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Brief article

Face inversion and acquired prosopagnosia reduce the size of the perceptual field of view

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ABSTRACT

Using a gaze-contingent morphing approach, we asked human observers to choose one of two faces that best matched the identity of a target face: one face corresponded to the reference face's fixated part only (e.g., one eye), the other corresponded to the unfixated area of the reference face. The face corresponding to the fixated part was selected significantly more frequently in the inverted than in the upright orientation. This observation provides evidence that face inversion reduces an observer's perceptual field of view, even when both upright and inverted faces are displayed at full view and there is no performance difference between these conditions. It rules out an account of the drop of performance for inverted faces – one of the most robust effects in experimental psychology – in terms of a mere difference in local processing efficiency. A brain-damaged patient with pure prosopagnosia, viewing only upright faces, systematically selected the face corresponding to the fixated part, as if her perceptual field was reduced relative to normal observers. Altogether, these observations indicate that the absence of visual knowledge reduces the perceptual field of view, supporting an indirect view of visual perception.

1. Introduction

The human face is commonly considered the quintessential whole, or Gestalt, i.e., a visual stimulus that is different from the sum of its parts (Biederman & Kalocsai, 1997; Pomerantz & Kubovy, 1986). Supporting this view, behavioral studies have shown that a part is better recognized if it is presented in a whole face than if it is presented in isolation (Tanaka & Farah, 1993). Also, performance at recognizing half of a face is decreased when it is aligned with half of another face (for a review Rossion, 2013; Young, Hellawell, & Hay, 1987). These effects are substantially reduced if the face is presented upside-down, suggesting that they depend on internal representations that have probably been derived from visual experience. The dominant account of these observations is that an upright face is perceived as a Gestalt, i.e., holistically/configurally, while an inverted face is perceived part-by-part (Farah, Wilson, Drain, & Tanaka, 1998).

An implication of this holistic/configural view is that an upright face is associated with a larger *perceptual field*, namely, the area of vision from which diagnostic information can be extracted, than an inverted face (Rossion (2009, 2013)). Faced with the exact same stimulus, an observer would perceive the whole face when it is upright, i.e., with a large perceptual field, but would see only a single part at a time when it is inverted, i.e., with a reduced perceptual field (Rossion, 2009, 2013; Xu & Tanaka, 2013). However, in contrast to the holistic/configural view, it has also been suggested that upright and inverted faces are processed the same way, using part-based local information more efficiently for upright than inverted faces (Sekuler,

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Gaspar, Gold, & Bennett, 2004; see also Gold, Mundy, & Tjan, 2012).

Clarifying this issue would contribute to our understanding of one of the most important phenomena observed in experimental psychology, namely, the detrimental effect of inversion on recognition of faces relative to other object categories (Yin, 1969).

To this end, we used a paradigm that differs from previous studies at two levels: (1) there is no decrease of performance (i.e., efficiency of processing) for inverted relative to upright faces and (2) only full faces are presented, rather than isolated local parts. This paradigm is inspired by the gaze-contingency (GC) technique developed in reading (McConkie & Rayner, 1975), and later applied to face stimuli with a gaze-contingent window and mask (Van Belle, de Graef, Verfaillie, Busigny, & Rossion, 2010b; Van Belle, de Graef, Verfaillie, Rossion, & Lefèvre, 2010a). Most recently, Miellet, Caldara, and Schyns (2011) developed a GC approach in which two face identities are displayed on top of each other, simultaneously providing one identity information on the window of fixation corresponding roughly to one face part, and the other identity information outside of that fixated part. Using this approach with famous faces, these authors showed that a given observer can use both kinds of information, which they called local and global, respectively, to recognize a face. Here, a similar GC approach was used in which a displayed full face was composed of a combination of two individual faces: one that corresponded to the fixated part in a gaze-contingent way, and the other one to the unfixated area of the face (Fig. 1). If inversion reduces the perceptual field, inverting the exact same face should increase the proportion of responses based on the fixated part ("part-based responses"), all other parameters remaining constant. Furthermore, with upright faces, we hypothesized that a brain-damaged patient with prosopagnosia who has normal peripheral vision but impaired holistic face perception (PS, Rossion et al., 2003) would systematically provide responses based on her fixated part only.

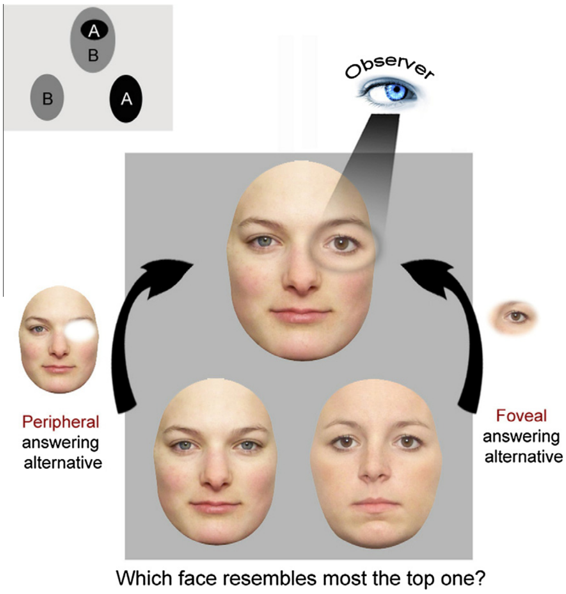

Fig. 1. Schematic illustration of the paradigm. On each trial, two full faces (A and B) are presented at the bottom of the screen, one of which must be chosen as more similar in identity to the target face above. The target face is made of a combination of the two faces, so that there is no 'correct' or 'incorrect' response. One of the faces corresponds to the fixated 'window' of the target face, which changes dynamically with fixation, while the other face corresponds to the information outside of fixation.

2. Materials and methods

2.1. Participants

Fourteen naïve participants (2 males, age range: 22–26 yrs., all but one right-handed), with normal or corrected-to-normal visual acuity were tested individually. The prosopagnosic patient PS (Rossion et al., 2003), and seven age-matched controls (age range 59–61, average age 61, all right-handed) were also tested. Following brain damage, PS suffers face-selective recognition impairment (Busigny, Graf, Mayer, & Rossion, 2010). Her case has been described in behavioral and neural studies: relevantly, she shows no face inversion effect (Busigny & Rossion, 2010), and shows no evidence for interactivity of processing between facial parts (Ramon, Busigny, & Rossion, 2010). Importantly, PS has a small left paracentral scotoma, but her peripheral vision is intact (Sorger, Goebel, Schiltz, & Rossion, 2007). The scotoma falls completely within the gaze-contingent window, so that, if anything, it could only reduce the proportion of choices based on the fixated part, not the periphery (contrary to our hypotheses). All other participants were specifically asked and did not report any difficulty at face recognition.

2.2. Procedure/experimental setup

Participants' eye movements were recorded while they performed a 2-alternative forced-choice task. Each trial started with a standard drift correction with a central fixation cross, followed by two faces presented side by side on the lower half of the screen and one target face on the top half. The target face was composed of a combination of the two bottom faces in a gaze-contingent way. That is, the fixated ('central' window) part corresponded to one of the two faces, while the remaining part (periphery, outside the fixated window) corresponded to the other face (Fig. 1). Therefore, the target face constantly changed, following changes in gaze position of the participant ("dynamic fixated window"). However, since the face remained constant during fixations, and changed only over saccades, the changes did not disturb the participants' natural perception of the face.

During the unlimited exploration of the faces, an average face in greyscale constantly covered the non-fixated faces (Van Belle et al., 2010a, 2010b). Thus, at each moment in time, only one face was visible. This procedure was used so that the target face was not identical to one of the two alternatives (i.e., the face corresponding to the periphery of fixation) when participants did not fixate on the target face. Faces were presented either inverted or upright (half of the trials for each orientation, random presentation order). The response was given by pressing a left or right key on the keyboard, corresponding to the position of the face that, according to the participant, resembled most the target face. Note that there was no right or wrong answer, and therefore no performance score, so that the responses only indicate a diagnosticity selection. Since PS shows no inversion effect at all in face matching tasks (Busigny & Rossion, 2010), her pattern of results is only relevant for the upright orientation.

2.3. Stimuli

The stimulus set contained 78 photographs of undergraduates (18 male and 60 female), with external features removed. The faces were resized so that the eyes and mouths were vertically aligned. They were then combined in pairs of two males or two females based on similarity of both the eye distance and face width. This was done in order to minimize distortions in the combined (reference) face.

2.4. Procedure

Stimuli were displayed with Matlab, using the Psychophysics and Eyelink Toolbox extensions (Brainard, 1997; Cornelissen, Peters, & Palmer, 2002; Pelli, 1997; see http://psychtoolbox.org/), on a 22″ Sony Trinitron monitor at a viewing distance of 58 cm, with a spatial resolution of 1280 by 1024 pixels and a refresh rate of 85 Hz. The target face was 12 visual deg in height and 9° in width on average (10.5° × 7.9° for the two lower faces).

For the target face, in the window area, face A was gradually morphed into face B in a Gaussian way, in order to avoid an abrupt border between the two facial parts determining the target face. The outside border of the window, so where 100% face B stops and starts going over into face A, subtended 6.5° × 4.5°. The inner border at which the image was 100% face A was 3.2° × 2.2°, so that it encompassed roughly one face part at a time (eye/eyebrow, nose, mouth). In between these two 100% borders, the morphing percentages of A and B were defined by half a Gaussian. So the 50–50% window subtended 4.8° × 3.35°.

Critically, the size of the window relative to the whole face was selected based on pilot tests with upright faces in three normal observers (not included in the results), so that it led to the selection of the face corresponding to the window about half of the time (50%), allowing to test the hypothesis of a differential bias for inverted faces.

Eye movements were registered with an SR Research Eyelink 1000 remote eye tracker at a sampling rate of 1000 Hz, and with a gaze position error smaller than 0.5°. Head movement was restricted by a chin and head rest. Each of the 39 face pairs, from which one was the central and the other the peripheral part of the target face, were presented two times, once in upright, and once in inverted orientation, resulting in a total of 78 trials per participant. The position of the central and peripheral answering alternatives was randomized.

3. Results

3.1. Inversion

Overall, the proportion of choices based on the "central" window (i.e., part-based responses) was significantly higher for inverted ($M = 53\%$) than for upright faces ($M = 41\%$, $F(1, 13) = 13.02$; $p = 0.0032$, partial eta$^2 = 0.50$) (Fig. 2A). The proportion of part-based responses differed considerably between participants, from 76% to 19% of the trials (Fig. 2B), in line with previous observations (Miellet et al., 2011). There was no difference in mean RT between part- and whole-based responses (4811 ms vs. 4478 ms, respectively; $F(1,13) = 1.80$; $p = .20$, partial eta$^2 = 0.12$), but there was an effect of inversion (slower RTs for inverted faces: upright: 4285 ms, inverted: 5004 ms; $F(1,13) = 21.15$; $p = .0005$, partial eta$^2 = 0.34$). Analysis of the eye gaze fixation patterns using a pixel-based comparison method (iMap, Caldara & Miellet, 2011) did not yield any significant differences between orientations nor response types (Fig. S1).

3.2. Prosopagnosia

Despite her preserved peripheral vision, the patient PS selected the 'central' window face in all trials but two, a proportion that did not significantly differ from 1 ($M = .97$; 95% confidence interval with a bootstrap procedure, 1000 repetitions: [.92, 1]) (Fig. 3). This proportion was significantly larger than that of the control participants considered altogether ($M = .51$, $p = .017$; Crawford & Howell, 1998). The response pattern of the age-matched participants ($M = .74$) did not differ from that of the younger controls ($t(9.8) = 1.24$, $p = .87$).

4. Discussion

In general, all other parameters being equal (i.e., face size and relative size of the window to the face size), typical observers rely relatively more on the fixated part of a face for inverted as compared to upright faces. These results are in line with previous evidence that gaze-contingently revealing only the central fixated part reduces the face inversion effect, while masking this central fixated part enhances the effect (Van Belle et al., 2010a). Compared to this previous gaze-contingency study the present approach provides a significant advantage: the observers always see upright and inverted faces in full view rather than with limited windows of vision or faces masked with a central hole. This compares favourably to response classification studies contrasting upright and inverted faces in which only local high-contrast diagnostic features, such as the eyes/eyebrows, emerge from noise (Sekuler et al., 2004). Moreover, contrary to classical studies comparing upright and inverted faces, here there was no measure of performance because both responses (part-based or whole-based) can be considered to be correct. Therefore the difference observed here between upright and inverted faces cannot be explained by a difference in local processing efficiency, and points to a *qualitative* rather than quan-

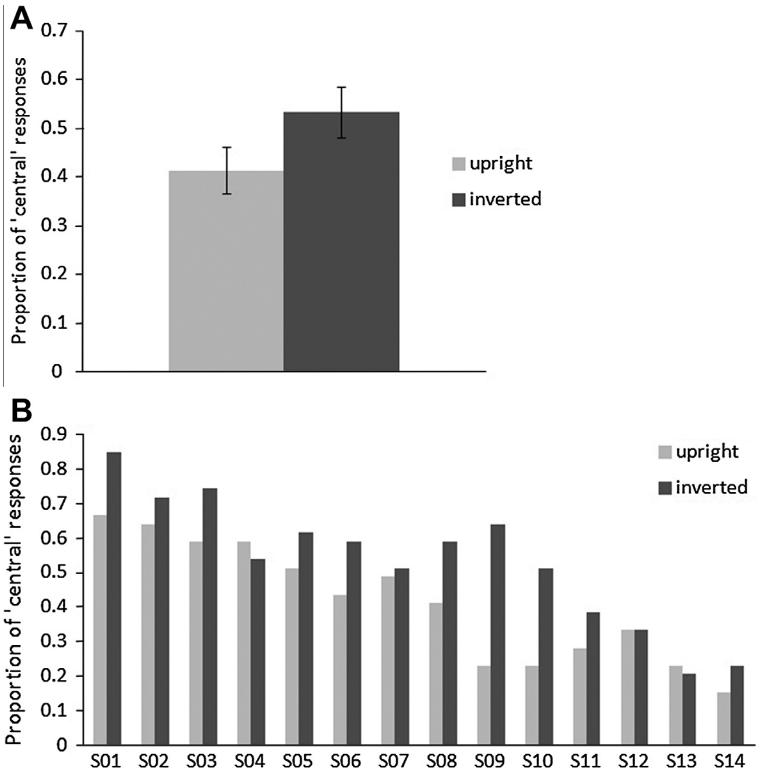

Fig. 2. Proportion of 'part-based' answers (A) averaged for all participants, (B) for each participant individually. The proportion of trials in which participants chose the face corresponding to information outside of the fixated part is then equal to 1-proportion central.

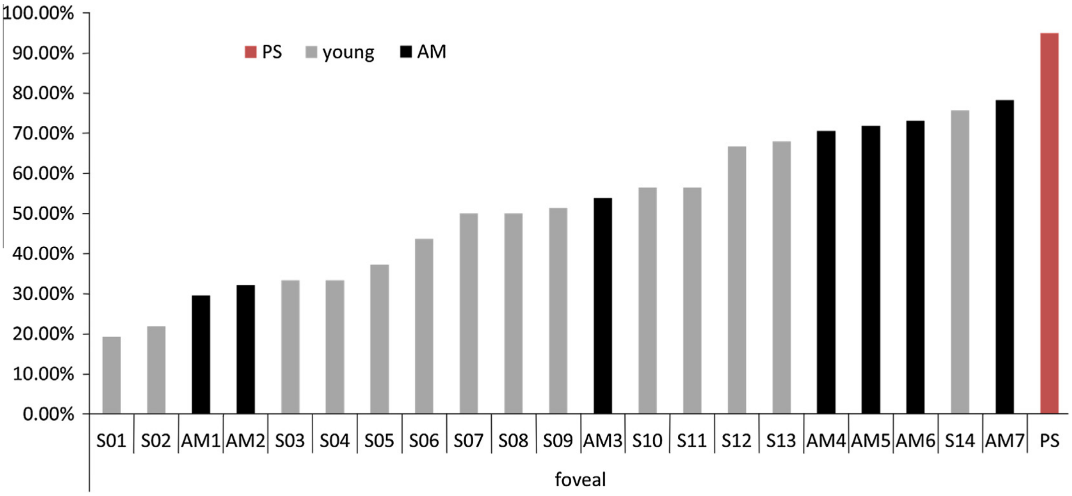

Fig. 3. Proportion of part-based responses in upright faces for PS and control participants (PS in red; age-matched participants in black). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

titative difference between the perception of upright and inverted faces.

Importantly, the absolute proportion of responses based on a single condition (e.g., "41% of choices based on the fixated part for upright faces") cannot be interpreted. Indeed, this proportion depends on the size of the face displayed and of the size of the fixated part with respect to the entire face. For instance, reducing the size of the window would reduce even further this proportion. Therefore, the absolute proportion of responses based on the fixated window and the surrounding face cannot be interpreted. What is interpretable, on the other hand, is the *relative* difference between two conditions, such as when the exact same stimuli are presented at upright and inverted orientations.

The face stimuli used here were larger than the size of face stimuli that is supposed to be optimal for holistic face perception (2–10 m distance, corresponding to about 4–0.8° of face width, McKone, 2009). However, this “optimal” size has been determined using face detection tasks (e.g., detection of a generic “Mooney” face in a display), rather than a face individualization task as used here, which requires finer-grained visual information. Moreover, previous studies have reported significant holistic processing effects with faces presented at similar sizes to those used here (McKone, 2009), and a recent study even suggests that stimulus sizes above 6° provide the largest face inversion effects (Yang, Shafai, & Oruc, 2014). Finally, the face size used here was similar to the main experiments in our previous studies with gaze-contingent masks and windows, in which the same results were obtained when the relative size of the stimuli was reduced substantially (i.e., the observer was further away from the display, see Van Belle et al., 2010a, 2010b).

Altogether, these observations support the view that a typical observer’s perceptual field of view is reduced when he/she sees inverted faces (Rossion, 2009, 2013). This view also accounts for the loss, or reduction, of the interdependence between face parts for inverted faces in normal observers (e.g., Sergent, 1984; Tanaka & Farah, 1993; Young et al., 1987). It can also account for the generally larger face inversion effects observed when matching inverted faces differing by relative distances between face parts, in particular long-range distances, as compared to faces differing by local parts (e.g., Freire, Lee, & Symons, 2000; Goffaux & Rossion, 2007; Sekunova & Barton, 2008).

Our observations indicate that there is a qualitative difference between upright and inverted face processing. Given that faces are processed more holistically than other objects (e.g., Robbins & McKone, 2007) and that individualization of nonface objects may essentially rely on part-based representations (Biederman & Kalocsai, 1997), we would not expect to observe the same outcome for nonface object categories if tested with this paradigm; except perhaps the human body (Reed, Stone, Bozova, & Tanaka, 2003), or headless faces with their bodies (Brandman and Yovel, 2012). Rather, our study suggests that the detrimental effect of inversion for recognition of faces relative to other object categories is due to a specific qualitative change that occurs when processing inverted faces.

Contrary to normal observers, we also found that with upright faces, a patient with acquired prosopagnosia relies almost exclusively on the fixated facial part. That is, the patient behaves as if, despite having normal peripheral vision, she did not perceive the face identity outside of the fixated part. This observation is consistent with previous observations collected on this and other patients with pure prosopagnosia, who appear to fixate each part of a face at a time, rather than fixating on a central point of the face to derive a whole face representation (e.g., Orban de Xivry, Ramon, Lefèvre, & Rossion, 2008; Peterson & Eckstein, 2012; Van Belle et al., 2010b). Compared to these previous observations, again, the strength of the present observation is that that there is no difference in performance between the patient and the controls in the present paradigm, only a qualitative difference. Moreover, the patient was presented with faces in full view here, not partially masked or revealed through a gaze-contingency mask or window. Thus, acquired prosopagnosia also appears to be associated with a reduction of the perceptual field of view to one face part at a time, even for upright faces.

In conclusion, our observations provide evidence that the perceptual field of view depends on the availability of internal representations, or *perceptual knowledge* (Gregory, 1997; Helmholtz, 1866): all other parameters being equal, the perceptual field is larger for experienced upright than inverted faces in normal observers. The perceptual field also appears limited to a single face part in a patient who has lost her knowledge of individual face representations following brain damage. Since holistic/configural perception is at the heart of our expertise in face processing (Farah et al., 1998; McKone, Martini, & Nakayama, 2003; Rossion, 2013), that it may partly account for changes in face processing abilities across development (Le Grand, Mondloch, Maurer, & Brent, 2014) and for differences between cases of congenital/developmental prosopagnosia and typically developing observers (Avidan, Tanzer, & Behrmann, 2011; DeGutis, Cohan, Mercado, Wilmer, & Nakayama, 2012), the present approach may prove highly valuable in future studies.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2014.11.037.

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