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Fearful faces impact in peripheral vision: Behavioral and neural evidence

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ABSTRACT

Many studies provided evidence that the emotional content of visual stimulations modulates behavioral performance and neuronal activity. Surprisingly, these studies were carried out using stimulations presented in the center of the visual field while the majority of visual events firstly appear in the peripheral visual field. In this study, we assessed the impact of the emotional facial expression of fear when projected in near and far periphery. Sixteen participants were asked to categorize fearful and neutral faces projected at four peripheral visual locations (15° and 30° of eccentricity in right and left sides of the visual field) while reaction times and event-related potentials (ERPs) were recorded. ERPs were analyzed by means of spatio-temporal principal component and baseline-to-peak methods. Behavioral data confirmed the decrease of performance with eccentricity and showed that fearful faces induced shorter reaction times than neutral ones. Electrophysiological data revealed that the spatial position and the emotional content of faces modulated ERPs components. In particular, the amplitude of N170 was enhanced by fearful facial expression. These findings shed light on how visual eccentricity modulates the processing of emotional faces and suggest that, despite impoverished visual conditions, the preferential neural coding of fearful expression of faces still persists in far peripheral vision. The emotional content of faces could therefore contribute to their foveal or attentional capture, like in social interactions.

1. Introduction

In an evolutionary perspective, the particular value of emotions is unquestionable and much specificity associated with emotional processing has been demonstrated through behavioral and brain imagery studies. Compared to neutral stimulations, stimuli with emotional content are faster detected (Öhman, Flykt, & Esteves, 2001), better remembered (Buchanan, 2007) and drive more attentional resources (Schupp, Junghöfer, Weike, & Hamm, 2003a; Schupp, Junghöfer, Weike, & Hamm, 2003b; Smith, Cacioppo, Larsen, & Chartrand, 2003; Vuilleumier, Armony, Driver, & Dolan, 2001). However, one underestimated factor in studies on the processing of emotional stimulations is the influence of their position in the visual field. This is surprising that the majority of observations concerning emotional modulations of visual processing relies on studies focused on stimulations projected to the center of the visual field while the main part of visual information appears outside this center. The main topic of this study is thus to investigate how emotional information appearing at eccentric locations is processed.

The central and the peripheral retina respectively subtend central (CV) and peripheral vision (PV), and, even if it is difficult to precisely locate the boundary between these two parts of the retina (Rossi & Roorda, 2010), their distinct anatomical and functional properties are widely demonstrated. Indeed, classical anatomical data show that the distribution, morphology and connections of the retinal photoreceptors change across eccentricity (Bullier, 2001). Furthermore, data suggest that central and peripheral retina are at the origin of parvocellular and magnocellular systems, respectively, which convey visual information across two parallel retino-geniculo-cortical pathways (Kaplan, 2004; Virsu, Lee, & Creutzfeld, 1987). Although these data are reconsidered by recent works which found connections between parvo- and magnocellular systems in the retina (Masland, 2001, 2004) and in the early visual areas (see Sincich & Horton, 2005), it appears that periph-

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eral vision is mainly related to the magnocellular system. Indeed, connections between rods and magnocellular cells (see Grünert, 1997; Lee, Smith, Pokorny, & Kremers, 1997; Purpura, Kaplan, & Shapley, 1988; Virsu et al., 1987) as well as relations between peripheral vision and dorsal pathway *versus* central vision and ventral pathway (see Baizer, Ungerleider, & Desimone, 1991; Stephen et al., 2002; Zeki, 1980) were found. Functionally, the decrease of acuity from CV to PV has been supported by several studies using letters, digits, sinusoidal gratings or compound Gabor patterns (Anderson, 1996; Chung, Mansfield, & Legge, 1998; Näsänen & O'Leary, 1998) and could be related to the spacing between retinal ganglion cells, which has been shown to increase in a roughly linear way with eccentricity (Thorpe, Gegenfurtner, Fabre-Thorpe, & Bulthoff, 2001).

Despite the strong decrease of visual performance with eccentricity, most visual events occur in the peripheral visual field and cause saccades which displace targets of interest into CV where detailed visual analysis can be performed (Liversedge & Findlay, 2000). This implies that some features are processed and selected in PV for saccadic capture. In agreement with this, several studies, using ecological or complex stimuli such as objects or natural scenes presented at very high eccentricities (up to 80°), showed unexpected good performances in object recognition (Jebara, Pins, Despretz, & Boucart, 2009), in colour detection (Naili, Despretz, & Boucart, 2006) or in categorization (Thorpe et al., 2001). In particular, Thorpe and colleagues interpreted the high performance in categorization of animal pictures as a phylogenetic advantage for species adaptation and individual survival. Given the high adaptive value of emotional information in terms of survey, the processing of emotional-laden information in PV is likely, even at far eccentric points of the visual field, despite the high decrease of acuity. This assumption is in line with other studies showing that emotional stimulations are still processed in experimentally deteriorated visual conditions like liminal central presentations (e.g., Gläscher & Adolphs, 2003; Kiss & Eimer, 2008; Phillips et al., 2004; Williams et al., 2006) or binocular rivalry (Alpers & Gerdes, 2007; Alpers, Ruhleder, Walz, Mühlberger, & Pauli, 2005; Williams, Morris, McGlone, Abbott, & Mattingley, 2004).

The processing of emotional information as a function of eccentricity in visual field has already been investigated but mostly in parafoveal positions, around 5° of eccentricity (Bayle, Henaff, & Krolak-Salmon, 2009; Calvo, 2006; Gutiérrez, Nummenmaa, & Calvo, 2009). Only a few studies presented emotional scenes in more eccentric positions. Thus, Calvo and Lang (2005) presented at 10° of eccentricity pairs of pictures of natural scenes, one neutral and one emotional, and observed that the first saccade of the participants was preferentially directed towards the emotional picture. They also showed that emotional pictures were better remembered than neutral, even when the pairs of pictures were briefly presented (150 ms). Two recent studies investigated the neural correlates of the processing of affective natural scenes projected in peripheral vision (De Cesarei, Codispoti, & Schupp, 2009 at 16°; Rigoulot et al., 2008 at 30°) and found affective modulation of early ERP components for both centrally and peripherally presented scenes.

However, these rare studies focused on how emotional information is processed in natural scenes leaving unexplored the case of emotional facial expressions. Yet, faces have an obvious simpler spatial configuration and are more homogeneous than natural scenes. Moreover, faces are known to play an important role from an evolutionary perspective (e.g., Darwin, 1872; Öhman & Mineka, 2001). Humans developed special sensitivity for faces (Yarbus, 1967) and quick analysis of facial expression is crucial in social communication (Adolphs, 2003). Moreover, electrophysiological studies confirmed this special status as they showed that the emotional expression of faces can modulate early (Batty & Taylor, 2003; Eger, Jedynak, Iwaki, & Skrandies, 2003; Pizzagalli, Regard, & Lehmann, 1999; Pourtois, Grandjean, Sander, & Vuilleumier, 2004) and late evoked components (Ashley, Vuilleumier, & Swick, 2004; Campanella et al., 2004; Eimer & Holmes, 2002; Eimer, Holmes, & McGlone, 2003; Krolak-Salmon, Fischer, Vighetto, & Mauguiere, 2001; Sato, Kochiyama, Yoshikawa, & Matsumura, 2001; Schupp et al., 2004). The data are less homogeneous concerning the classical N170 component indexing specific face processing (Bentin, Allison, Puce, Perez, & McCarthy, 1996; George, Evans, Fiori, Davidoff, & Renault, 1996; Itier & Taylor, 2004). Some studies found no emotional modulation (Eimer & Holmes, 2002, 2007; Herrmann et al., 2002; Krolak-Salmon et al., 2001), while others showed differences of amplitude and latency according to the emotional expression of faces (Batty & Taylor, 2003; Eger et al., 2003; Pizzagalli et al., 2002).

As a whole, these studies performed in CV showed that emotional facial expressions engage a specific brain network. However, very few studies explored whether emotional facial expressions are still processed in far eccentric positions. Only two recent studies using magnetoencephalography (Bayle et al., 2009; Liu & Ioannides, 2010) observed increased cerebral activations in amygdala and fusiform gyrus in response to fearful and happy expressions when they were presented at 5° of eccentricity for the former study and at 10° for the latter, in line with the role of these structures in the processing of emotional expressions (Adolphs, 2002).

Among the emotional facial expressions, fear is a significant biological indicator of potential threat in the environment and allows a rapid behavioral response to danger (Eccleston & Crombez, 1999; Mathews & Mackintosh, 1998; Öhman & Soares, 1993). Moreover, a recent study (Bocanegra & Zeelenberg, 2009) showed that fearful faces could improve behavioral performance in a tilt-detection task of low spatial frequencies (LSF) Gabor patches but not of high spatial frequencies (HSF) ones, in agreement with studies suggesting that the processing of emotional facial expression would be supported by LSF rather than by HSF (Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005; Vlamings, Goffaux, & Kemner, 2009; Vuilleumier, Armony, Driver, & Dolan, 2003). Given that LSF information is conveyed by the visual magnocellular pathway and that peripheral vision is mainly related to this pathway, these results suggest that PV processes could be specifically modulated by the emotional expression of fear.

Consequently, our hypothesis is that the enhancement of electrophysiological responses to fearful faces, well-documented in CV, persists in PV even at large eccentricities. Accordingly, the behavioral and neural impact of fearful and neutral faces, presented in near and far locations in peripheral vision, was evaluated by means of reaction times and ERPs recordings. Considering the rare available electrophysiological data related to peripheral vision, particularly the processing of faces at far eccentricities, we conducted a spatio-temporal principal component analysis (PCA) to investigate ERPs data without *a priori* hypotheses (see Pourtois, Delplanque, Michel, & Vuilleumier, 2008). In addition, PCA techniques have already demonstrated their relevance to analyze ERPs in response to emotional stimuli (Delplanque, Lavoie, Hot, Silvert, & Sequeira, 2004; Delplanque, Silvert, Hot, & Sequeira, 2005; Delplanque, Silvert, Hot, Rigoulot, & Sequeira, 2006; Hot, Saito, Mandai, Kobayashi, & Sequeira, 2006; Kayser & Tenke, 2003; Rigoulot et al., 2008).

2. Methods

2.1. Participants

Sixteen right-handed women were included in the study (mean age: 19.1 ± 3.5 years). Only women were included in this study because they are known to be more reactive to emotional information than men (Larsen & Diener, 1987), especially to threatening information (Bradley, Codispoti, Sabatinelli, & Lang, 2001; Collignon et al., 2010; Kring & Gordon, 1997). They all had normal or corrected to normal vision. Prior to the experiment, participants were given a questionnaire in order to get their consent and another to test their handedness (Hécaen, 1984). They also filled a