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Faces as objects of non-expertise: Processing of thatcherised faces in congenital prosopagnosia

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Abstract. Congenital prosopagnosia (cPA) is a severe disorder in recognising familiar faces, a human characteristic that is presumably innate, without any macro-spatial brain anomalies. Following the idea that cPA is based on deficits of configural face processing, we used a speeded grotesqueness decision task with thatcherised faces, since the Thatcher illusion can serve as a test of configural disruption (Lewis and Johnston, 1997 *Perception* **26** 225 – 227). The time needed to report the grotesqueness of a face in relation to orientation showed dissociate patterns between a group of fourteen people with cPA and a group of matched controls: whereas the RTs of controls followed a strong sigmoid function depending on rotation from the upright orientation, the RTs of people with cPA showed a much weaker sigmoid trend approaching a linear function. The latter result is interpreted as a diagnostic sign of impaired configural processing, being the primary cause of the absence of 'face expertise' in prosopagnosia.

1 Introduction

Under normal circumstances, humans are remarkably accurate and fast at identifying faces of their own species. Humans can identify faces after a presentation time of only 26 ms (Carbon and Leder 2005; Carbon et al 2005) or after a time period of 50 years (Bahrick et al 1975), and detect micro-spatial alterations below the perceptual threshold for ordinary objects (Bruce et al 1991). This has led to the idea that face processing is an outstanding human ability ('face expertise') (Diamond and Carey 1986; Schwaninger et al 2003), which is strongly based on configural processing (Leder and Carbon 2006; Maurer et al 2002) as well as 3-D processing (Carbon and Leder 2006). While the general face-recognition ability is present at birth (eg Bushnell et al 1989), the maturation of face expertise is assumed to require about 10 years of experience (Diamond and Carey 1977; Geldart et al 2002).

1.1 *Prosopagnosia*

Some people, though, suffer from a markedly reduced visual face-learning and recognition ability, a condition which is known as prosopagnosia (Bodamer 1947). In acquired prosopagnosia, neural tissue damage disrupts the previously normal face-recognition ability. In developmental or congenital prosopagnosia (cPA),[1] the defect is inborn and in many cases inherited (Grüter and Grüter 2007; Kennerknecht et al 2006; see also Schwarzer et al 2006). While each case of acquired prosopagnosia with a unique pattern of disabilities accompanies the face-recognition problem, cPA has been shown to be a rather well defined entity without further severe cognitive deficits (Behrmann et al 2005; Kress and Daum 2003).

[1] We use the term congenital prosopagnosia (cPA) instead of developmental prosopagnosia (DP) throughout this paper, as this term indicates more clearly that our prosopagnosic participants have suffered from face-recognition problems since birth or early childhood (cf Behrmann et al 2005).

People suffering from this disorder report very similar clinical symptoms (Kennerknecht et al 2006) although the recognition of facial emotion is unimpaired (Humphreys 2006). In addition to the core deficit of face learning and recognition, cPA has been shown to be characterised by a facial-imagery deficit (Grüter and Grüter 2007) and a specific impairment in configural face processing (Duchaine 2000; Le Grand et al 2003a) or even a global impairment in configural processing (Behrmann et al 2005). Several publications suggest that face expertise forms mainly for upright faces and is based on configural (Leder and Carbon 2006; Le Grand et al 2003b; Mondloch et al 2002) and holistic processing (Leder and Carbon 2005, 2006; Tanaka and Farah 1993). Through many years of practice, the normal human face-recognition system improves steadily, but also becomes more constrained to the 'normal' upright orientation (Schwaninger et al 2003). The severe configural face-processing impairment in cPA might stretch the acquisition of face expertise over a period which spans more than a lifetime, a hypothesis, that to our knowledge has not yet been tested.

1.2 *The Thatcher illusion*

If this is true, we should see a lack of upright-face recognition preference in people with cPA. In this paper, we present an experimental setting based on the so-called 'Thatcher illusion' (Thompson 1980) to test this hypothesis. The Thatcher illusion originates from the dissociative perception of upright and inverted thatcherised faces, which are constructed by turning eyes and mouth of a face in a photograph upside down (180°). Whereas an inverted thatcherised face is hardly identifiable as being manipulated, the upright version immediately looks distorted and grotesque (Carbon and Leder 2005). In an inverted presentation, configural processing is assumed to be disrupted (Bertin and Bhatt 2004; Carbon and Leder 2005; Lewis 2001); only featural aspects are being processed, creating the illusion of an undistorted face (Carbon et al 2005). This makes systematically rotated thatcherised faces a reliable indicator for the amount of configural processing at a certain angle of view (Lewis and Johnston 1997).

1.3 *Mental rotation*

Recognising visual objects rotated out of their canonical angles is assumed to employ a mental rotation mechanism (Heil et al 1998; Shepard and Metzler 1971). Recognition delay was found to be a linear function of the rotation angle (Shepard and Metzler 1971) for objects of non-expertise (eg novel objects, mirrored letters, etc). For objects of expertise, though, Cooper and Shepard (1973) found a different relation: reaction time (RT) increased slowly for small deviations from the canonical angle, and then sharply at higher rotational angles.

Koriat and Norman (1985) confirmed these results, and proposed that extensive practice, high familiarity, and consequently expertise with a visual stimulus result in a broadly tuned (orientation tolerant) memory representation. This would allow direct recognition without the need for mental rotation over a wide range of stimulus orientations. Face expertise should allow direct recognition in a range around the perfect upright orientation (Edmonds and Lewis 2007), which is the most frequently perceived one (Schwaninger et al 2003). Valentine and Bruce (1988) investigated RT data for a face-recognition task with varying facial expressions as well as for an expression–decision task. They found that the RT shows a linear dependence on the rotational angle, but, as figure 1 shows, a regression to a sigmoid function would be a better fit for their data (cf Stevenage and Osborne 2006). This would be in accordance with the assumption that faces are objects of expertise.

1.4 *Sigmoid function*

As competitive sigmoid fitting function, the Fermi–Dirac function (equation 1), was utilised, since this function is a more general form of the typical nonlinear transfer

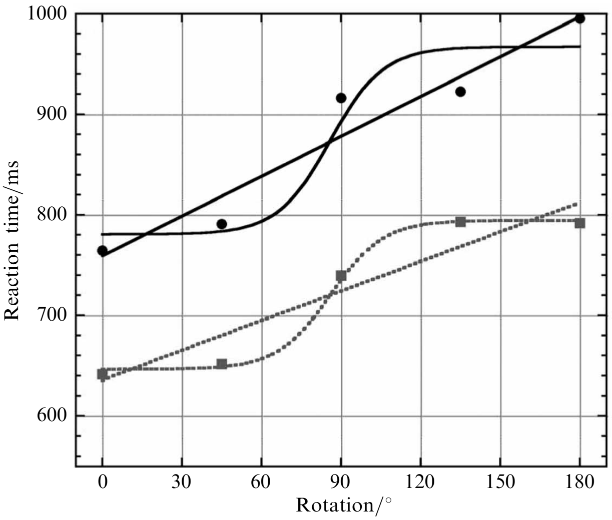


Figure 1. A re-analysis of the original data from Valentine and Bruce (1988). The solid black line shows the so-called diff expr (faces with different expressions) data; the dotted line shows the so-called same expr data (faces with same expressions). The same expr data fit nicely a sigmoid function ($R^2 = 0.997$), here given by the Fermi–Dirac function (see details in the methods section), whereas the linear function does not seem to be the most preferable fit to the data.

functions used for neural networks (Amit 1989). It requires three fixed parameters (RT_{max}, RT_{min}, μ), a steepness parameter (δ), plus the variable parameter (x) of the angular difference from 0°. We fixed RT_{min} with RT_{0° (canonical angle for faces), and RT_{max} with RT_{180°. The parameter μ, which determines the inflection point of the function, was set to the empirically found changeover point where the perception of thatcherised faces changes from pleasant to grotesque. Stürzel and Spillmann (2000) identified the changeover range between 94° and 100° with an averaged changeover point of 97.7°; therefore we fixed μ at 97.7°. The steepness parameter δ was used for curve fitting.

$$RT(x) = RT_{max} - \frac{RT_{max} - RT_{min}}{e^{(x-\mu)/\delta} + 1}; \text{ defined range: } 0^\circ \leqslant x \leqslant 180^\circ \qquad (1)$$

$$RT_{max} = RT_{180^\circ}; RT_{min} = RT_{0^\circ}; \ \mu = \text{inflection point}; \ \delta = \text{slope}.$$

1.5 *The present study*

We investigated whether the amount of configural processing is reduced in a group of fourteen people with cPA by using a speeded grotesqueness decision task with thatcherised faces. Control participants are expected to follow a clear sigmoid function in terms of reaction times versus rotational angle. People with cPA, whose face processing has been strongly impaired from birth, are assumed not to be 'face experts' and should mentally rotate faces like other objects of non-expertise. Their RTs should follow a much weaker sigmoid function with a strong trend of linear dependence on the angular difference from the upright orientation. We tested RT effects by using a speeded grotesqueness decision task with thatcherised faces, as the Thatcher illusion can serve as a test of configural processing (Lewis and Johnston 1997).

2 Experiment

2.1 *Method*

2.1.1 *Participants.* Fourteen individuals (eleven female) with cPA (mean age 34.6 years) participated in the study. The controls were fourteen participants (eleven female) with a similar mean age of 31.1 years. All participants had normal or corrected-to-normal vision and were not familiar with the Thatcher illusion.

All people with cPA reported medium to severe deficits in recognising familiar faces in everyday life from early childhood on. The clinical symptoms were established by means of a standardised semistructured interview on prosopagnosia (Grüter 2004; Grüter et al, in press). The participants were asked to perform a paper-and-pencil test with 20 famous persons, for whom they had to evaluate the faces and names in separate tests. All face-specific tests placed the people with congenital prosopagnosia clearly behind the control group (face familiarity: 8.1/20 versus 16.9/20, $t_{26} = 6.9$, $p < 0.0001$, $\eta_p^2 = 0.65$; face recognition: 6.4/20 versus 15.2/20, $t_{26} = 7.1$, $p < 0.0001$, $\eta_p^2 = 0.66$; face imagery: 4.6/20 versus 17.2/20, $t_{26} = 9.3$, $p < 0.0001$, $\eta_p^2 = 0.77$). However, they had no general deficit in recognising familiar persons as indicated by their high performance of recognising familiar names (19.1/20 versus 19.8/20, $t_{26} = 1.4$, ns). To exclude a more general central visual processing deficit, we investigated the participants' ability to identify non-face objects with subtest 2 (silhouettes), subtest 3 (object decision), and subtest 4 (progressive silhouettes) of the Visual Object and Space Perception (VOSP) test battery. The ability of the subjects with cPA to identify objects in general was found to be not impaired as indicated by nonsignificant differences between their VOSP scores and those of same-age controls (silhouettes: $t_{26} < 1$, ns; object decision: $t_{26} < 1$, ns; progressive silhouettes: $t_{26} < 1$, ns).

As none of the participants with cPA reported any history of severe head injuries, incidents of severe hypoxia, epilepsy, stroke, autism spectrum disorders, or psychiatric diseases, the face-processing deficits were categorised as due to cPA.

2.1.2 *Apparatus and stimuli.* As stimuli, we used frontal photographs of Claudia Schiffer, Princess Diana, Gwyneth Paltrow, and Pamela Anderson covering the faces from the top of the hair to the bottom of the chin (220 × 220 pixels, 32767 colours, example in figure 2). Any resulting edges of the thatcherised versions were smoothed to remove graphical inconsistencies of the pictures.

Figure 2. Selection of stimuli based on a photograph of Princess Diana; from left to right: original full, thatcherised full, original inner, and thatcherised inner versions.

The images were rotated counterclockwise in steps of 30° from 0° (upright) to 180° (inverted) for the original versions as well as for their thatcherised versions. Two versions of each photograph were shown: a 'full' version (the full face) and an 'inner' version. The inner version was constructed by masking out the outer parts of the faces (hair and ears) with a standard oval mask. This inner version was used following the advice of Behrmann and Avidan (2005) who pointed out that people with prosopagnosia are adept at using salient facial features (eg the hairstyle) and may even perform unobtrusively in face-processing tasks if given enough time. In sum, there were 4 [faces] × 2 [class: thatcherised versus normal] × 2 [size: full versus inner] × 7 [rotation: 0°, 30°, 60°, 90°, 120°, 150°, 180°] = 112 different stimuli; all of these were used in a within-subjects design.

2.1.3 *Procedure.* The experiment was conducted on a Macintosh Emac-1000 (MacOs 9.2.2) with a 17 inch CRT screen (1024 × 768 pixels at 75 Hz) and controlled by the experimentation software PsyScope PPC 1.25 (Cohen et al 1993). The distance between participants' eyes and the computer screen was about 65 cm resulting in a visual angle of the target of about 6.5 deg.

Each stimulus presentation started with the question: "Is the following picture grotesque or not?" After this, the screen went blank (500 ms) and a fixation cross appeared in the centre of the screen for 200 ms, followed by another blank screen (500 ms). Then the photograph was presented, either for 80 ms (short presentation time) or for 500 ms (long presentation time). Rather short presentation times were used to minimise artificial-recognition strategies that cover face-processing deficits (see Behrmann and Avidan 2005). The participants were instructed to answer as fast and accurately as possible by pressing the left ('x') or right ('m') key. The assignment of the keys was counterbalanced across the participants.

The presentation was split into four blocks, separated by 2 min breaks. Stimuli were presented in a randomised order over all blocks. Five extra stimuli at the beginning of each block showed randomly selected stimuli. They were used for practicing purposes and were excluded from further analyses.

2.2 *Results and discussion*

Controls as well as participants with cPA reported that they got used to the experimental task very quickly, although they had difficulties in recognising the faces in the first trials. In the following, the participants' data were first analysed in terms of grotesqueness ratings and then with regard to their RTs.

2.2.1 *Grotesque or not grotesque?* As correct answers we considered the classification of a thatcherised face as grotesque and of a normal face as not grotesque. Figure 3 shows the percentage of correct classifications in dependence on the rotation for both face classes (thatcherised versus original) by the experimental groups (people with cPA and control subjects).

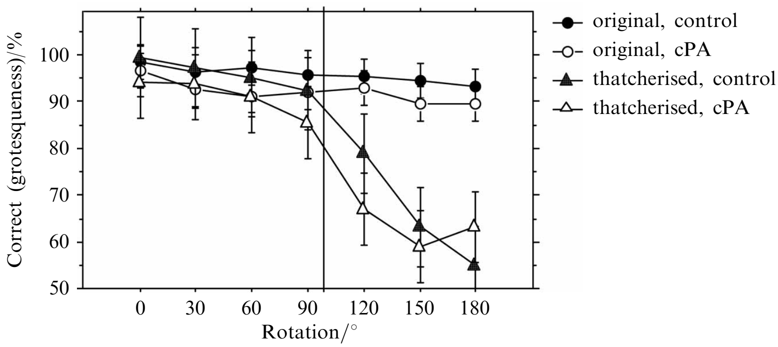


Figure 3. Percentage of correctly evaluated grotesqueness of faces for rotation from upright, split by class and group. The vertical line indicates the empirically found changeover point by Stürzel and Spillmann (2000) in evaluating a thatcherised face as being odd. The error bars show 95% confidence intervals for within-subjects designs according to Loftus and Masson (1994).

Participants performed very well in evaluating the grotesqueness of original faces, relatively independently of the degree of rotation. For the thatcherised faces the error rate increased slowly with angular deviation from 0° to 90° and then sharply to 180°. Although the performance curves for people with cPA and controls were very similar for rotations between 0° and 90°, there was a different trend for rotations between 120° and 180°, which we will focus on in an additional analysis.

The grotesqueness evaluations were analysed by a five-way mixed-design ANOVA with group (cPA versus control) as between-subjects factor and class, size, rotation, and presentation time as within-subjects factors. As there were no interactions between size and group and between presentation time and group nor main effects of size and presentation time, we sampled the data of both sizes and presentation times in a second mixed-design ANOVA in order to improve the readability of the results.

Such a three-way mixed-design ANOVA with group (cPA versus control) as between-subjects factor and class and rotation as within-subjects factors revealed main effects of class ($F_{1,26} = 15.92$, $p < 0.001$, $\eta_p^2 = 0.380$) and rotation ($F_{6,156} = 36.44$, $p < 0.001$, $\eta_p^2 = 0.584$). There was also an interaction between class and rotation ($F_{6,156} = 19.93$, $p < 0.001$, $\eta_p^2 = 0.434$). Analysis of simple main effects revealed that participants' performance decreased with increasing rotation significantly for thatcherised faces ($F_{6,21} = 8.70$, $p < 0.001$, $\eta_p^2 = 0.713$) but only as a trend for original faces ($F_{6,21} = 2.31$, $p = 0.072$, ns).

The progressive decline of the curve for thatcherised faces from about 90° onward demonstrated a sudden changeover from grotesque to nongrotesque (cf Lewis 2001; Stürzel and Spillmann 2000; Thompson 1980). From rotations of 120° onward, result patterns differed between the groups. An additional three-way mixed-design ANOVA with group as between-subjects factor and class and rotation$_{120°-180°}$ (120°, 150°, 180°) revealed main effects of class ($F_{1,26} = 23.65$, $p < 0.001$, $\eta_p^2 = 0.476$), and rotation$_{120°-180°}$ ($F_{2,52} = 13.46$, $p < 0.001$, $\eta_p^2 = 0.341$), an interaction between class and rotation$_{120°-180°}$ ($F_{2,52} = 4.82$, $p = 0.012$, $\eta_p^2 = 0.156$), and between group, class, and rotation$_{120°-180°}$ ($F_{2,52} = 3.82$, $p = 0.028$, $\eta_p^2 = 0.128$). Analysis of simple main effects of rotation for thatcherised faces showed that performance decreased with increasing rotation significantly for controls ($F_{2,25} = 17.39$, $p < 0.001$, $\eta_p^2 = 0.582$), but not for people with cPA ($F_{2,25} = 1.47$, $p = 0.249$, ns). For normal faces, the rotational angle had no significant effect on the error rate. Both groups classified most of them correctly at all angles (figure 3).

2.2.2 *Reaction times.* The increase of the RTs with the rotational angle follows a pronounced sigmoid function in the control group, whereas the distribution of RTs for the cPA group follows a nearly linear relation (figure 4). For curve fitting, we used the Fermi–Dirac function as described above [see equation (1)].

The averaged data of the people with cPA followed obviously a more strongly linear trend ($R^2 = 0.96$) than the reaction times of the controls ($R^2 = 0.87$).(2)

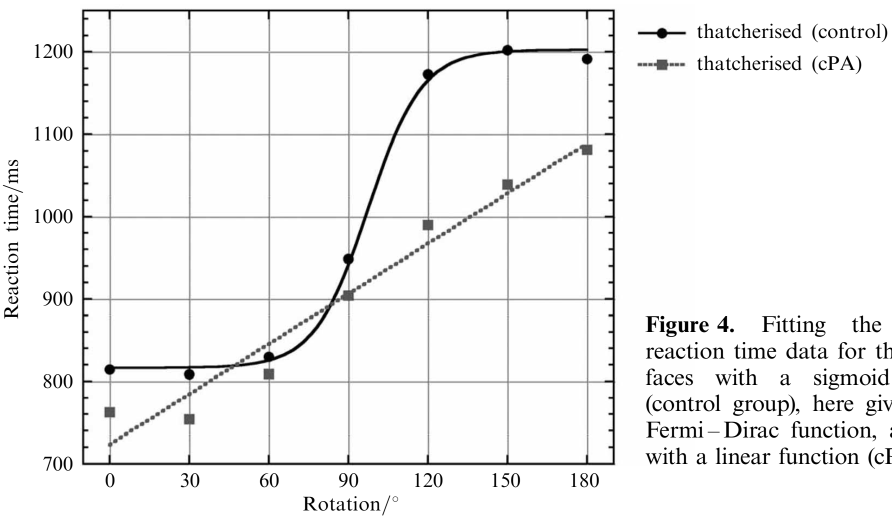


Figure 4. Fitting the averaged reaction time data for thatcherised faces with a sigmoid function (control group), here given by the Fermi–Dirac function, as well as with a linear function (cPA group).

(2) Although both curve fits are reasonably high, these fits have to be interpreted cautiously owing to the relative low number of (seven) to-be-fitted points. In contrast, the Fermi–Dirac function revealed a nearly perfect fit for the data of the controls ($R^2 = 0.998$), which was much better than the linear fit.

We replicated these group-level analyses by employing additional analyses on the individual data. This was done by fitting the individual RT data to Fermi – Dirac functions with the same fixed parameters as above, as well as by fitting the data to linear functions. As shown in figure 5, the data of the controls followed a more sigmoid trend than the data of people with cPA.

To analyse statistically whether the two experimental groups differed in the sigmoidity of the curve fits, we used the slopes [δ; see equation (1)] of the individual curve fits as dependent variables in an unpaired t-test. Indeed, the curve fits for the controls showed significantly steeper slopes than the curve fits for people with prosopagnosia ($t_{26} = 2.16$, $p = 0.0201$, $\eta_p^2 = 0.15$).

Thus, we could show not only a stronger sigmoid trend for the group level data of the control group, but also for the individual level data. These findings appear to confirm the assumption that people with cPA have a configural face-processing deficit and process faces as objects of non-expertise.

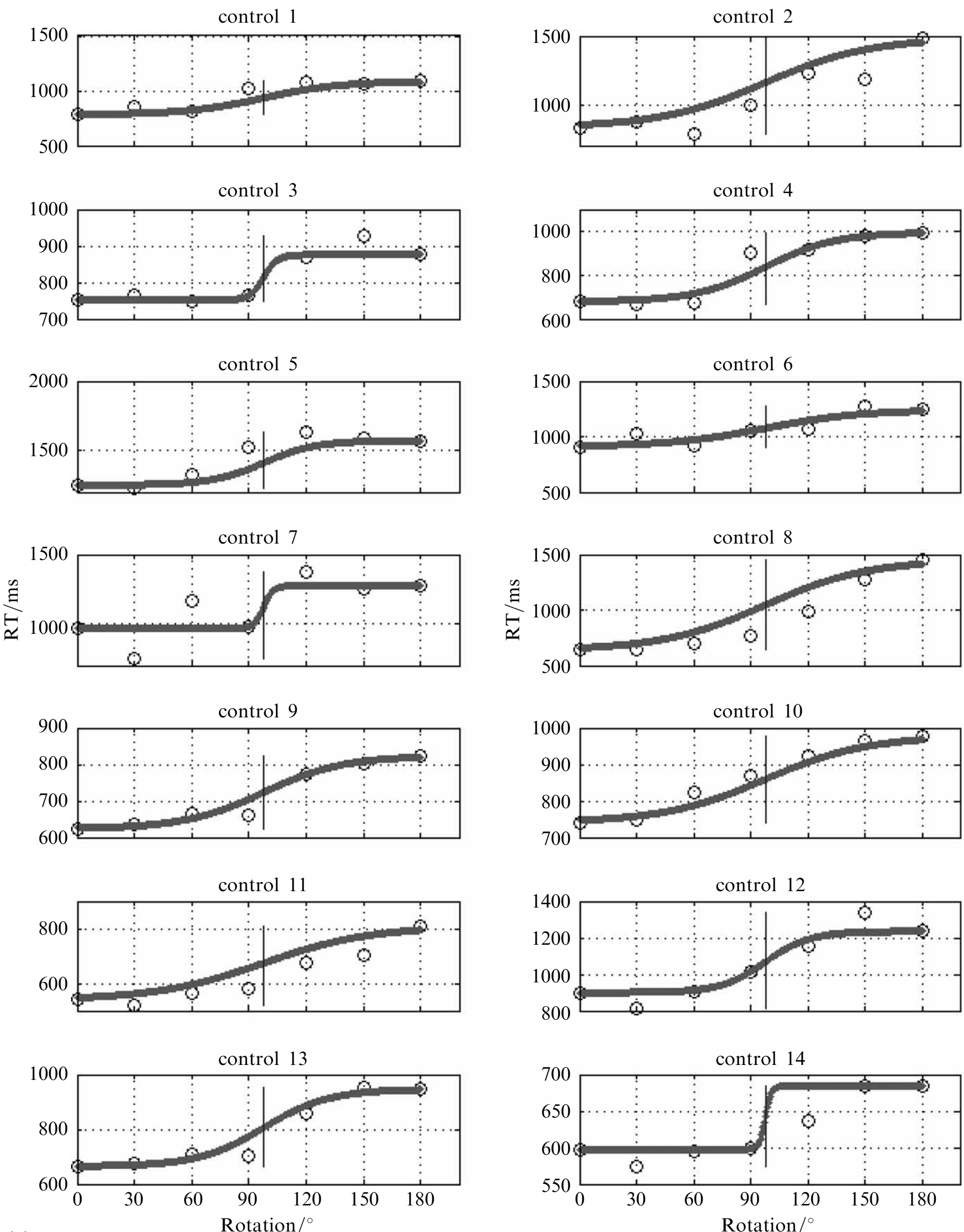
3 General discussion

We investigated the configural processing of faces by employing a speeded grotesqueness decision task with thatcherised faces (Thompson 1980), comparing people with congenital prosopagnosia (cPA) with matched control participants. The group with cPA, although performing at a high level, processed faces as objects of non-expertise, whereas controls show a disruption of configural processing at higher rotational angles that is typically expected for objects of expertise.

This does not imply that people with cPA need more time for simple face-processing tasks; on the contrary, they showed shorter RTs when they had to decide whether a face was grotesque or not. Perhaps their face processing follows a simpler routine than that of controls, which is based on specialised face-processing strategies.

While both groups correctly classified most normal and thatcherised faces up to an angle of 90°, their performance differed at greater angles. In the cPA group the number of errors increased sharply at 120° and stayed at a high level, whereas the controls showed a monotonous increase of errors as a function of the rotational angle. This is evidence of increased analytical processing in which faces were not processed holistically, but parts of the faces were analysed (Carbon and Leder 2005; Schwaninger et al 2003).

The RTs of people with cPA for decisions of grotesqueness of thatcherised faces followed a different trend than the RTs of the control participants. Whereas the RTs of controls followed a pronounced sigmoid function, this sigmoidity could only rudimentarily be seen in the RTs of the group with cPA. The RT-function for the group with prosopagnosia is better described as following a nearly linear trend, which indicates only a single underlying cognitive mechanism (Bruyer et al 1993). Bruyer et al have interpreted such nonlinear functions, especially like the RT data of the control participants, as reflecting complex processing involving at least two different kinds of cognitive mechanisms (eg featural and configural processing—cf Carbon et al 2005; Rakover 2002). As we have also found a residual sigmoidity for the group with cPA, it seems plausible that there is residual capacity of configural processing in prosopagnosics. Furthermore, Cooper and Shepard (1973) have demonstrated that objects of expertise follow a function that is robust against deviations from optimal upright orientation. This is also in accordance with the data for the controls. We interpret this finding as straightforwardly as possible: being ‘face experts’, normal subjects use a mixture of cognitive strategies for processing faces (eg featural plus configural processing—Carbon and Leder 2005), whereas prosopagnosics process faces predominantly with rather simple and non-face-specific strategies (eg featural processing—Stürzel and

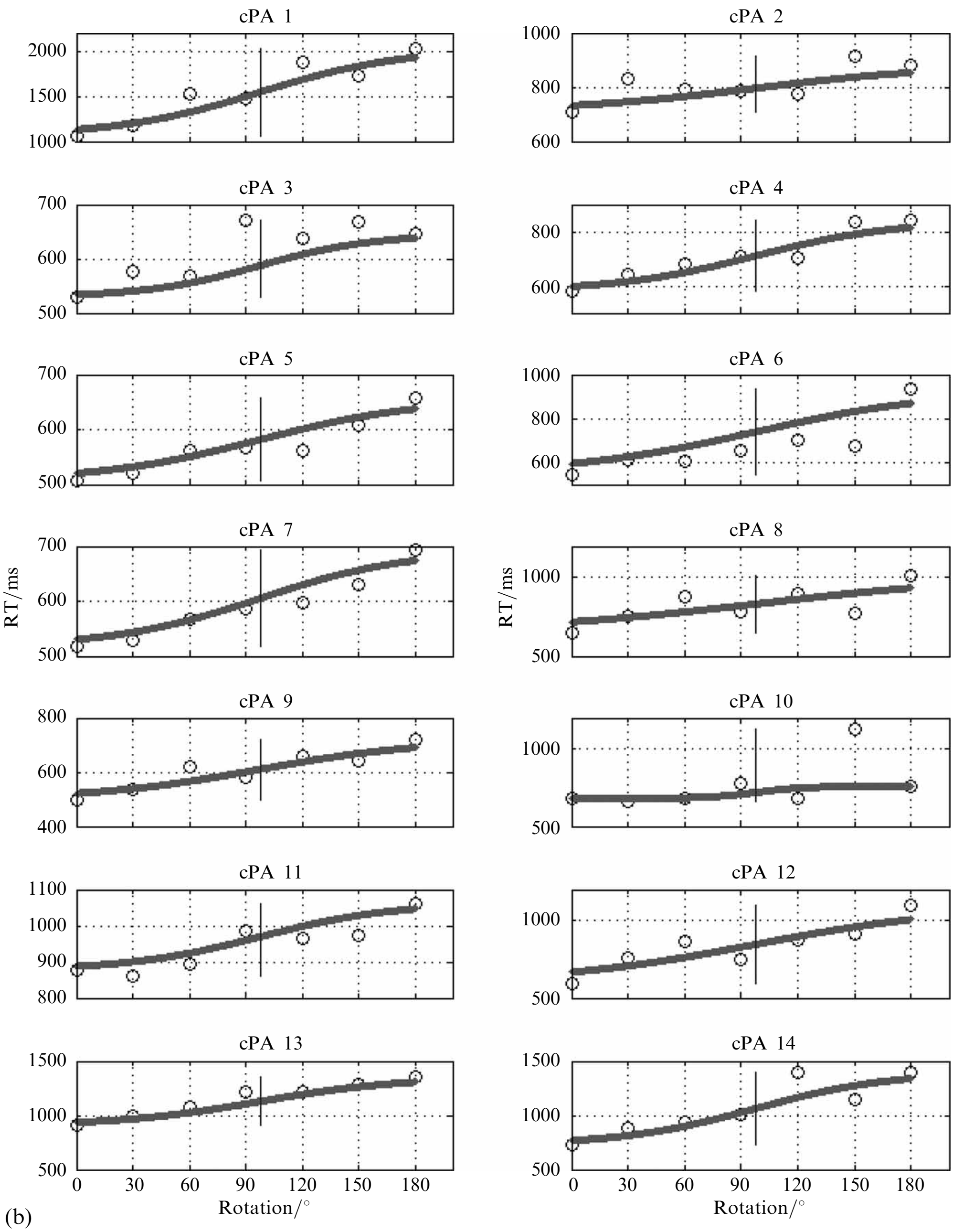


(a)

Figure 5. Curve fits of the Fermi – Dirac function for the individuals' reaction-time (RT) data. (a) Fits for the controls; (b) fits for people with congenital prosopagnosia. The vertical line shows the assumed changeover point where the perception of thatcherised faces changes from pleasant to grotesque (Stürzel and Spillmann 2000).

Spillmann 2000). In short: the hallmark of being prosopagnosic is that faces are processed as objects of non-expertise.

It has been shown that the development of face expertise takes about 10 years (Diamond and Carey 1986) and that early impairments of vision, like a cataract at birth, may lead to a life-long decrease of face-recognition ability (Geldart et al 2002). In our study, we have shown that people with cPA do not develop normal face expertise.



(b)

Figure 5 (continued)

Perhaps the configural face-processing deficit, as demonstrated by Le Grand and colleagues (2003a) or Behrmann and Avidan (2005), may slow down face learning to such a degree that a lifetime is not enough to acquire this expertise.

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