be available before information carried by high frequency bands, also because of the high contrast gain of the magnocellular pathway. This would explain why processing of the global configuration is faster than that of the local elements, and is not greatly affected by conflicting local cues.

The nature of global advantage, whether perceptual or attentive, is an object of great debate in the literature. The role of sensory mechanisms in the global advantage, and in particular that of a different sensitivity and transmission time of spatial frequency channels, has been demonstrated for instance by Lagasse [12] using high-pass filtered stimuli, and by Hughes et al. [8] using contrast-balanced dots. Other studies have proposed that an asymmetric inhibition between spatial frequency channels might be potentially responsible for a sensory advantage of low frequency patterns, as for instance advanced first by Hughes [7] and later on by Lovegrove et al. [15]. According to the attentional hypothesis, however, the global advantage would be mediated by post-perceptual mechanisms, and global and local information would be encoded in parallel and available at the same time [3,4]. Rather recently, Hübner [6] provided evidence supporting the intriguing hypothesis that both sensory and attentional mechanisms might be responsible for the global advantage. In his study, the author adopted both unfiltered and high-pass filtered compound stimuli. He found that low frequency content was sufficient but not necessary to elicit a global advantage, while the attentional set, manipulated by keeping either randomized or fixed the target level in different experiments, produced a strong interaction between filtering and global/local processing.

Goal of the present study was to investigate how selective attention modulates the perception of hierarchical stimuli by means of electrophysiological and behavioural techniques. In particular, the experiment was designed to test the aforementioned models of perceptual vs. attentional precedence of global/local analysis. Previous electrophysiological studies [1,3,4,10] have indicated a posterior N250 component as the first sign of independent processing of the global/local levels. In the experimental paradigm usually adopted (i.e., a divided attention task), subjects were asked to respond to a target letter independent of its hierarchical level (global or local), so that both levels were always targets. Thus, the effect of interference was evaluated indirectly by comparing the interference given by the introduction of stimuli and distractors characterized by a different degree of perceptual similarity. In the study by Deruelle and Neville [1], the onset of the late posterior negativity related to target selection was earlier in the global than local condition, while Johannes et al. [10], Heinze and Münte [3] and Heinze et al. [4] found no clear pattern of either advantage or interference between the two levels. The latter studies only provided evidence of separate mechanisms for global/local levels at late stages of information processing.

In their electrophysiological study, Ridderinkhof and van der Molen [19] adopted a choice reaction time task in which the target level was kept fixed within a given run, and subject had to discriminate between two targets. The authors considered only the latency of late P300 components, and contrasted them with the onset of readiness potential and response-locked electromyogram (EMG) to assess whether the locus of interference of the irrelevant level was perceptual or induced by response competition. They failed to provide direct evidence of a global advantage on the local level. The results also showed no asymmetry in the magnitude of global vs. local interference because of the large intra-subjects variability. Interestingly, they indicated no effect of stimulus incongruence on the latency of readiness potential, thus, suggesting a perceptual locus for the interference effect.

In the present experiment, we adopted a selective attention task in which subjects were told to respond to target letters at a given level, either the global or local one, and to ignore the identity of the constituent letters in the opposite level. This paradigm allowed us to measure directly the effect of interference given by the perceptual incongruence of the unattended level with the attended one. Event-related potentials (ERPs) of the brain to relevant and irrelevant stimuli, as well as RTs to targets, were recorded to monitor the time course and topographical distribution of brain activity during processing of compound stimuli as a function of the attended level (local vs. global) or incongruence. We expected that if the global advantage was perceptual in nature, there had to be an effect of attended level and incongruence (or both) on the sensory responses of visual areas earlier than N250.

2. Materials and methods

2.1. Subjects

Eight right-handed volunteers served as subjects in this experiment. All had normal vision or a mild myopia corrected by glasses. Their ages ranged among 24 and 33 years. One subject was excluded from statistical analyses for exceeding ocular artefacts.

2.2. Stimuli

Stimuli were $3^\circ \times 2^\circ$ 15' large capital letters (H or S) made up of smaller letters (H or S) subtending $22^\prime \times 15^\prime$ of visual angle. Small letters were arranged in a $5 \times 5$ matrix as in Lamb’s and Robertson’s study [13]. Because letters H and S at the global level (i.e., large letters) were combined
with H and S letters at the local level, there were four stimuli in all: H/H (global H and local H), H/S, S/S, S/H. Stimuli were white on a black background; their luminance, measured on small letters, was 2.4 cd/m². They were randomly presented for 100 ms at two eccentric locations (i.e., 2° from their external border) of the right and left visual hemifields along the horizontal meridian. Stimulus presentation was equiprobable. ISI randomly varied among 1000 and 1500 ms. A white cross at the center of the screen served as fixation point.

2.3. Procedure

Subjects were comfortably seated within a sound attenuated, electrically shielded, and dimly illuminated chamber. The high resolution screen of a 486 IBM-compatible computer was located outside the chamber in front of a window, at the viewing distance of 114 cm from the subject. The task consisted in paying selectively attention and to respond by pressing a button as accurately and fast as possible to the S or H letter at a given level (i.e., local or global) independent of visual field of presentation left or right. Due to the combination of letters at the two levels, when attention was paid to either the large or small letters, stimuli were considered respectively global, or local ‘congruent’ if they had the same identity at the two levels (i.e., S/S or H/H), or ‘incongruent’ if they had different identity at the two levels (i.e., S/H and H/S). The experiment consisted in the presentation of 40 sequences of 80 stimuli. At the beginning of each sequence, which lasted about 2 min, subjects were instructed about the target letter (i.e., S or H) and the level (i.e., global or local) that they had to attend, as well as about the hand that they were supposed to use. They were told to maintain their gaze on the central fixation point and to minimize any kind of body or eye movements throughout each experimental run. Each sequence was followed by a short pause, while every 15 min a longer pause was given to the subjects. Stimuli, responding hand and attention conditions were randomized across experimental runs and counterbalanced across subjects.

2.4. ERP recording

The electroencephalogram (EEG) was continuously recorded from 28 scalp sites using tin electrodes mounted in an elastic cap (Electro-cap). The electrodes were located

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Summary of repeated measure ANOVAs and statistical significances</th>
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<tbody>
<tr>
<td>Data</td>
<td>ANOVA Factors</td>
</tr>
<tr>
<td>RTs</td>
<td>4 ways A, C, F, R</td>
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<td></td>
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<td></td>
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<tr>
<td>N115 (ampl.)</td>
<td>5 ways A, C, F, E, H</td>
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<tr>
<td>N140 frontal (lat.)</td>
<td>5 ways A, C, F, E, H</td>
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<tr>
<td>N140 frontal (ampl.)</td>
<td>5 ways A, C, F, E, H</td>
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<tr>
<td>N180 (lat.)</td>
<td>5 ways A, C, F, E, H</td>
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<tr>
<td>N180 (ampl.)</td>
<td>5 ways A, C, F, E, H</td>
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<tr>
<td>P300 300–620 ms (lat.)</td>
<td>5 ways A, C, F, E, H</td>
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<td>P300 300–620 ms (ampl.)</td>
<td>5 ways A, C, F, E, H</td>
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<tr>
<td>Central–parietal P300 (lat.)</td>
<td>5 ways A, C, F, E, H</td>
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<tr>
<td>Occipital P300 (lat.)</td>
<td>5 ways A, C, F, E, H</td>
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<tr>
<td>P3-I 300–460 ms (ampl.)</td>
<td>5 ways A, C, F, E, H</td>
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<tr>
<td>P3-II 460–620 ms (ampl.)</td>
<td>5 ways A, C, F, E, H</td>
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<tr>
<td>SN amplitude</td>
<td>4 ways A, C, E, H</td>
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<tr>
<td>180–310 ms</td>
<td>A × C × H</td>
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<tr>
<td>SN latency</td>
<td>4 ways A, C, E, H</td>
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<tr>
<td>(Difference waves)</td>
<td>4 ways A, C, E, H</td>
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</table>

A – Attention level: global, local; C – congruence: congruent, incongruent; F – visual field: LVF, RVF; R – responding hand: left and right; H – hemisphere: LH, RH; E – electrode site: depending on the ERP component (see text for specifications).
at frontal (Fp1, Fp2, Fz, F3, F4, F7, F8), central (Cz, C3, C4), anterior-temporal (T3, T4), posterior-temporal (T5, T6), parietal (Pz, P3, P4), and occipital scalp sites (Oz, O1, O2) of the International 10–20 System. Additional electrodes were placed half the distance between anterior-temporal and central sites (FTC1, FTC2), central and parietal sites (CP1, CP2), anterior-temporal and parietal sites (TCP1, TCP2), and posterior-temporal and occipital sites (OL, OR). Blinks and vertical eye movements (i.e., EOG) were monitored by means of two electrodes placed below and above the right eye, while horizontal movements were recorded from electrodes placed at the outer canthi of the eyes. Linked earlobes served as reference lead. The EEG and the EOG were amplified with a half-amplitude band pass of 0.1–70 Hz and 0.01–70 Hz, respectively.

2.5. ERP data analysis

Continuous EEG and EOG were digitized for 100 ms prior and 1000 ms following each stimulus presentation, at a rate of 512 samples/s. They were stored with stimulus and response codes for off-line analysis. Before averaging, a computerized artefact rejection was performed to discard epochs in which eyes or muscle artefacts occurred. Average ERPs were separately computed for each of the four stimuli under the different attention conditions in the two visual fields. The major ERP components were identified and measured automatically by a computer program, and quantified by measuring peak latency and baseline-to-peak amplitude and mean area values.

N115 component, prominent at occipital–temporal sites, was defined as the most negative peak between 80 and 140 ms; N140 as the most negative peak between 120 and 180 ms at frontal–central sites; N180 as the most negative peak between 145 and 215 ms at posterior occipital–temporal sites; P2 as the most positive peak between 180 and 260 ms, and P3 as the most positive peak between 300 and 620 ms. Mean area values were also measured for the two time windows in the P3 latency corresponding to P3-I (300–460 ms) and P3-II (460–620 ms). Difference-waves were obtained by subtracting nontarget from target responses both for congruent and incongruent configurations. Selection negativity (SN) was measured as the mean amplitude area between 180 and 310 ms at temporal–occipital electrode sites.

RT and ERP measures associated with ocular and muscular artefacts, misses, and false alarms, were excluded from statistical analyses. For each subject, response time faster than 140 ms or exceeding 2 standard deviations from the mean were also excluded from the analyses. Both RT and ERP measures were analyzed with repeated-measure analyses of variance (ANOVAs), adjusting for nonsphericity with the Greenhouse–Geisser epsilon coefficient. Factors were ‘attention level’ (global and local), ‘congruence’ (congruent and incongruent), ‘visual hemifield’ of presentation (left and right) and ‘response hand’ (left and right). Additional factors were considered for ERP measures. They were ‘electrode site’ (i.e., O1–O2, OL–OR, and T5–T6 for N115 and N180 posterior components);

Table 2

<table>
<thead>
<tr>
<th></th>
<th>Global</th>
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<th>Local</th>
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<td>LVF</td>
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<td>LH</td>
<td>383</td>
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<td>LH</td>
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<tr>
<td>RH</td>
<td>34</td>
<td>31</td>
<td>30</td>
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</table>

Fig. 1. Mean reaction times and standard deviations of responses to global and local targets as a function of congruence with the unattended level.
C3–C4, F3–F4, F7–F8 sites for anterior N140; T3–T4, OL–OR for SN; C3–C4, P3–P4, T3–T4, OL–OR, O1–O2 for the P3-I and P3-II components) and ‘hemisphere’ (left and right). Student’s t-test were carried out for post-hoc comparisons between means. Table 1 summarizes all the statistical analyses with their significant factors.

3. Results

3.1. Behavioral results

RTs were significantly faster in the global than local condition (see Fig. 1) as proven by the significant main
electrode site

Also, the analysis most prominent at mesial-occipital, lateral-occipital and statistical analysis.

Since this component represented the most significant source of potential Zani and Proverbio’s VEP study 24. Since this composition, especially with a high spatial frequency content as in differences from the classical positive–negative–positive P± component for global and local targets as a function of potential peaking at about 150 ms. This particular morphology also yielded a significant interaction of ‘attention level’ × ‘congruence’ (F 1,6 = 33.15; p < 0.001). Post-hoc comparisons indicated that the incongruent level negatively affected speed of response only in the local attention level (p < 0.01), thus showing an effect of interference of the global toward the local level. No effect of visual field was found, although RTs to local targets tended to be faster when stimuli were presented in the right than left visual hemifield (see means of Table 2).

### 3.2. Electrophysiological results

In Fig. 2 are displayed the grand-average ERPs to global (top) and local (bottom) targets as a function of congruence. As can be clearly seen, the waveshape morphology at an early latency stage is characterized by a prominent negative deflection, peaking at about N115 ms and followed by a tiny somewhat later positive deflection peaking at about 150 ms. This particular morphology differs from the classical positive–negative–positive (P–N–P) complex described in VEP literature, but may be often found when using large bright patterns for stimulation, especially with a high spatial frequency content (as in Zani and Proverbio’s VEP study [24]). Since this component represented the most significant source of potential variation in the early latency range, it was considered for statistical analysis.

ANOVA performed on peak amplitude values of N115, most prominent at mesial-occipital, lateral-occipital and posterior-temporal sites, revealed a significant effect of electrode site (F 2,12 = 5.3; p < 0.02), indicating for this component the focus of maximum amplitude at mesial-occipital sites (see Fig. 3). Most interestingly, the analysis also yielded a significant interaction of ‘attention level’ × ‘congruence’ (F 1,6 = 7.13; p < 0.04). Post-hoc t-tests (p < 0.03) indicated that, when paying attention to the local level, sensory-evoked responses were significantly smaller if the latter was part of an incongruent rather than congruent configuration. Conversely, no difference was found for global patterns as a function of congruence (see Table 3). These different effects of congruence as a function of the attended level can be clearly appreciated in Fig. 2.

The negative component N180 focused over secondary visual areas (OL, OR; T5, T6), showed an earlier peak in the global than local condition (F 1,6 = 13.4, p < 0.01; global = 185 ± 16, local = 192 ± 16 ms). This peak was larger to global than local stimuli at lateral-occipital (p < 0.01), and posterior-temporal sites (p < 0.02), but not at mesial-occipital sites (‘attention level’ × ‘electrode’; F 2,12 = 5.4, p < 0.02). Furthermore, it was of greater amplitude over the right than left hemisphere (p < 0.0001) independent of visual field of presentation (see Table 4), as indicated by the post-hoc comparisons (p < 0.025) for the significant interaction of ‘hemisphere’ × ‘visual field’ (F 1,6 = 8.8; p < 0.025).

Over fronto-central sites the earlier negativity N140 showed a strong tendency to be faster to congruent than incongruent configurations (F 1,6 = 5.04; p = 0.06), and to global than local ones (F 1,6 = 4.7; p = 0.07). Table 5 shows mean N140 amplitudes and standard deviations for these conditions.

P300 component, broadly distributed over central–parietal areas, was extremely affected both in latency and in amplitude by ‘attention level’ and ‘congruence’. P300 to configurations attended at the global level were much faster and larger than those to configurations attended at the local level (see Fig. 4). P3 peaked earlier for global than local targets both at parietal–central (F 1,6 = 22; p < 0.003) and occipital scalp sites (F 1,6 = 12.7; p < 0.003). Post-hoc t-tests also indicated that the incongruent level negatively affected speed of response only in the local attention level (p < 0.01), thus showing an effect of interference of the global toward the local level. No effect of visual field was found, although RTs to local targets tended to be faster when stimuli were presented in the right than left visual hemifield (see means of Table 2).
Table 5
Mean latency values (ms) and standard deviations of anterior N140 component as a function of target congruence and visual field

<table>
<thead>
<tr>
<th>Congruent</th>
<th>Incongruent</th>
<th>Global</th>
<th>Local</th>
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<tr>
<td>138</td>
<td>141</td>
<td>137</td>
<td>142</td>
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<td>17</td>
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0.01, as indicated by statistical analysis performed on peak latency (see means of Table 6). Furthermore, P300 was faster at parietal than central sites ($F_{1,6} = 13.6; p < 0.01$). The ANOVA performed on peak amplitude showed a significant interaction between ‘attention level’ and ‘electrode site’ ($F_{1,6} = 6; p < 0.05$). Post-hoc comparisons between means indicated that P300 differed in its

Fig. 5. (a) Grand-average ERPs to global and local targets as a function of stimulus congruence as recorded at the F8 right lateral frontal site. (b) Grand-average ERPs to global and local targets as a function of stimulus congruence as recorded at the F7 left lateral frontal site. Note that the large positive complex has two phases in the local attended condition.
distribution as a function of the attended level, it being more anteriorly distributed for the local one ($p < 0.01$).

It is interesting that this broad positivity showed two phases, the first being larger to the global targets, and the second to the local ones. In addition, they showed different topographical distributions, and were clearly differentiated in two sub-components in many of the subjects. For these reasons, separate ANOVAs were performed on mean area values computed within two different time-windows: from 300 to 460 ms (i.e., P3-I), and from 460 to 620 ms (i.e., P3-II).

Attention to local elements gave rise to a larger P3-II (‘attention level’ factor: $F_{1,6} = 15; p < 0.008$), while attention to global patterns gave rise to a larger P3-I ($F_{1,6} = 8.5; p < 0.025$). For both time windows, P3 showed larger amplitudes to congruent than incongruent patterns, but a different hemispheric lateralization. Indeed, the significant interactions of ‘congruence’×‘hemisphere’ ($F_{1,6} = 8.9; p < 0.02$) indicated that P3-I was larger to congruent than incongruent patterns over the right hemisphere ($p < 0.0001$), whereas P3-II showed the same pattern of results over the left hemisphere ($F_{1,6} = 12.3; p < 0.01$; post-hoc test: $p < 0.006$). These asymmetric distributions can be seen comparing the right-sided waveforms of Fig. 5a with the left-sided ones of Fig. 5b. Maps of Fig. 6 show the spatio-temporal progression of brain activation linked to target congruence with the unattended level. Global congruent targets elicited a significantly enhanced response in the P3-I phase especially over right centro–parietal sites (see for instance the upper row around 380 ms), whereas local congruent targets displayed an enhanced response at left frontal sites in the P3-II phase (see for instance the lower row around 560 ms). Thus, the effect of congruence in P300 showed a posterior distribu-

![Fig. 6. Isocontour voltage maps of brain activation in the P300 latency range (300–620 ms). Maps were computed on difference waves obtained by subtracting ERPs to incongruent from those to congruent targets. The color scale indexes the polarity and amplitudes of the topographical maps. Note that P3-I (300–460 ms) was more sensitive to congruence over the right centro–parietal sites for global targets, while P3-II (460–620 ms) was more sensitive to congruence over anterior left sites.](image-url)
Fig. 7

Global congruent

Fig. 8

Local congruent
Fig. 9. Isocontour voltage maps of difference waves for the global (upper maps) and local (lower maps) congruent conditions. Difference waves were obtained by subtracting ERPs to nontargets from ERPs to targets. The color scale indexes the polarity and amplitudes of the topographical maps. Upper and lower left maps show brain activation relative to selection negativity, whereas upper and lower right maps show brain activation relative to P300 component. At all latency ranges the maps indicate clearcut spatio-temporal differences in the progression of brain activation dependent on the attention condition. Selection negativity was much earlier to global than local targets, and had a right anterior temporal distribution for the former ones, and a left occipital–temporal distribution for the latter ones. As for P300 component, in the upper map it is visible P3-I to global targets focused at posterior sites, with an evident asymmetry over the right hemisphere. The lower map shows P3-II to local targets strongly lateralized over left centro–frontal sites.

Fig. 7. Difference waves for global congruent stimuli obtained by subtracting ERPs to nontargets from those to targets. Overlapped are waveforms recorded from middle-temporal (i.e., T3, T4) and lateral-occipital (i.e., OL, OR) electrode sites.

Fig. 8. Difference waves for local congruent stimuli obtained by subtracting ERPs to nontargets from those to targets. Overlapped are waveforms recorded from middle-temporal (i.e., T3, T4) and lateral-occipital (i.e., OL, OR) electrode sites.

Fig. 10. Isocontour voltage maps of difference waves for the global upper maps and local lower maps congruent conditions. Difference waves were obtained by subtracting ERPs to nontargets from ERPs to targets. The color scale indexes the polarity and amplitudes of the topographical maps. Upper and lower left maps show brain activation relative to selection negativity, whereas upper and lower right maps show brain activation relative to P300 component. At all latency ranges the maps indicate clearcut spatio-temporal differences in the progression of brain activation dependent on the attention condition. Selection negativity was much earlier to global than local targets, and had a right anterior temporal distribution for the former ones, and a left occipital–temporal distribution for the latter ones. As for P300 component, in the upper map it is visible P3-I to global targets focused at posterior sites, with an evident asymmetry over the right hemisphere. The lower map shows P3-II to local targets strongly lateralized over left centro–frontal sites.

3.3. Difference waves

The attention effects per se appeared after about 140 ms post-stimulus latency as a negative potential having a posterior distribution and being followed by a later positivity. Difference waves, obtained by subtracting ERPs to nontargets from those to targets, evidenced a posterior negativity specific to target selection (selection negativity = SN), peaking on average at about 259 ms. ANOVA performed on peak amplitude revealed that SN was much faster to global (227 ± 56 ms) than local (292 ± 76 ms) targets ($F_{1,6} = 5.5; p < 0.05$). In addition, it was earlier over occipital than temporal left sites (post-hoc test: $p < 0.01$), whereas it was about of the same latency over the
right hemisphere, as shown by the significant interaction of Electrode × Hemisphere (F 1,6 = 7.6; p < 0.03; see means of Table 7).

Interestingly, ANOVA performed on mean area amplitude of this component supported the evidence of an anatomical specificity, in that SN reached its maximum amplitude at middle-temporal sites for global targets (post-hoc test: p < 0.01), and at lateral-occipital sites for local targets (p < 0.05), as indicated by the significant interaction of ‘electrode’ × ‘attention level’ (F 1,6 = 41; p < 0.0007). Furthermore, its amplitude changed significantly as a function of the interaction between task, congruence, and hemisphere (F 1,6 = 6.4; p < 0.04). Indeed, for congruent patterns, target selection resulted in an increased SN asymmetrically distributed over the right hemisphere when attention was paid to the global patterns (p < 0.01; see Fig. 7), and over the left hemisphere when attention was paid to the local elements (p < 0.05; see Fig. 8). For incongruent patterns, SN was also larger over the right hemisphere for global targets (post-hoc test: p < 0.05), but no asymmetry was evident for local incongruent targets. Further post-hoc comparisons indicated that incongruence affected only targets at the local level over the left hemisphere, with congruent targets leading to a bigger SN than incongruent ones (p < 0.01).

Basically, then, this component showed a very different time-course and topography as a function of the attended level. It was much earlier for global targets and reached its maximum amplitude at the right temporal site, whereas, during selection of the local level, it was later and distributed more posteriorly at occipital sites, with a left-sided asymmetry for congruent targets.

Maps of Fig. 9 summarize the effects of target selection conveyed by target–nontarget difference waves, by showing the spatio-temporal distribution of selection negativity and P300 to global and local congruent targets. It is evident the anterior distribution of attention effects for the late positive phase of P300 component (P3-II).

4. Discussion

Overall, the behavioral data obtained in the present study showed a strong advantage of global over local targets, along with an interference effect for local, but not global, incongruent targets. The electrophysiological results were consistent with such a pattern of results. In addition, they provided robust evidence for the hypothesis of a sensory advantage of information conveyed by the global vs. local level. They also indicated an early modulation of brain electrical activity of visual areas during an attention task based on features discrimination. These effects are consistent with early latency attention effects shown in literature for selection of check size and spatial frequency gratings [24,25] as well as alphanumeric and geometrical stimuli [23]. In the present experiment, early N115 responses linked to primary visual areas activation showed to be differentially modulated by stimulus incongruence and attended level. The diminished visual evoked-response to local targets incongruent with the global configuration indicates a dominance of global spatial information, as suggested by Hughes et al. [9]. The electrophysiological techniques do not allow us to ascertain definitely whether this advantage is due to the faster conduction times and greater sensitivity gain of low frequency channels, or to other factors, but certainly the data suggest that the information conveyed by the latter channels is capable of inhibiting sensory processing of local elements.

This asymmetry in visual processing for inputs conveyed at the two perceptual levels was evident also at later processing stages as indexed by N1, SN and P3 components. Occipital N180 was significantly faster and larger to global targets, whereas P300 was much earlier to global targets and larger to them in its first phase (P3-I). Interestingly, for both components it appeared an anatomical dissociation suggesting the existence of two separate processing channels. N180 was larger to global than local targets at lateral occipital and infero-temporal sites, whereas this difference disappeared at mesial-occipital sites. The large positive P3-I had a more posterior distribution compared to P3-II. Again, the effect of congruence with the unattended level, and the effect of attentional selection (target vs. nontarget) showed an early posterior distribution for P3-I and a later anterior distribution for P3-II phase of P3 complex. This anterior–posterior distribution for P300 component does not overlap with the classical distribution of early anterior P3a and posterior P3b elicited by novel irrelevant and target stimuli, respectively, as shown for example by Knight [11]). Indeed, P3-I and P3-II were both elicited by target stimuli, and their differential distribution probably reflects different cortical attentional selection systems.

The finding of a different time course and topography for the SN provides further evidence for different selection mechanisms for local vs. global aspects of visual information, in agreement with previous electrophysiological data [10]. Furthermore, this negativity related to target selection showed a task-dependent asymmetric lateralization. It was focused at temporal sites when attention was paid to the global level, and at occipital sites when attention was paid to the local level. Results showed that, when the unattended level did not interfere with the attended one, in that stimuli were congruent at the two levels, the selection of local elements resulted in a strong left-sided occipital activation, whereas the selection of the global configuration resulted in a right-sided temporal activation.

These results are strongly consistent with neuropsychological data providing evidence of a hemispheric specialization for processing of local/global configurations. For example, a well-known series of neuropsychological studies on unilateral brain damaged patients [14,21,22] has shown that patients suffering from temporoparietal le-
sions are impaired in global processing when the right hemisphere is damaged, and in local processing when the left hemisphere was damaged. Moreover, the recent neurometabolic study (rCBF) by Fink et al. [2] has clearly demonstrated the role of temporal areas in the attentional control of global and local processing. In particular, target selection at the global level resulted in an increased activity of the right temporal–parietal–occipital junction, whereas target selection at the local level resulted in an increased activity of the left posterior aspect of the superior temporal gyrus. In addition, the authors found that in a blocked condition, where the target level was kept fixed throughout the run, there was an increased metabolic activity at the right lingual gyrus when attention was paid to the global level, and at the left inferior occipital cortex, when attention was maintained to the local level. Thus, the different involvement of left and right portions of Brodmann’s area 18 in this rCBF experiment might indicate that the hemispheric asymmetry is not confined to attentional selection mechanisms at higher cognitive levels, but is present at perceptual level too.

The electrophysiological results obtained in the present study are somewhat different from those of Heinze and Münte [3] and Johannes et al. [10], who failed to find a clear global advantage effect at either behavioral or electrophysiological level. It has to be mentioned that these studies adopted divided attention tasks in which subjects were forced to switch their attention from one level to the other one on a trial-by-trial basis, because targets could be at either levels. With such a paradigm, Johannes et al. [10] found RTs of the same speed for targets of both levels and no interference effects. This was true even for brain potentials. Heinze and Münte [3], who adopted hierarchical stimuli of different sizes, found a size-dependent precedence effect (i.e., a local advantage for 7\textsuperscript{o}, and a global advantage for 2\textsuperscript{o} stimuli), but no clear interference effects. The onset of a selection-related N250 was earlier for local than global targets in the 7\textsuperscript{o} condition, but equal for the two levels in the 2\textsuperscript{o} condition. Overall, it seems that switching the attentional focus from one level to the other one might have reduced the effect of global precedence and a clear pattern of asymmetric interference. At these regards, it is important to mention that Robertson [20], in a series of behavioral experiments with hierarchical stimuli, clearly demonstrated the effect of attentional persistence (i.e., level-specific priming) in global/local selection. The author found that switching from a larger global target to a smaller local target or vice-versa slowed response time compared to conditions where the target level remained the same. Very interestingly, it was shown that this priming effect was related to the stimulus spatial frequency content. Indeed, the specific sequential effects due to the attentional persistence were eliminated by filtering the low spatial frequencies in the pattern preceding a not-filtered hierarchical pattern. Similarly, Hübner [6] found a clear effect of stimulus spatial frequency in interaction with task switching. When the target level was kept constant throughout a run (e.g., Expt. 2), he found a normal advantage of the global configuration, which disappeared in the case of hierarchical high-passed filtered stimuli. The same did not occur when the target level was made to vary on a trial-by-trial basis (e.g., Expt. 1). Then, it seems as global/local processing is greatly affected by both sensory and attentional variables. It is very interesting, at this regard, that rCBF data by Fink et al. [2] have shown that different brain areas are involved in global/local processing during fixed vs. switching attention tasks.

Overall, the data of the present study suggest the intervention of late-latency attentional factors in determining hemispheric asymmetries for the two processing levels. Indeed, a clear pattern of hemispheric dominance appeared for the temporal–occipital SN and later central–parietal P300 component. In this regard, a large behavioral literature supports the view that a hemispheric asymmetry may only arise in tasks where spatial frequency processing is actually demanded (see for example the review by Hellige [5], Navon [16] and Proverbio et al. [17]), which means that a frequency-based selection is required by the task. However, there is also electrophysiological evidence of pure sensory-perceptual based hemispheric asymmetries in the processing of low vs. high frequency stimuli [18,24]. Indeed, the occipital locus for brain activation during global vs. local selection reported by Fink et al. [2] (i.e., right lingual gyrus and left inferior occipital cortex) seems to support the involvement of perceptual mechanisms in the hemispheric specialization. However, further investigation is needed to reach a definitive conclusion on this issue.

In conclusion, the current study provided an instance of perceptual dominance of global level of visual information. This is supported by the finding of an advantage of global targets both in terms of speed of RTs, and latency and amplitude of ERP components. Interestingly, electrophysiological results provided evidence of an early interference effect, as indexed by the modulation of a N115 component, of the global incongruent information over the local one. Last but not least, evidence was also provided for two separate processing channels, subserved by distinct anatomical systems asymmetrically lateralized, for the attentional selection of global vs. local elements of hierarchically organized visual patterns.

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