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Research Report

Using spatial frequency scales for processing face features and face configuration: An ERP analysis

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ABSTRACT

In the present study we examined the influence of spatial filtering on the N170-effect, a relatively early face-selective ERP difference associated with face detection. We compared modulation of the N170-effect using spatially filtered stimuli that either facilitated feature analysis or impeded configural analysis. The salience of inner face components was enhanced by presenting them in isolation. Configural processing was manipulated by face inversion. The N170-effects elicited by upright faces and isolated inner components were similar across low- and high-spatial frequency scales. In contrast, the inversion effect (enhanced N170 amplitude for inverted compared with upright faces) was only observed with broadband and low-spatial frequency stimuli. These findings demonstrate that the N170-effect can be influenced by both low- and high-spatial frequency channels. Moreover, they indicate that different configural manipulations (isolated features vs. face inversion) affect face detection in distinct ways, consistent with separate processing mechanisms for different types of configural encoding.

1. Introduction

All visual images in the natural environment are composed of a range of spatial frequencies (SFs), and the visual system filters incoming information via a number of SF channels (De Valois and De Valois, 1990). Perceptual demands such as stimulus characteristics and the task at hand can bias the spatial scale used during visual perception in any given instance (Davis, 1981; Davis and Graham, 1981). Consistently, psychophysical studies of face perception have reported that frequency channels are selectively used according to the task-determined type of categorization (Morrison and Schyns, 2001; Schyns and Gosselin, 2003; Schyns and Oliva, 1999; for a recent review see Ruiz-Soler and Beltran, 2006). In order to better understand how faces are processed by the visual system it is therefore necessary to determine what type of visual information is required for a given process and how this information is affected by different frequency scales.

Behavioral studies of face perception have revealed that normal recognition relies on the analysis of both the individual features in a face as well as their spatial configuration. Abundant research has revealed the importance of holistic processing of faces, that is, integrated processing of the features in conjunction. Research has also shown that face identification relies on computing spatial relations among inner face components, relative to each other and relative to

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the face contour, referred to as 2nd order configural processing (Maurer et al., 2002). This is distinct from 1st order configural processing, which refers to the processing of the global face shape (i.e., two eyes above a nose above a mouth), which allows for the basic level categorization of a face. Particularly relevant for face processing is behavioral evidence suggesting that global and configural processing in vision relies on relatively low spatial frequencies (LSFs) more than on relatively high spatial frequencies (HSFs; Badcock et al., 1990; Hughes et al., 1990; Lamb and Yund 1993; Shulman et al., 1986; Shulman and Wilson, 1987). Conversely, HSFs appear to be more important for local/feature processing (e.g. Shulman and Wilson, 1987). Since both details and their configuration are needed for different levels of face analysis, both LSF and HSF channels should be utilized during face perception. However, the relationship between global and local processing and low and high spatial frequency scales is not independent of task (see overview by Ivry and Robertson, 1998). The relative importance of different frequency scales is determined by the relative diagnostic value of the face components and global or configural shapes for the task at hand (Morrison and Schyns, 2001, see also Loftus and Harley, 2004).

Several studies have examined which spatial frequency scales are relevant for different face perception tasks. Generally speaking, these studies have found that high spatial frequencies are less critical for face identification than low spatial frequencies. They are also consistent with the importance of the spatial configuration of inner components for discriminating among individual faces and with the association between global vs. local analysis and the preferential processing of low vs. high spatial frequencies. For instance, face identification relies on a range of relatively low and mid SFs (~8–16 cycles/ image) while at higher SFs faces can lose their identity (Costen et al., 1996, Fiorentini et al., 1983; Hayes et al., 1986). Furthermore, Goffaux et al. (2005) directly linked 2nd order configural analysis with the processing of LSFs and feature analysis with the processing of HSFs in a face-matching task. In that study they manipulated either the spatial relations between the features of a face, or the features themselves, and found that frequencies below 1.86 cycles/ degree (8 cycles/image) were more important when faces differed on the basis of second-order configuration (that is, the relative location of the inner face components within the face contour; Maurer et al., 2002), while frequencies above 7.44 cycles/degree (32 cycles/image) were more important when matching required processing the feature properties. Other studies exploring face categorization have found that the frequency scale used depends on the nature of the categorization task. For example, deciding if a face is expressive or not requires LSFs (below 2 cycles/degree; 8 cycles/image), whereas categorization of particular expressions (such as happiness) seems to rely on higher SFs (above 6 cycles/degree; 24 cycles/image; Schyns and Oliva, 1999).

The spatial scales used during early stages of face perception were recently investigated by examining how SF affects the N170 component, an electrophysiological index of relatively early face processing. While all visual stimuli elicit negative or negative-going ERPs during this epoch (N1), the N170 is larger (more negative) in response to faces than to other objects, a difference referred to as the “N170-effect” (Bentin et al., 1996; George et al., 1996). There is evidence that the N170-effect is not modulated by face identity (Bentin and Deouell, 2000) and that it is at least as distinctive for isolated eyes as for full faces (Bentin et al., 1996; Itier et al., 2006), though there is also evidence for its sensitivity to the individuality of faces (Jacques and Rossion, 2006). Nonetheless, the N170-effect is insensitive to the configuration of the face features within or isolated from the face contour (Zion-Golumbic and Bentin, 2007). That is, the N170-effect is equally large in response to faces with normally-configured and spatially-scrambled inner components, albeit slightly delayed in the latter condition. Hence, Bentin et al. have claimed that the N170-effect is associated with base-level categorization (i.e., face detection) including the additional analysis of face features elicited by default when faces are detected. According to this view, the N170-effect is dissociated from neural events involving second-order configural processing. Rather, the mechanism manifested in the N170-effect is triggered by the occurrence of any type of physiognomic information in the visual field such as the global face contour (and 1st order configuration) as well as the presence of the features (Bentin et al., 2006; Sagiv and Bentin, 2001; Zion-Golumbic and Bentin, 2007).

If the N170-effect is associated with a face detection mechanism, reflecting base-level categorization as well as initial processing of face features, it should be relatively insensitive to frequency scale (within certain limits). This is because face detection may rely on analyzing the first-order configuration (which presumably relies preferentially on low spatial frequencies) as well as processing the features (which is presumed to rely more on high spatial frequencies). Hence, the difference between the N170 elicited by full-face and non-face objects could reflect either LSF information (supporting the global distinction) or HSF information (supporting the analysis of finer features). However, studies exploring the frequency scales that elicit the N170-effect have yielded mixed results.

Goffaux et al. (2003a) found that the N170-effect (face–car difference) was absent when spatial frequencies below 6.5 cycles/degree (32 cycles/image) were filtered out of the images (i.e., high pass). However, the task in that study was orientation judgment, which may have encouraged participants to adopt a strategy that diverted their attention from the face features. Supporting this notion, the N170-effect was not enhanced by face inversion, as commonly found in N170 studies (e.g. Rossion et al., 1999). The absence of this enhancement when using an orientation judgment task suggests that this task may have induced a different strategy than under conditions where participants are simply detecting or identifying faces. In a different paper, Goffaux et al. (2003b) found further evidence for the importance of task differences in determining the spatial scale eliciting the N170-effect. In a gender categorization task, they replicated their previous finding: the N170-effect was absent in high pass filtered images. However, in a familiarity task that required face recognition, they found similar N170-effects for low- and high-pass images. Another study examining processing of emotional faces also found no differential effects of frequency scale on the N170-effect (Holmes et al., 2005). Still another study using MEG found a reduction of the M170 only when the