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Cognitive Brain Research 24 (2005) 228–236
COGNITIVE BRAIN RESEARCH
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Research report

The relationship between local and global processing and the processing of high and low spatial frequencies studied by event-related potentials and source modeling

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Accepted 28 January 2005
Available online 24 March 2005

Abstract

The processing of global and local elements and of low- and high-spatial frequencies are thought to be interrelated. Evidence for this stems from findings showing that brain localizations for global/local elements and for low/high spatial frequencies seem to overlap. The present study aimed to provide direct evidence that topographical differences between the processing of global and local visual elements can directly be explained by their spatial frequency content, and to study at which point in time this relation is present. This was done by studying the event-related potentials (ERPs) and source models elicited by unfiltered, low- or high-pass filtered hierarchical stimuli.

Results showed that performance for global and local targets was affected by removing low and high spatial frequencies, respectively. ERP data indicated that at 250 ms, there was an interaction between the processing of global/local targets and of spatial frequencies because at this time-point removal of low spatial frequencies decreased activity associated with the processing of global targets.

When localizing this effect, we found evidence implying that spatial frequency content indeed affected the brain region in which local/global targets were processed. Results implicated that the processing of global information depended on its low spatial frequency content, which was processed more laterally. Instead, processing of local information seemed to depend on its high spatial frequency content, which was processed more medially. Thereby, present results extend former results showing that global and local processing is dependent on spatial frequency and mapped retinotopically in the visual cortex.

Theme: Sensory systems
Topic: Visual cortex: extrastriate

Keywords: Global and local processing; Spatial frequency; Event Related Potentials; Dipole source analysis

1. Introduction

An important aspect of visual perception is the analysis of features and wholes in hierarchically organized objects and scenes. In a series of experiments [26–28], Navon et al. investigated whether different perceptual mechanisms are involved in the processing of features and wholes. For this purpose, Navon et al. introduced a task with hierarchical stimuli. In this task, subjects were presented with large letter shapes made up of smaller letters of either the same kind or a different kind. The task consisted of identifying the large letter (i.e., target at the global level) or the small letters (i.e., target at the local level) ([26–28], for a review, see Ref. [19]). In this task, the definition of one of the stimuli as

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doi:10.1016/j.cogbrainres.2005.01.021

being global and the other as local is therefore based on top-down regulated target processing, which is executed at the global or local level, respectively.

Navon et al. found that healthy subjects made more errors and were slower to identify the letters at the local than at the global level, a situation they referred to as *global advantage*. In addition, in conditions where the local and the global letter were not the same kind (i.e., incongruent), healthy subjects were slower to detect the target letter when it was at the local compared to when it was at the global level a situation they referred to as the *global interference* effect. The concurrence of these effects was described as a *global precedence effect*.

This difference in performance for global and local targets raises the question whether global and local processing are in fact governed by different neural processes. There is evidence that differences in the processing of global and local targets may be related to underlying properties of channels involved in the processing of low- and high-spatial frequencies, respectively. For instance, Shulman et al. [38] measured perception of global and local targets after desensitization due to repeated presentation of sine-wave gratings of low and high spatial frequency. They found that the processing of global targets was impaired by desensitization to lower spatial frequencies to those that affected the processing of local targets. Also, several studies have shown that removal of low spatial frequencies (i.e., by means of filtering) removes or greatly attenuates the global precedence effect [1,14,20]. These studies illustrate that top-down processing of global and local information in hierarchical stimuli seems to be mediated by bottom-up spatial frequency processing.

Functional brain imaging, including ERP, source modeling, and fMRI, has already identified various brain areas which seem to be involved in the processing of low and high spatial frequencies. Both ERP and source modeling studies have indicated a right hemisphere specialization for the processing of low spatial frequencies and a left hemisphere specialization for the processing of high spatial frequencies ([17] [experiment 1], [35,41]). Still, not all studies support this hemispheric difference ([5,6,17,33,37][experiment 2]). Also, other studies have indicated that the processing of low- and high-spatial frequencies is mapped retinotopically in the occipital cortex [17,37]. More specifically, it is indicated that high spatial frequencies activated the foveal representation of the cortex, that is, medial visual areas, and low spatial frequencies activated the peripheral representation of the cortex, that is, more lateral visual areas [17,37].

Following the data on filtered hierarchical stimuli above, it would seem logical to expect similar topographical differences in the processing of global and local targets. More specific, that besides frontal activity related with attention, top-down processing of global information would result in stronger activation of areas related to the processing of low spatial frequencies, whereas top-down processing of local information would result in stronger activation of areas related to the processing of high spatial frequencies. Indeed, results from fMRI, PET, and ERP studies indicate that global targets, in parallel with low spatial frequencies, preferentially activate the right hemisphere, whereas local targets, in parallel with high spatial frequencies, activate the left hemisphere [3,4,12,22,24,32], although these hemispheric differences are not consistently found [5,12,15,37]. Nevertheless, the spatial overlap between the areas activated by local targets/high spatial frequencies and global targets/low spatial frequencies remains because there is evidence that global and local processing also seem to be mapped retinotopically in the occipital cortex. Using fMRI, Sasaki et al. [37] found that attention to local targets activated the medial areas of the occipital cortex, while attention to global targets activated the lateral areas of the occipital cortex. The findings of Sasaki et al. are in accordance with the PET data of Fink et al. [4], who also found that global information activated more lateral areas than did local information (see comments Sasaki et al. [37]).

Importantly, these results support the notion that the visual areas that govern the processing of low- and high-spatial frequencies also process global and local targets, respectively. However, to date, no brain imaging study has manipulated the high- and low-spatial frequency content of hierarchical stimuli to assess directly bottom-up effects of spatial frequency on top-down local and global processing. We were interested to know to what extent topographical differences in global and local processing could be explained by the spatial frequency content of global and local targets. We hypothesized that by magnifying the global or local information of hierarchical stimuli, by means of low- or high-pass filters, respectively, we would be able to answer this question. In addition, we were interested in the question whether spatial frequency-dependent differences in global and local processing occurred early or late during processing. For instance, it might be that retinotopical activation and hemispheric lateralization both occur but at different times. In order to assess both the timing and the location of effects of spatial filtering on global and local processing, we used a combination of ERPs and brain source analysis techniques.

2. Material and methods

2.1. Subjects

Twenty graduate and undergraduate students (8 males and 12 females) aged between 18 and 20 years took part and were paid for their participation. All subjects were right handed, in good health, and had normal or corrected-to-normal vision. The data for one subject were lost due to technical problems. The data for three subjects were rejected because too few trials remained after deduction of error trials and artifact correction.