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Strabismic amblyopia affects relational but not featural and Gestalt processing of faces

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ABSTRACT

The ability to identify faces is of critical importance for normal social interactions. Previous evidence suggests that early visual deprivation may impair certain aspects of face recognition. The effects of strabismic amblyopia on face processing have not been investigated previously. In this study, a group of individuals with amblyopia were administered two tasks known to selectively measure face detection based on a Gestalt representation of a face (Mooney faces task) and featural and relational processing of faces (Jane faces task). Our data show that – when relying on their amblyopic eye only – strabismic amblyopes perform as well as normally sighted individuals in face detection and recognition on the basis of their single features. However, they are significantly impaired in discriminating among different faces on the basis of the spacing of their single features (i.e., configural processing of relational information). Our findings are the first to demonstrate that strabismic amblyopia may cause specific deficits in face recognition, and add to previous reports characterizing visual perceptual deficits associated in amblyopia as high-level and not only as low-level processing.

1. Introduction

Faces are of capital importance for human social interactions. In fact, faces convey information about individuals' unique identity, but also more general information such as their gender, ethnicity, emotional states, and health status. A deficit in face recognition can therefore be highly detrimental for everyday social interactions (cf. Grüter & Carbon, 2010). A great deal of literature has investigated severe face perception deficits that are due, for instance, to congenital or acquired prosopagnosia (e.g., Avidan, Tanzer, & Behrmann, 2011; Duchaine & Nakayama, 2005). However, there is evidence that more subtle facial processing deficits may be associated with other conditions such as autism (e.g., Simmons et al., 2009, for a review) or visual deficits of various etiologies, such as anisometropic or deprivation amblyopia (e.g., Bankó et al., 2012; Geldart et al., 2002; Le Grand et al., 2001; Le Grand et al., 2003, 2004; Robbins et al., 2012) or monocular blindness due to enucleation (Kelly, Gallie, & Steeves, 2011). In the last decade, the effects of particular visual deficits on face processing have received increasing attention, as indicated by the increasing number of publications appearing in top scientific journals and linking different areas of research (e.g., Le Grand et al., 2001, 2003, 2004).

Amblyopia is a largely diffused developmental disorder of spatial vision that has been found to affect visual cortical responses to faces (see Bankó et al., 2012). It is characterized by reduced visual acuity and contrast sensitivity usually affecting one eye and is typically associated with an uncorrected ocular misalignment (i.e., strabismic amblyopia) and/or a significant refractive error between the two eyes (i.e., anisometropic amblyopia) occurring early in development. A more rare form of amblyopia is deprivation amblyopia, which occurs when patterned visual input to one or both eyes is reduced due to a congenital dense cataract or to ptosis (drooping of the eyelid that restricts or blocks vision). In association with monocular loss of visual function, amblyopia is also accompanied by impaired or absent binocular vision (Sireteanu, 2000), as a

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result of suppression of the amblyopic eye input to the visual cortex. In an extensive study carried out on amblyopic adults (or with risk factors for amblyopia during development because of associated conditions such as strabismus), McKee, Levi, and Movshon (2003) measured visual functions that are known to be abnormal in amblyopia (e.g., *optotype* (Snellen) visual acuity, contrast sensitivity, grating acuity, Vernier acuity, and binocularity) in more than 400 patients that were assigned to different predetermined clinical categories (e.g., Anisometropes, Strabismic-anisometropes, Strabismics, Former Strabismics, Eccentric fixators, Deprivationals, Refractives, and Other abnormal). Interestingly, McKee, Levi, and Movshon (2003)'s findings showed that although *optotype* (Snellen) visual acuity accounted for much of the variance in the other functional measurements, significant differences emerged in the patterns of visual loss among the clinically defined categories of patients, and particularly between strabismic and anisometropic observers, suggesting that reduced resolution and loss of binocularity play a major role in determining the actual pattern of visual deficit. Moreover, the severity of amblyopia depends on the degree of imbalance between the two eyes and to the age at which the amblyogenic factor occurred (McKee, Levi, & Movshon, 2003). Without early corrective intervention (i.e. optical and/or surgical) the impaired visual function of the eye persists given that the neural processing of information from that eye has become impaired (Hess, 2001). Notably, converging findings suggest that amblyopia causes physiological alterations in both early and late visual areas, affecting not only low perceptual functions but also higher visual functions and visuo-spatial attention (e.g., Barnes et al., 2001; Imamura et al., 1997; Muckli et al., 2006). In particular, not only the functioning of the ventral (i.e. "what" object processing) as well as the dorsal (i.e. "where" spatial processing) visual pathways seem to be affected in amblyopia (e.g., Ho & Giaschi, 2006; Simmers et al., 2006), but even parietal and frontal functions may be affected (e.g., Farzin & Norcia, 2011).

Face recognition is a complex process that involves both early and late visual areas, the core face processing network (according to recent models) involving the fusiform face area in the occipitotemporal cortex, the occipital face area in the lateral occipital cortex, and the superior temporal sulcus (see Grill-Spector, Knouf, & Kanwisher, 2004; Haxby, Hoffman, & Gobbini, 2000; Rossion et al., 2003). At the functional level, face recognition appears to rely on multiple parallel processes operating simultaneously (Bruce & Young, 1986). In particular, a face can be recognized mainly on the basis of the global organization of its elements, even when the elementary components cannot be individually recognized as parts of a face (e.g., Leder & Carbon, 2005; Tanaka & Farah, 1993; Taubert et al., 2011). In fact, although the single elements of a face (eyes, nose, mouth, etc.) can occur in different shapes and sizes, their spatial arrangement is fixed (e.g., the mouth is below the nose, the nose is below the eyes, etc.), and individuals are likely to use this "first-order" spatial arrangement (see Maurer, Le Grand, & Mondloch, 2002) to classify an image as a face. A typical example of this strategy is the processing of Mooney faces. Mooney faces are two-tone (thresholded black and white) images first used in the 1950s to measure children's capacity to form a coherent percept or the closure of shape on the basis of global structure missing reliable local details (Mooney, 1956, 1957). In a Mooney face, the single elements are too ambiguous to be identified as parts of a face. Therefore, to find any facial feature (such as an eye or the mouth), one must first detect that the stimulus has the structure of a generic face (e.g., Latinus & Taylor, 2005; McKone, 2004; Rossion et al., 2011).

However, in daily life, we do not just need to recognize a face as a face, but also to recognize that a face belongs to a particular individual, that is, we are continuously required to discriminate between different faces. Several findings suggest that we are able to discriminate between different faces by mainly relying on relational and featural processing (e.g., Carbon & Leder, 2005; Collishaw & Hole, 2000; Leder & Carbon, 2006; for a review see Maurer, Le Grand, & Mondloch, 2002). Relational (or spacing) information refers to the specific spatial arrangement (a specific distance between the eyes, the eyes and the nose, etc., also referred to as "second-order" spatial relations) that characterizes each single face (see Rhodes, 1988). Featural information refers to featural cues, that is, the shape, or size of individual facial features. Individuals' sensitivity to relational and featural information has been measured in paradigms requiring to discriminate between different faces that only differed in terms of single features (with the spatial arrangement being kept constant) or relational aspects (with single features being kept constant) (for a review, see Maurer, Le Grand, & Mondloch, 2002). Overall, normally sighted adult individuals are quite accurate in deciding whether two faces are identical or different for featural or relational aspects, with accuracy being higher (Freire, Lee, & Symons, 2000; Mondloch, Le Grand, & Maurer, 2002; Mondloch, Robbins, & Maurer, 2010) and speed being faster overall for featural differences (Carbon & Leder, 2005).

Relational-based and featural-based processes have been demonstrated to be independent and parallel processes demonstrated by different experimental manipulations such as stimuli inversion (e.g., Mondloch, Le Grand, & Maurer, 2002; with inversion typically affecting more detection of relational changes than of featural changes), backward masking (Carbon, 2011), or by the analysis of scanpaths of the eyes (Bombari, Mast, & Lobmaier, 2009). Moreover, the capacity to process features seems to develop faster than the capability to discriminate faces on the basis of their relational information (Mondloch, Le Grand, & Maurer, 2003, 2002). From a neuropsychological point of view, the two processes seem to involve, at least partially, different neural circuits (Maurer et al., 2007; Mercure, Dick, & Johnson, 2008; Scott & Nelson, 2006) and there is evidence that featural and configural processing of faces is differently affected in certain conditions such as prosopagnosia (e.g., Lobmaier et al., 2010).

Interestingly, it has been reported that individuals who suffered early visual deprivation due to bilateral congenital cataracts perform normally in a face detection task in which Mooney faces were used as stimuli (Mondloch, Le Grand, & Maurer, 2003), whereas they performed sub-optimally on a relationally manipulated but not a featurally manipulated set of faces, even after several years' recovery (Le Grand et al., 2001, 2004). Hence, a normal earlier visual experience may be necessary to develop the typical shift from featural to configural face processing (e.g., Schwarzer, Zauner, & Jovanovic, 2007) but not to detect that a stimulus is a face. Given that strabismus causes abnormal binocular input, which in turn can lead to amblyopia, we investigated (Experiment 1) the effects of this condition on different aspects of faces processing, and in particular, face detection as measured by the Mooney faces task and relational and featural processing (using the "Jane faces task" , see Mondloch, Le Grand, & Maurer, 2002).

Finally, given that participants in our main experiment (Experiment 1) were tested twice on the same task, a second experiment was carried out to assess whether individuals' performance was stable across time (test–retest reliability) in the different experimental tasks we employed. In fact, we are not aware of direct measures of test–retest reliability for the Mooney faces task, although there is evidence that training with the task in the same experimental session leads to increased accuracy (Latinus & Taylor, 2005). In turn, test–retest reliability has been directly investigated earlier for the Jane faces task (Mondloch & Desjarlais, 2010; Mondloch, Maurer, & Ahola, 2006). In particular, Mondloch and Desjarlais (2010) investigated whether performance in the featural and relational set of the Jane faces task was stable over time by