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Impaired holistic processing of unfamiliar individual faces in acquired prosopagnosia

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ABSTRACT

Prosopagnosia is an impairment at individualizing faces that classically follows brain damage. Several studies have reported observations supporting an impairment of holistic/configural face processing in acquired prosopagnosia. However, this issue may require more compelling evidence as the cases reported were generally patients suffering from integrative visual agnosia, and the sensitivity of the paradigms used to measure holistic/configural face processing in normal individuals remains unclear. Here we tested a well-characterized case of acquired prosopagnosia (PS) with no object recognition impairment, in five behavioral experiments (whole/part and composite face paradigms with unfamiliar faces). In all experiments, for normal observers we found that processing of a given facial feature was affected by the location and identity of the other features in a whole face configuration. In contrast, the patient's results over these experiments indicate that she encodes local facial information independently of the other features embedded in the whole facial context. These observations and a survey of the literature indicate that abnormal holistic processing of the individual face may be a characteristic hallmark of prosopagnosia following brain damage, perhaps with various degrees of severity.

1. Introduction

Brain damage to bilateral or right unilateral occipito-temporal regions can cause a massive impairment at recognizing familiar faces. This rare neurological condition has been termed 'prosopagnosia' (Bodamer, 1947) and has attained a considerable degree of popularity in the neuropsychological literature since the first clinical observations (Quaglino, Borelli, Della Sala & Young, 2003; Wigan, 1844). The clinical and anatomical conditions of prosopagnosia have been of great interest to cognitive neuroscientists willing to clarify the neuro-functional mechanisms of normal face processing. For instance, the study of prosopagnosia is at the origin of the idea that there are neural processes devoted exclusively to faces in the adult human brain (Bodamer, 1947). Anatomical descriptions of prosopagnosia have also provided the first and strongest evidence for the critical role of the right occipito-temporal cortex in face recognition (Meadows, 1974; Landis, Regard, Bliestle, & Kleihues, 1988; Michel, Poncet, & Signoret, 1989; Sergent & Signoret, 1992a; Barton, Press, Keenan, & O'Connor, 2002; Bouvier & Engel, 2006). However, despite the relatively large number of cases of acquired prosopagnosia (AP) reported since the first descriptions, there is yet no unified account for these patients' inability to recognize or discriminate individuals by means of their faces.

Following early proposals (e.g., Levine & Calvanio, 1989; Sergent & Villemure, 1989), it has been suggested that AP patients suffer from an inability to process faces configurally/holistically.[1] Levine and Calvanio (1989) described the patient LH as being unable to "*get an immediate overview of a face [. . .] as a whole at a single glance*" (p.159). Following experiments with non-face patterns and tests of visual closure, these authors concluded that AP represents a general loss of visual "*configural [i.e. holistic] processing*"—a view supported by subsequent observations.

A number of studies have inferred a deficit of holistic face processing (HP) in prosopagnosia from an abnormal effect of face inversion: contrary to controls the patients either showed a reduced effect, or no performance decrease at all (e.g., Gauthier,

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[1] These terms have been used interchangeably in the face processing literature, even though a number of authors have used the term "configural" to refer specifically to the processing of relative distances between features that would be diagnostic of someone's identity (e.g. Rhodes, 1988; Carey, 1992; Maurer et al., 2002). Here we will use the term "holistic" or "configural" to refer to a process, not to specific cues of the stimulus. In line with earlier proposals (Farah et al., 1998), this process can be defined as the "*ability to perceive the multiple elements of a(n) (upright) face simultaneously, as an integrated representation*" (Rossion, 2008a). Its empirical manifestation is characterized by the inter-dependence between facial features.

Behrmann, & Tarr, 1999; Marotta, McKeeff, & Behrmann, 2002; Delvenne, Seron, Coyette, & Rossion, 2004), or even a paradoxical superior performance with inverted faces (e.g., Farah, Wilson, Drain, & Tanaka, 1995; but see Busigny & Rossion, 2009). However, since the nature of the face inversion effect remains a matter of debate (Rossion, 2008a), abnormal effects of inversion in AP provide only indirect evidence that the cause of the processing impairment is a deficit of HP (see Busigny & Rossion, 2009, for a recent discussion).

Other authors have followed Levine and Calvanio's (1989) approach and showed general holistic processing impairments in AP with non-face stimuli (overlapping figures, Gestalt-completion figures, global texture, dot patterns, hierarchical Navon stimuli, . . . e.g., Evans, Heggs, Antoun, & Hodges, 1995; Takahashi, Kawamura, Hirayama, Shiota, & Isono, 1995; for a review of global/holistic processing in object perception in general see also Kimchi, 1992).

A lack of HP in prosopagnosia has been more directly and specifically inferred from observations made based on matching or priming experiments with schematic faces made of multiple features, and multidimensional analysis (Sergent & Villemure, 1989; Sergent & Signoret, 1992b; Saumier, Arguin, & Lassonde, 2001), or from whole–part interference paradigms such as the Thatcher illusion (Boutsen & Humphreys, 2002; Riddoch, Johnston, Bracewell, Boutsen, & Humphreys, 2008). Finally, some authors have emphasized the difficulty of AP patients in processing relative distances between features (Barton et al., 2002; Joubert et al., 2003), a type of information diagnostic for face individuation that has been characterized as "configural" (Carey, 1992; Maurer, Le Grand, & Mondloch, 2002).

Together, these studies have provided some evidence supporting the view that AP is characterized by a particular lack of the ability to integrate facial features into a global (i.e., holistic) representation. However, more compelling evidence to support the above-mentioned hypothesis may be necessary, for at least two reasons. First, all studies (with the exception of one case in Sergent & Signoret, 1992a, and one recent case by Riddoch et al., 2008) have tested patients presenting clear basic-level object recognition impairments (Levine & Calvanio, 1989; Sergent & Signoret, 1992a, two cases; Farah et al., 1995; Evans et al., 1995; Takahashi et al., 1995; de Gelder, Bachoud-Lévi, & Degos, 1998; Gauthier et al., 1999; Saumier et al., 2001; Barton et al., 2002; Boutsen & Humphreys, 2002; Marotta et al., 2002; Delvenne et al., 2004; Anaki, Kaufman, Freedman, & Moscovitch, 2007). Thus, while Levine and Calvanio's (1989) view is that AP represents a *general* loss of visual "*configural [i.e. holistic] processing*", this hypothesis may require further investigation from single case studies of patients presenting a *selective* deficit for face recognition, tested for their holistic processing abilities with face (rather then object) stimuli.

Second, there are two paradigms that have been used extensively in the behavioral literature with normal viewers to demonstrate HP: the composite face paradigm (Young, Hellawell, & Hay, 1987) and the whole-part paradigm (Tanaka & Farah, 1993). Both reveal effects that are acknowledged to demonstrate holistic processing of facial features (Maurer et al., 2002; McKone & Robbins, 2007; Rossion, 2008a). While variants of the whole/part paradigm have been tested with visual agnosic patients (e.g., Boutsen & Humphreys, 2002), the composite face paradigm, which is more consistently used and gives more robust holistic effects has not been tested in AP (see Le Grand, Mondloch, Maurer, & Brent, 2003, for composite face effects tested in congenital prosopagnosia). Since these effects have been well demonstrated in the normal population, and are acknowledged to be highly sensitive at measuring HP, an absence or reduction of composite and whole/part effects in a case of AP would provide strong evidence for HP difficulties.

Taking into account these issues, we tested HP of the prosopagnosic patient PS, who suffers from a selective deficit at recognizing and matching individual faces following brain damage (Rossion et al., 2003), applying both the whole/part and composite face paradigms, across five experiments. In line with previous proposals (e.g., Galton, 1883; Goldstein & Chance, 1980; Farah, Wilson, Drain, & Tanaka, 1998; Ingvalson & Wenger, 2005), here we conceptualize HP as the "*simultaneous perception of the multiple features of an individual face, that are integrated into a single global representation*" (Rossion, 2008a). A direct consequence of this holistic mode of processing is that normally a given facial feature cannot be processed independently of the other features. We hypothesize that the patient PS – deprived of this holistic mode of processing faces – would process a given facial feature without being influenced by other features of the whole face.

2. Case description

The patient PS has been described in detail elsewhere, both functionally and neuro-anatomically (Rossion et al., 2003; Caldara et al., 2005; Schiltz et al., 2006; Sorger, Goebel, Schiltz, & Rossion, 2007; Orban de Xivry, Ramon, Lefèvre, & Rossion, 2008). She sustained closed head injury in 1992, which caused extensive lesions, mainly to the right inferior occipital and the left mid-ventral cortex (mainly fusiform gyrus) (for all anatomical details see Sorger et al., 2007). She complains only of a profound difficulty in recognizing faces. PS can discriminate faces from other objects, but is impaired and particularly slow at recognizing faces at the individual level (Schiltz et al., 2006). She performs below normal range on the Benton Face Recognition Test (Benton & Van Allen, 1972) (Busigny & Rossion, 2009), and her low score on the Warrington Recognition Memory Test (Warrington, 1984) for faces characterizes her as impaired (see Table 1, Sorger et al., 2007). PS is not impaired at recognizing/discriminating objects, even at the subordinate level (Rossion et al., 2003; Schiltz et al., 2006). Her visual field is almost full (with exception of a small left paracentral scotoma), her visual acuity good (.8 for both eyes as tested in August 2003) and her color perception is in the normal lower range (Sorger et al., 2007).

3. Experimental studies of holistic processing

3.1. General methodological considerations

It is generally acknowledged that – apart from their difficulties at recognizing familiar faces (e.g., Benton, 1980) – AP patients present with impairments at matching unfamiliar faces at the individual level, either in terms of accuracy scores, or prolonged RTs due to the use of slow, piecemeal strategies (Farah, 1990; Davidoff & Landis, 1990; Delvenne et al., 2004). The patient PS is similar to other cases of AP in this respect: she is markedly impaired at recognizing familiar faces (personally familiar, or famous) and is also strongly deficient and particularly slow at discriminating individual unfamiliar faces, as well as matching different pictures of the same individuals (Rossion et al., 2003; Schiltz et al., 2006; Rossion, Kaiser, Bub, & Tanaka, 2009). Here, across a range of (unfamiliar face) matching tasks, we investigated the interactivity of processing facial parts. In all experiments the stimuli were presented until a response was provided in order to avoid putting the patient under pressure and chance level performance.

In the 2 experiments (1 and 2) involving the whole–part advantage paradigm, a target was presented, followed by two probe stimuli (simultaneously), and participants had to choose which one corresponded to the target. This forced-choice procedure could not be applied for the composite face experiments (3–5), which require "same" and "different" trials to be treated separately, given that the composite effect is observed only on "same" trials (Le Grand,