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Mapping Self-Face Recognition Strategies in Congenital Prosopagnosia

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Objective: Recent evidence showed that individuals with congenital face processing impairment (congenital prosopagnosia [CP]) are highly accurate when they have to recognize their own face (self-face advantage) in an implicit matching task, with a preference for the right-half of the self-face (right perceptual bias). Yet the perceptual strategies underlying this advantage are unclear. Here, we aimed to verify whether both the self-face advantage and the right perceptual bias emerge in an explicit task, and whether those effects are linked to a different scanning strategy between the self-face and unfamiliar faces. ***Method:*** Eye movements were recorded from 7 CPs and 13 controls, during a self/other discrimination task of stimuli depicting the self-face and another unfamiliar face, presented upright and inverted. ***Results:*** Individuals with CP and controls differed significantly in how they explored faces. In particular, compared with controls, CPs used a distinct eye movement sampling strategy for processing inverted faces, by deploying significantly more fixations toward the nose and mouth areas, which resulted in more efficient recognition. Moreover, the results confirmed the presence of a self-face advantage in both groups, but the eye movement analyses failed to reveal any differences in the exploration of the self-face compared with the unfamiliar face. Finally, no bias toward the right-half of the self-face was found. ***Conclusions:*** Our data suggest that the self-face advantage emerges both in implicit and explicit recognition tasks in CPs as much as in good recognizers, and it is not linked to any specific visual exploration strategies.

General Scientific Summary
Individuals with face recognition impairment from birth (i.e., congenital prosopagnosia) show normal accuracy when they have to recognize their own face (self-face advantage) both in implicit and explicit identification tasks. In particular, this advantage does not depend on any specific visual exploration strategies and it seems more likely related to a general self-recognition mechanism, which allows them to overcome their deficit at least in the case of one's own face.

Keywords: congenital prosopagnosia, self-face recognition, face inversion, eye movements

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The term "prosopagnosia" refers to a selective deficit affecting the recognition of both familiar and unfamiliar people by using face information alone (Bodamer, 1947). This impairment has been primarily described in individuals who have sustained cortical lesions in adulthood, often as a consequence of head trauma or stroke. In its acquired form (acquired prosopagnosia), the face recognition deficit is attributed to a lesion in the ventral occipito-temporal cortex, limited to the right hemisphere (De Renzi & di Pellegrino, 1998) or bilateral (Sergent & Signoret, 1992), and it is usually perceived by the patients as they start to encounter some unexpected difficulties in recognizing familiar people after the trauma. Congenital Prosopagnosia (CP; also known as "developmental prosopagnosia," e.g., Susilo & Duchaine, 2013) instead refers to a face-processing impairment that is present at birth in the

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absence of brain damage and in the presence of preserved sensory and intellectual functions (Ariel & Sadeh, 1996; McConachie, 1976; Schmalzl, Palermo, Green, Brunsdon, & Coltheart, 2008). In accordance with previous evidence suggesting a genetic contribution to the impairment (Grüter, Grüter, & Carbon, 2008; Kennerknecht et al., 2006), recent preliminary findings indicate that CP could be associated with the DNA polymorphism of the receptor gene of oxytocin (a hormone that regulates basic social and reproductive behaviors; Cattaneo et al., 2016). On the contrary of acquired prosopagnosics, individuals with CP are often not even aware of their impairment because face perception was never normal in the lifetime of these individuals (Behrmann & Avidan, 2005), so that they are not able to compare their actual face recognition abilities with previously normal abilities. Furthermore, congenital prosopagnosics have had the opportunity to develop different compensatory strategies in their lifetime, so that they are often able to recognize people by using different types of cues, such aphysiognomic cues (e.g., clothing, posture, and style of walking) or acoustic cues (e.g., voice; Palermo et al., 2011).

Despite some heterogeneity in CP, most studies agree that there is a relationship between the face recognition impairment of this population and their anomalous scan path behavior during the exploration of faces (Schmalzl et al., 2008; Schwarzer et al., 2007). Although good recognizers focus their gaze primarily on central facial features, suggesting that these regions are the most informative regions in a human face (Hsiao & Cottrell, 2008; Peterson & Eckstein, 2012; Schmalzl et al., 2008; Schwarzer et al., 2007), individuals with CP tend to show a more dispersed gaze, directing their attention not only on central features but also on external features with both unfamiliar and famous faces (Barton, Radcliffe, Cherkasova, & Edelman, 2007; Schmalzl et al., 2008; Schwarzer et al., 2007). Furthermore, congenital prosopagnosics typically show no or weaker familiarity modulation in their scan path behavior: Whereas good recognizers use fewer fixations and less viewing time to identify famous faces compared with unfamiliar faces, individuals with CP typically use a similar number of fixations and viewing time in exploring both unfamiliar and famous faces (Barton et al., 2007; Schmalzl et al., 2008; Schwarzer et al., 2007). As a possible explanation for this behavior, it has been suggested that the lack of a familiarity modulation in congenital prosopagnosics' eye movements could be related to the absence of residual facial memories or internal viewing schema in these individuals (Barton et al., 2007; Lê, Raufaste, & Démonet, 2003; Schmalzl et al., 2008), because they never developed normal face recognition abilities.

Thus, previous findings seem to support the idea that, along with the inability to recognize familiar and unfamiliar faces and the presence of an anomalous scan path behavior, individuals with CP explore every face in the same way, independently of whether the face is familiar (or famous) to them or not. However, recent findings have demonstrated that despite their face recognition impairment, congenital prosopagnosics (Malaspina, Albonico & Daini, 2016) achieve considerable accuracy when they have to recognize their own face. Similarly, one study on an acquired prosopagnosic patient showed preserved trait inferencing from the self-face but not from familiar faces (Klein, Gabriel, Gangi, & Robertson, 2008). These results seem consistent with previous evidence in healthy controls suggesting that we have specific knowledge for the self, and that the processing of self-information is distinct from the processing of other-information (Frassinetti, Ferri, Maini, Benassi, & Gallese, 2011; Kircher et al., 2000). In particular, the existence of a specific advantage for the self-face (i.e., the self-face advantage [SFA]) has already been proven, and it consists of faster response times (RTs) when participants have to recognize their own face compared with unfamiliar or familiar faces (Ma & Han, 2010; Sugiura et al., 2005). This advantage also seems to be present with both upright and inverted faces (Keyes & Brady, 2010), despite the difficulty that characterizes the recognition of the latter ones because of the unusual orientation of presentation (i.e., the face inversion effect (IE), which consists of better performance for upright compared with inverted faces; e.g., Farah, Wilson, Drain, & Tanaka, 1995).

As further proof of the specificity of the self-face, although the recognition of familiar and unfamiliar faces seems characterized by a tendency to visually process the hemi-face that falls in the observer's left visual hemi-space (i.e., a left perceptual bias), self-face recognition seems to be related to the opposite bias. Both good recognizers and individuals with CP, indeed, tend to rely more on the right half-side of their face (i.e., a right perceptual bias), which falls in the right visual hemi-space looking at the mirror, when they are asked to recognize themselves (Brady, Campbell, & Flaherty, 2004; Malaspina et al., 2016), thus suggesting the existence of an asymmetry in the perception of the self-face, and that the SFA might be related to a preference for the right-half of the self-face. However, the possibility that the right perceptual bias could be detected also in terms of eye movements has still to be determined.

The first aim of the present studies was to investigate whether the SFA showed by good recognizers and individuals with CP during self-face recognition is also reflected in their scan path behavior. For this reason, we recruited a group of congenital prosopagnosics and healthy controls who underwent a simple recognition task involving different facial stimuli depicting the participant's self-face and another unfamiliar face. We wanted to compare the eye movements made by the two groups on these two types of stimuli and investigate whether the SFA is detectable also as a change in gaze behavior. Moreover, because the existing study showing the advantage in the congenital prosopagnosic population used an indirect task (Malaspina et al., 2016), here, by means of a direct task, "me/not me," we tested whether these individuals also still show the same advantage when asked to consciously identify themselves. In particular, in this case, the use of both eye movement and behavioral measurements could allow us to obtain information on both the online visual processing of the stimulus as well as on the resulting outcome. Eye movements can give us information about how the efficiency and distribution of gaze control affect the perception (and recognition) of a stimulus (Bloom & Mudd, 1991), and provide insights into how prosopagnosic individuals process the information in faces (Barton et al., 2007). Finally, because the advantage for the self-face has been demonstrated with both upright and inverted faces (Keyes & Brady, 2010), here, we decided to test both orientations of presentation as well.

Finally, we asked whether the rightward bias characterizing "indirect" self-face perception is also detectable in a "direct" task, and whether it is linked to a different visual exploration of the two halves of the facial stimulus. Thus, we used chimeric stimuli created from the original picture of the face of each participant (i.e., a composite face made of two right half-faces and a composite face made of two left half-faces) in addition to the original face and mirror-reversed face. In particular, we would expect the right perceptual bias to be present and reflected in an increased visual exploration of the right self-hemi-face, independently of its position in the visual field.

Method

Participant Selection

A total of 38 participants (recruited as described in the next section) took part in the experiment. All participants had normal or corrected-to-normal vision, and each of them received course credits for participation in two 1-hr sessions. An informed consent form for the processing of personal data and for the use of their photographs was obtained from all participants before testing, and the ethical approval for this study was specifically granted by the Ethics Committee of the University of Milano-Bicocca.

Control participants. In order to select individuals with no face recognition difficulties, 31 undergraduate students of the University of Milano-Bicocca (all females, right-handed, age range = 19–27 years, mean age = 22.23 ± 2.43) were recruited through the Milano-Bicocca Sona System and underwent a battery of tests assessing face and object recognition (see below).

After the screening phase, on the basis of the participants' agreement to come back to undergo the second part of the study (because participants were receiving course credit for their participation, roughly half of them did not return for the second part of the experiment, as they had already completed their course requirement), 13 of the initial group of 31 participants returned for the main experiment and served as the final control group for the experimental phase (CG group; all females, right-handed, age range = 19–23 years, mean age = 21.46 ± 1.56). None of them experienced face recognition difficulties during their lives.

Congenital prosopagnosics. Seven females (all right-handed, age range = 20–25 years, mean age = 21.23 ± 1.89) with CP took part in this study and composed our experimental group (CP group). They were recalled from previous studies (Cattaneo et al., 2016; Malaspina et al., 2016; Malaspina, Albonico, Toneatto & Daini, 2017) because of their verified impairments in recognizing unfamiliar and familiar faces. Furthermore, all these individuals showed a DNA polymorphism of the receptor gene of oxytocin in a previous study (Cattaneo et al., 2016), further confirming the diagnosis of the congenital form of the face recognition impairment.

As the controls, all the CP participants underwent a battery of tests investigating face and object recognition, and a semistructured interview conducted by an experienced neuropsychologist in order to assess the presence of CP and to exclude possible alternative explanations for face recognition impairment. All congenital prosopagnosics reported significant difficulty in recognizing people starting from face information alone and provided detailed examples about it. They also reported that they did not have any history of brain damage, that their impairment was present from birth and other common symptoms of prosopagnosia, as their strategy of relying on nonfacial cues to recognize the others.

Face and Object Recognition Abilities Assessment

All participants underwent a first screening session during which their face and object recognition abilities were assessed. In particular, our battery was composed of five tests: the Benton Facial Recognition Test (BFRT; Benton, 1994; Benton & Van Allen, 1968), the Cambridge Face Memory Test (CFMT; Duchaine & Nakayama, 2006), the Boston Naming Test (BNT; Kaplan, Goodglass, & Weintraub, 1983), a Famous Faces Recognition Test (FFRT), and a Famous Monuments Recognition Test (FMRT). These tests were selected to determine the presence of prosopagnosia by assessing participants' ability to recognize unfamiliar and familiar faces (i.e., BFRT, CFMT and FFRT, respectively), and their visual object recognition and general visual processing abilities (i.e., BNT, FMRT).

The CFMT (Duchaine & Nakayama, 2006) is one of the most commonly used tests for assessing prosopagnosia (Wilmer et al., 2012). It has been proven to be the most sensitive test for detecting face recognition impairment and to have impressive test–retest reliability (Bowles et al., 2009; Duchaine & Nakayama, 2004, 2006; Wilmer et al., 2010). In addition, we calculated an additional index from the CFMT: the IE (Yin, 1969). The IE is the difference between the total score of the upright and inverted faces (i.e., the "cost" for recognizing inverted faces) and was included as a further criterion of face recognition impairment because it represents a qualitative index of face processing, which is often not present or inverted in participants with prosopagnosia (e.g., Behrmann & Avidan, 2005). The BFRT (Benton, 1994; Benton & Van Allen, 1968) was included as part of the neuropsychological battery in order to investigate the perceptual aspects of face recognition in our participants, as some studies have suggested that some, but not all, individuals with CP can experience face discrimination difficulties in addition to face memory impairment (Ariel & Sadeh, 1996; de Gelder & Rouw, 2000). The FFRT was administered in order to assess participants' ability to identify famous people from their faces (see Malaspina et al., 2017 for more details). Lastly, participants also underwent two control tests on object recognition: an FMRT (described in Cattaneo et al., 2016), asking participants to name pictures of national and international monuments taken in their most conventional perspective (all pictures were taken from the Internet and labeled for reuse with modification), and the BNT (Kaplan et al., 1983), in order to assess each participant's visual object recognition and visual naming ability by using black-and-white line drawings.

The scores obtained in these tests by the 31 initial healthy participants who took part in the screening phase formed the sample for the calculation of z scores for the CP and CG participants. The mean scores for each test (± 1 SE) were as follows: 47.61 ± 3.12 for the BFRT, 58.29 ± 8.99 for the upright version of the CFMT, 43.39 ± 5.95 for the inverted version of the CFMT, 14.90 ± 6.44 for the IE, 31.39 ± 5.76 for the FFRT, 20.68 ± 5.42 for the FMRT, and 55.55 ± 3.13 for the BNT. In Table 1, the individual test scores for each congenital prosopagnosic and the z scores calculated for each individual CP against the data from the initial group of 31 participants are reported. In addition, to further confirm the presence of prosopagnosia in the CP group, our z scores were compared with the published control scores for this test (Duchaine & Nakayama, 2006).

Table 1
Demographic Details and Scores (Raw and z Scores) at the Tests Investigating Face and Nonface Object Recognition for the 7 Congenital Prosopagnosics (CP) and Average Score for the Control Group (CG)

Participant	Age	BFRT		CFMT Upright			CFMT Inverted		Inversion effect		FFRT		FMRT		BNT	
		Raw score	*z* score	Raw score	*z* score	*z* score (Duchaine & Nakayama, 2006)	Raw score	*z* score	Raw score	*z* score	Raw score	*z* score	Raw score	*z* score	Raw score	*z* score
A.D.	22	45	−.84	40	−2.03[a]	−2.14[a]	34	−1.58	6	−1.38	14	−3.02[a]	20	−.13	53	−.81
C.R.	25	40	−2.44[a]	36	−2.48[a]	−2.77[a]	30	−2.25[a]	6	−1.38	11	−3.53[a]	18	−.49	58	1.10
E.B.	20	40	−2.44[a]	36	−2.48[a]	−2.77[a]	35	−1.41	1	−2.16[a]	14	−3.02[a]	17	−.68	56	.46
G.M.	19	50	.77	37	−2.37[a]	−2.65[a]	31	−2.08[a]	6	−1.38	17	−2.50[a]	18	−.49	54	−.50
M.B.	19	47	−.20	34	−2.70[a]	−3.03[a]	37	−1.07	−3	−2.78[a]	18	−2.32[a]	27	1.17	58	1.10
R.B.	22	46	−.52	40	−2.03[a]	−2.27[a]	44	.10	−4	−2.93[a]	12	−3.37[a]	18	−.49	55	−.18
S.E.	20	46	−.52	37	−2.37[a]	−2.37[a]	44	.10	−7	−3.30[a]	18	−2.32[a]	24	.61	57	.78
CP mean ± *SD*		44.86 ± 3.67		37.14 ± 2.19			36.43 ± 5.68		.71 ± 5.47		14.86 ± 2.85		20.29 ± 3.77		55.86 ± 1.95	
CG mean ± *SD*		48.62 ± 2.99		65.62 ± 4.68			46.54 ± 3.71		19.08 ± 4.77		32.08 ± 5.95		20.85 ± 5.56		56.00 ± 2.20	

Note. BFRT = Benton Facial Recognition Test; CFMT = Cambridge Face Memory Test; FFRT = Famous Face Recognition Test; FMRT = Famous Monuments Recognition Test; BNT = Boston Naming Test.
[a] Pathological score.

All seven of the congenital prosopagnosics were impaired in face recognition; indeed, they all performed poorly (i.e., 2 *SD* below the mean of the control group) in the upright version of the CFMT (both considering our control sample and the published data of the controls from Duchaine & Nakayama, 2006) and the FFRT. Furthermore, all congenital prosopagnosics showed a smaller IE and, particularly, four of them had an IE score two standard deviations lower than controls. In the BFRT, only two of seven congenital prosopagnosics performed pathologically, consistently with other studies proving that some individuals with CP can experience difficulty with face discrimination in addition to face memory (Ariel & Sadeh, 1996; de Gelder & Rouw, 2000). Moreover, previous studies have also highlighted that individuals with prosopagnosia may achieve normal score on the BFRT, thanks to the availability of external cues in this test (Duchaine & Nakayama, 2004).

By contrast, in the tests investigating object recognition abilities (FMRT and BNT), all congenital prosopagnosics performed in the normal range, further confirming the selectivity of their impairment. None of the controls who agreed to come back for the second part of the study (13 females) showed any impaired performance in any tests.

Material and Stimuli

Apparatus and procedure. Participants sat in a comfortable chair approximately 57 cm from a Sony Trinitron monitor (27-in., 1920 × 1080 pixels, refresh rate of 120 Hz in 32-bit color) in a silent room and with their head stabilized with a chin and forehead rest. Participant's eye movements were monitored at a rate of 1,000 Hz with a spatial resolution of 0.2° by an Eye-Link 1000 eye tracking system (SR Research, Mississauga, Canada). Although viewing was binocular, only the right eye was tracked. Before the experiment began, participants underwent a 5-point calibration (calibration target of 0.15° diameter black circle overlaid on a 0.35° diameter white circle). The calibration was accepted when the worst error point in the calibration was less than 0.75° and the average error for the 5 points less than 0.5°.

The experiment was controlled by MATLAB R2012a, and a Microsoft video-game controller was used to collect participants' responses. The instructions of the task were displayed by using a self-paced presentation on the screen at the beginning of the experiment. Each trial began with a central drift correction circle (0.5°), which participants were asked to accurately fixate on, in order to check fixation drift for minor changes in head position (in the case that the drift correction error was larger than 0.5°, the calibration procedure was repeated). When the participant's fixation remained stable within 0.75° of this drift correction circle for at least 200 ms, one of the possible facial stimuli (see the Stimuli section) appeared on a black background and remained on the screen for as long as the participant responded. Participants were instructed to freely look at the stimulus and to decide whether the chimeric face represented the self-face or another individual's face by pressing one of two keys on the video-game controller. They were asked to be as accurate and as fast as possible. Participant's response was then followed by a 500-ms random noise mask, in order to eliminate any possible afterimage before the beginning of the next trial. Although viewing was binocular, only the right eye was tracked, and the eye movements were recorded from the stimulus onset until participant's response.

The experiment consisted of two blocks: a first block (upright condition), during which the original mirror image and two composite faces of the participant and matched control were presented in the upright perspective, and a second block (inverted condition), involving the same stimuli but presented upside-down. Each condition (upright and inverted) consisted of 80 randomized trials depicting the four facial stimuli of the participant and four facial stimuli of the control unknown to the participant. The order of the two tasks was counterbalanced across participants. Furthermore, in order to avoid possible differences related to stimulus–response spatial compatibility, response key buttons were also counterbalanced across participants.

Before each condition, a practice session was run in order to let the participants familiarize themselves with the task and to practice making responses. This practice session consisted of eight trials depicting all the possible facial stimuli used for the experiment and gave the participants the opportunity to take a first look at each of them. Practice trials were not counted for statistical analysis.

Stimuli. A unique set of face stimuli was created for each participant. This set included four facial stimuli, built starting from the participant's own face and four facial stimuli, created starting from a control face (unknown to the participant). A participant's face could also be used as control face for another participant. In this case, it was verified that our participants did not know one another before the experiment. Moreover, the control face was always matched so that it looked as similar as possible to the participant's face (i.e., eyes and eyebrows color, skin texture).

All participants agreed to be photographed under symmetrical ambient light on a white background in order to create the facial stimuli needed for the experiment (see Malaspina et al., 2016 for more details). Participants were asked to look directly at the camera (Nikon d5100) with a neutral expression. At a later stage, each photograph was converted into grayscale using Adobe Photoshop CS4, and, if necessary, the whole image (3648 × 2736 pixels) was rotated between −1° and 1° and scaled in order to adjust eye collinearity between the two hemi-faces. Then, each face was cropped into an oval shape so that external features such as hair were excluded; any specific traits (e.g., pimples, moles and scars) that could facilitate self-recognition were also removed. A vertical line passing through the face midline was used to crop the oval faces exactly at midpoint in order to obtain the right and left sides of the face (192 × 243 pixels), which were afterward duplicated and mirror-reversed in order to create four facial stimuli for each participant: an original face (R_L, as people know their own face as a photograph image), a mirror face (L_R, as people know their own face as a mirror image), a composite face made by two left half-faces (L_L chimeric), and a composite face made by two right half-faces (R_R chimeric; see Figure 1). The final images were fully included in a 384 × 486 pixel rectangle (approximately 12 cm × 14.5 cm and 12° × 15° of visual angle).

Summarizing, all these steps resulted in four images (original face-R_L, mirror face-L_R, left-chimeric-L_L, and right-chimeric-R_R) of each person's face (participant and matched control) for a total of eight images in each unique stimulus set—four images of the participant's face and four of the matched control—which could also be presented upside-down depending on the block of the experiment. The facial stimuli needed for the inverted condition were created by vertically flipping each of the four facial stimuli of the participant and matched control.

Stimuli nomenclature. Stimuli nomenclature was based on the observer's point of view. In order to better assess which of the two hemi-faces and which of the two visual hemi-spaces were more relevant for self and others' recognition, we followed the following rules: The first letter of the stimulus indicated which half-face was falling in the observer's left visual space, and the second one indicated which half-face was falling in the observer's right visual space (e.g., "R_L" means that the stimulus was composed on the left side by the right half-face falling and on the right side by the left half-face).

Results

Behavioral Data

Proportion of correct responses and RTs from correct trials were adopted as dependent measures. RTs were measured from the stimulus onset until the participant's response. RT outliers (2.5 *SD* above or below the mean for each participant) were discarded and not analyzed (less than 1% for each participant). In order to provide a better summary of our findings, we also analyzed the inverse efficiency score (IES), defined as RT/accuracy (Bruyer & Brysbaert, 2011).

The behavioral data (i.e., accuracy, RTs, and IES) from the control and congenital prosopagnosic groups were analyzed using a linear mixed model with the lme4 package (Bates et al., 2014) in R (R Core Team, 2014). A first model was run including the factors Face Identity (self vs. other), Orientation (upright vs. inverted), Group (CG vs. CP), and a random intercept for each participant. Then, a second model was run in order to investigate any possible effect of the four facial stimuli (L_L, L_R, R_R, and R_R) on participants' performance only in the self-condition (i.e., in the familiar face condition, as no effect should be expected in the case of an unfamiliar face). Thus, in this second model, the factors included were Stimulus (L_L, L_R, R_R, and R_R), Orientation (upright and inverted), Group (CG and CP), and a random intercept for each participant. For both models, F tests from the LMER results are presented (Type III with Satterthwaite approximation for degrees of freedom), and significant differences were further explored by Bonferroni post hoc multiple comparisons (corrected p values are reported). Effect sizes were also calculated as Cohen's f^2 following the procedure described in Selya, Rose, Dierker, Hedeker, and Mermelstein (2012).

Accuracy analysis failed to reveal a significant effect of Group, $F(1, 18) = 0.07$, $p = .79$, $f^2 = 0.017$, but revealed significant main effects of Orientation, $F(1, 294) = 22.80$, $p < .001$, $f^2 = 0.074$, and Face Identity, $F(1, 294) = 8.65$, $p < .01$, $f^2 = 0.031$, showing that, overall, both groups were more accurate in recognizing upright than inverted faces (0.966 ± 0.01 and 0.914 ± 0.03, respectively) and in recognizing the self-face compared with the other-face (0.951 ± 0.02 and 0.928 ± 0.03, respectively). The interaction between the Face Identity and the Group was also significant, $F(1, 294) = 4.99$, $p < .05$, $f^2 = 0.016$, highlighting that, in terms of accuracy, the SFA (i.e., the difference between the accuracy in the self- and the other-condition) was significant only in the CP group (control group = .007, $p = 1.00$; CP group = .053, $p = .02$).

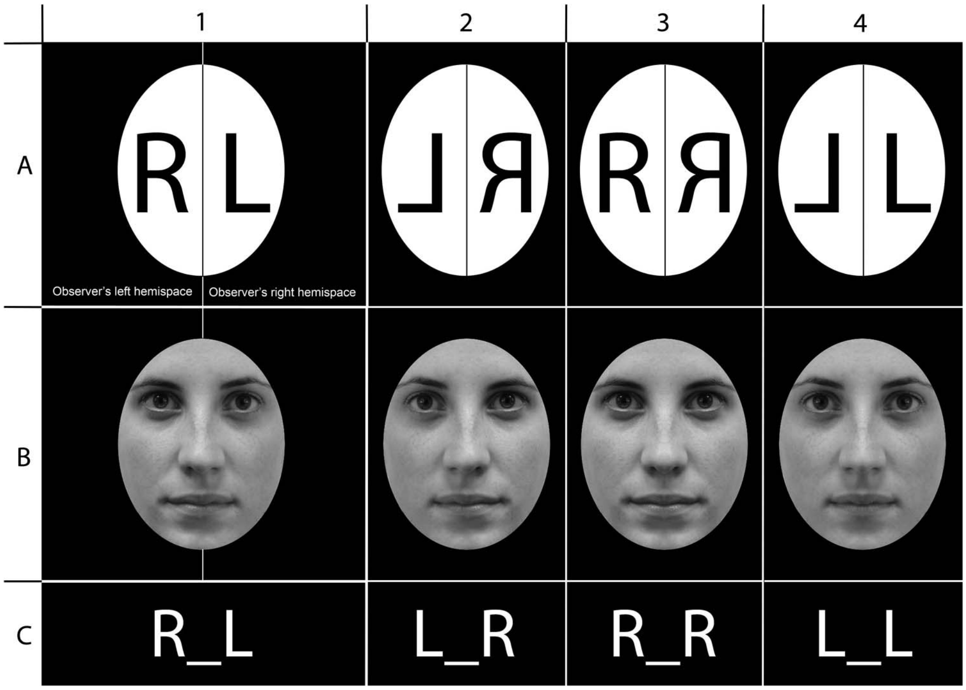

Figure 1. Examples of facial stimuli. (A) Letters "R" and "L" refer to side of the model's face from the model's perspective. For example, the farthest left image in A1 demonstrates the layout of an original photograph. with the right side of the models face in the observer's left visual space and the left side of the models face in the observer's right visual space ("R–L" means that the stimulus was composed of the right half-face falling in the observer's left visual space and the left half-face falling in the observer's right visual space). Images A2 to A4 demonstrate how each image was modified relative to the original layout (A1). (B) Examples of four stimuli used in the experiment for one model: (B1) The original photograph; (B2) the left-right reversal, or mirror image, of the original photograph; (B3) a right-half-of-model's-face chimeric; and (B4) the left-half-of-model's-face chimeric. (C) The labels used for each type of stimulus (adapted from "Right perceptual bias and self-face recognition in individuals with congenital prosopagnosia" by M. Malaspina, A. Albonico, & R. Daini, 2016, *Laterality: Asymmetries of Body, Brain, and Cognition, 21*, Copyright 2016 by Taylor & Francis pp. 118–142. Reprinted with permission.).

Analysis on RTs failed to reveal a significant effect of Group, $F(1, 18) = 2.76$, $p = .11$, $f^2 = 0.119$, but showed that the main effects of Face Identity, $F(1, 294.13) = 71.11$, $p < .001$, $f^2 = 0.110$, and Orientation, $F(1, 294.13) = 165.79$, $p < .001$, $f^2 = 0.243$, were significant: Both groups were faster in responding to their own face (637 ± 24 ms) than to the other-face (693 ± 26 ms), and they were also faster in responding to upright faces (619 ± 19 ms) than to inverted faces (711 ± 27 ms). More interestingly, the interaction between Group and Face Identity, $F(1, 294.13) = 18.34$, $p < .001$, $f^2 = 0.029$, was also significant: The SFA (i.e., the difference between the RTs in the other- and self-conditions) was significant for both groups (control group = 32 ms, $p < .001$; CP group = 98 ms, $p < .001$), and the CP group was significantly slower than the control group only in the Other condition (751 ± 50 ms and 661 ± 25 ms, respectively, $p < .001$) but not in the Self condition (653 ± 39 ms and 629 ± 29 ms, respectively, $p = 1.00$). This result suggests that in the self-condition, participants with CP improved their performance to the point that it could be comparable with one of controls. Finally, the interaction between Group and Orientation was significant, $F(1, 294.13) = 11.85$, $p < .001$, $f^2 = 0.020$, showing that congenital prosopagnosics were significantly slower than controls only with inverted faces (765 and 682 ms, respectively).

The analysis on the IES confirmed the presence of a significant effect of Orientation, $F(1, 291.42) = 26.99$, $p < .001$, $f^2 = 0.086$, and Face Identity, $F(1, 291.42) = 13.69$, $p < .001$, $f^2 = 0.055$: Both groups performed better with upright than inverted faces (647 ± 27 ms and 810 ± 97 ms, respectively), and in the self-condition compared with the other-condition (678 ± 32 ms and 787 ± 101 ms, respectively). The main effect of Group was not significant, $F(1, 18) = 2.73$, $p = .12$, $f^2 = 0.053$; however, once again, the interaction between Group and Face Identity was significant, $F(1, 291.42) = 6.94$, $p < .01$, $f^2 = 0.026$, highlighting that congenital prosopagnosics showed a performance comparable with controls in the self-condition (control group = 677 ± 45; CP group = 681 ± 42; $p = 1.00$), whereas in the other-condition, they performed significantly worse than controls (control group = 713 ± 38; CP group = 925 ± 69; $p < .001$; see Figure 2).

The type of facial stimulus (L_L, L_R, R_R, and R_R) did not seem to influence participant's performance neither in terms of accuracy, $F(3, 126) = 1.11$, $p = .348$, $f^2 = 0.053$, nor RTs, $F(3,$

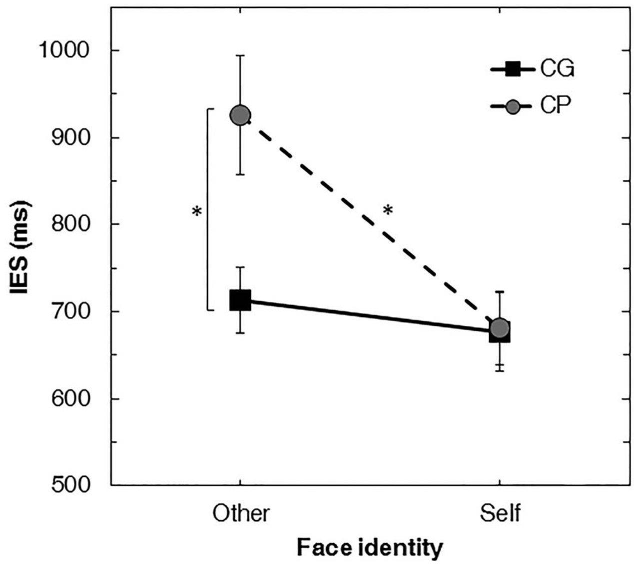

Figure 2. Mean inverse efficiency score of the control group (CG) and congenital prosopagnosia group (CP) for the other- and self-conditions. Vertical lines indicate ±1 standard error. IES = inverse efficiency score. * $p < .05$.

125.93, $f^2 = 0.004$) = 0.274, $p = .844$, or IES, $F(3, 125.98) = 1.01$, $p = .392$, $f^2 = 0.024$.

Taken together, these results confirmed the findings of previous studies showing that the SFA is detectable both in good recognizers and individuals with CP. In particular, the SFA is detectable in terms of RTs in the control group and in terms of accuracy, RTs and IES in the CP group. Moreover, the SFA in the CP group is so effective that in the self-face condition, their performance is comparable with controls.

Eye Movement Data

Eye movement data were preprocessed using EyeLink Data Viewer software (SR Research Ltd., Mississauga, Canada). All fixations were recorded from the beginning to the end of each trial. Because the initial fixation was always at the center of the screen, superimposed on the fixation dot, it was discarded, and the fixation following this first fixation was taken as the onset of the scanning sequence.

First, we looked at the basic characteristics of the eye movements made by participants while they were encoding the face. The total scan time per stimulus (i.e., the sum of the durations of all fixations) was analyzed in order to investigate the amount of scanning the participants needed to recognize the face; mean fixation number and duration per stimulus were also examined to determine whether any change in total scan time was related to an increase in the number or the length of fixations. Finally, mean first fixation duration was also analyzed as indicator of participants' preference when starting to explore the facial stimulus.

Second, we explored the scanning distribution over the face stimulus. Fixation distribution was analyzed by iMap4 (Lao, Miellet, Pernet, Sokhn, & Caldara, 2017), which has the advantage to avoid any issues related to the use of predefined regions of interest (Caldara & Miellet, 2011) by providing a completely data-driven way to analyze the scanning distribution.

Fixation features. Eye movement data were analyzed using a linear mixed model with the lme4 package (Bates et al., 2014) in R (R Core Team, 2014). The same models tested on the behavioral results were run also on the eye movement data. Again, for both models, F tests from the linear mixed-effects model (LMER) results are presented (Type III with Satterthwaite approximation for degrees of freedom), and significant differences were further explored by Bonferroni post hoc multiple (corrected p values are reported).

The main effect of the Group was significant in the total scan time, $F(1, 18) = 5.13$, $p < .05$, $f^2 = 0.122$, in the mean number of fixations per stimulus, $F(1, 18) = 6.50$, $p < .05$, $f^2 = 0.235$, and in the mean first fixation duration, $F(1, 18) = 7.02$, $p < .05$, $f^2 = 0.200$, showing that overall congenital prosopagnosics differed in the way they explored the facial stimulus (see Figure 3). Indeed, participants with CP needed more time (735 ± 39 ms) and more fixations (3.70 ± 0.25) to encode the stimulus compared with controls (668 ± 26 ms and 3.06 ± 0.17, respectively); accordingly, they also made shorter first fixations (253 ± 40 ms) and overall fixations (307 ± 29 ms) than controls (356 ± 31 ms and 361 ± 24 ms, respectively).

The main effect of the Orientation was significant in the total scan time, $F(1, 294.2) = 28.99$, $p < .001$, $f^2 = 0.055$, in the mean number of fixations, $F(1, 294) = 71.28$, $p < .001$, $f^2 = 0.070$, in the mean fixation duration, $F(1, 294.02) = 22.29$, $p < .001$, $f^2 = 0.031$, and in the mean first fixation duration, $F(1, 294.11) = 12.92$, $p < .001$, $f^2 = 0.024$. Both congenital prosopagnosics and controls used more scan time and more (and shorter) fixations in the inverted conditions (scan time = 713 ± 23 ms; mean fixation number = 3.45 ± 0.16; mean fixation duration = 328 ± 83 ms; mean first fixation duration = 304 ± 25 ms) compared with the upright one (scan time = 670 ± 22 ms; mean fixation number = 3.12 ± 0.14; mean fixation duration = 356 ± 91 ms; mean first fixation duration = 337 ± 28 ms). The interaction between Group and Orientation was also significant in the mean number of fixations per stimulus, $F(1, 294) = 6.06$, $p < .01$, $f^2 = 0.015$, showing that the increase in the number of fixations in the inverted condition was greater in the CP group (control group = 0.25; CP group = 0.45).

Finally, the Face Identity factor significantly influenced the total scan time, $F(1, 294.2) = 18.87$, $p < .001$, $f^2 = 0.036$, and the mean number of fixation per stimulus, $F(1, 294) = 6.82$, $p < .01$, $f^2 = 0.014$, highlighting that the SFA is evident also in terms of eye movements (see Figure 3). Indeed, participants needed less time and less fixations in order to recognize their own face (675 ± 21 and 3.24 ± 0.16) compared with an unfamiliar face (708 ± 23 ms and 3.33 ± 0.15). By contrast, the analysis on the fixation duration did not show any difference between the self- and other-conditions, suggesting that even though the self-face requires less information in order to be recognized, the amount of information extracted with each fixation is similar in the two conditions.

Interestingly, the interaction between Group and Face Identity was nearly significant in the total scan time, $F(1, 294.2) = 3.19$, $p = .07$, $f^2 = 0.009$, showing that, similar to the IES results, the difference between CPs and controls was bigger in the other-condition (762 ± 39 and 679 ± 26 ms) than in the self-condition

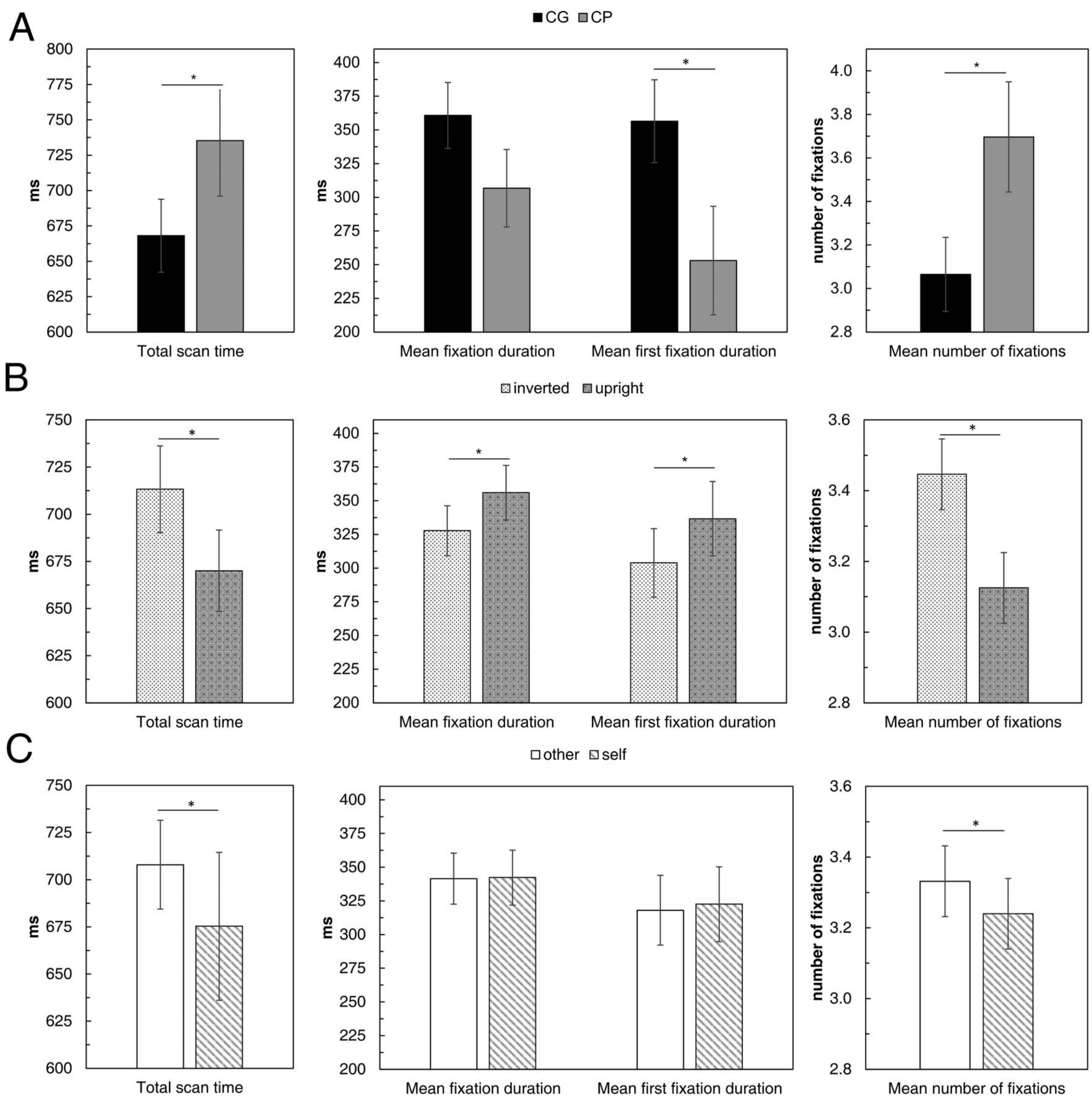

Figure 3. Eye movements data for (A) the control group (CG) and congenital prosopagnosia group (CP); (B) the inverted and upright conditions; and (C) the other- and self-conditions. * $p < .05$.

(709 ± 37 and 657 ± 25 ms). In accordance with the behavioral results, the type of facial stimulus (L_L, L_R, R_R, and R_R) did not seem to influence participant's eye movements neither in terms of total scan time, $F(3, 126.08) = 0.33$, $p = .804$, $f^2 = 0.013$, nor in mean number of fixations, $F(3, 126) = 0.27$, $p = .848$, $f^2 = 0.0001$, or in fixation duration (first fixation duration, $F[3, 126.01] = 1.65$, $p = .18$, $f^2 = 0.008$; overall fixations duration, $F[3, 125.93] = 0.37$, $p = .77$, $f^2 = 0.021$).

Taken together, these results showed that congenital prosopagnosics required longer scan times to recognize faces, and it seems that this could be largely not related to the fact that their fixations lasted longer, but it could happen because they used more fixations. Furthermore, confirming previous findings, both groups made fewer fixations and had shorter scan time with upright faces than inverted faces, reflecting the presence of an IE in the characteristics of their eye movements. Finally, all participants required fewer fixations and less viewing time to recognize their own face than the unfamiliar face—that is, they showed an SFA.

Spatial fixation mapping using iMap4. The spatial mapping of the fixation distribution was performed using iMap4 (Caldara & Miellet, 2011; Lao et al., 2017). iMap4 is a data-driven analysis framework for statistical fixation mapping, in which fixation distribution is modeled using linear mixed model and hypothesis testing is performed using nonparametric statistics based on resampling and spatial clustering (Lao et al., 2017).

iMap4 projects the fixation durations into two-dimensional space according to the *x*- and *y*-coordinates at the single-trial level. The sparse fixation duration maps were then smoothed with a 2D Gaussian kernel function of full width at half maximum around 1° of visual angle. The smoothed fixation map for each condition is then estimated within each participant by taking the mean of the trials in the same condition. To model the spatial pattern of fixation pattern, the conditional mean fixation maps were normalized using the z score (Figure 4A). The resulting 3D matrix (Trials × x-Size × y-Size) was then modeled as the response variable in iMap4. Each pixel in the smoothed fixation map was fitted with a linear mixed model using the following formula:

$$\begin{aligned} \textit{Fixation Intensity}_{(s,y)} \sim 1 &+ \textit{Group} + \textit{Face Indentity} \\ &+ \textit{Face Orientation} + \textit{Group} * \textit{Face Identity} \\ &+ \textit{Group} * \textit{Face Orientation} \\ &+ \textit{Face Identity} * \textit{Face Orientation} \\ &+ \textit{Group} * \textit{Face Identity} * \textit{Face Orientation} \\ &+ (1|\textit{Subject}), 1 \le x \le \textit{ x Size}, \; 1 \le y \le \textit{ySize} \end{aligned}$$

Thus, the fixation duration at different spatial location (e.g., eyes, nose, or mouth) was fitted as a linear function of Group (CG or CP), Face Identity (self or other), Face Orientation (upright or inverted face), and their interactions. The effect of subject was fitted as a random intercept. iMap4 uses the LinearMixedModel class from the Statistics Toolbox in MATLAB for model fitting. The linear mixed model coefficients were estimated using restricted maximal likelihood with the default iMap4 settings. A bootstrap spatial clustering procedure threshold on the cluster size was applied for the null hypothesis significance testing and for multiple comparison corrections (Lao et al., 2017).

An ANOVA on the linear mixed model revealed a significant main effect of Face Orientation on the right eye and the mouth region, and a significant interaction of Group and Face Orientation around the right eye and nose (see Figure 4B). The effect of Face Identity does not modulate the fixation pattern, as its main effect and interaction are not significant after multiple comparison correction using bootstrap clustering. Overall, participants fixated more the mouth and nose areas with inverted faces compared with upright faces (local maximum within the significant cluster, $F[1, 280] = 33.88$, $\beta_{upright} = 0.17$ [−0.338, 0.670], and $\beta_{inverted} = 1.08$ [0.577, 1.586]; local minimum, $F[1, 280] = 3.88$, $\beta_{upright} = -0.09$ [−0.202, 0.022], and $\beta_{inverted} = 0.07$ [−0.043, 0.181]; $p < .05$ cluster corrected; brackets show 95% confidence intervals), whereas the eye region was fixated more in the upright than in the inverted condition (local maximum within the significant cluster, $F[1, 280] = 53.99$, $\beta_{upright} = 1.07$ [0.570, 1.568], and $\beta_{inverted} = 0.08$ [−0.418, 0.579]; local minimum, $F[1, 280] = 3.90$, $\beta_{upright} = 2.93$ [2.062, 3.796], and $\beta_{inverted} = 2.34$ [1.472, 3.206]; $p < .05$ cluster corrected; brackets show 95% confidence intervals).

To clarify the significant main effect and interaction, we mapped the fixation area above chance level of the following predictors: CG_upright, CG_inverted, CP_upright, and CP_inverted, and then performed linear contrasts among these conditions (see Figure 4A). The main effect of face orientation was mostly driven by the change of fixation pattern between the upright and inverted condition in CP: They fixated more on the nose and mouth area in the inverted condition, whereas in

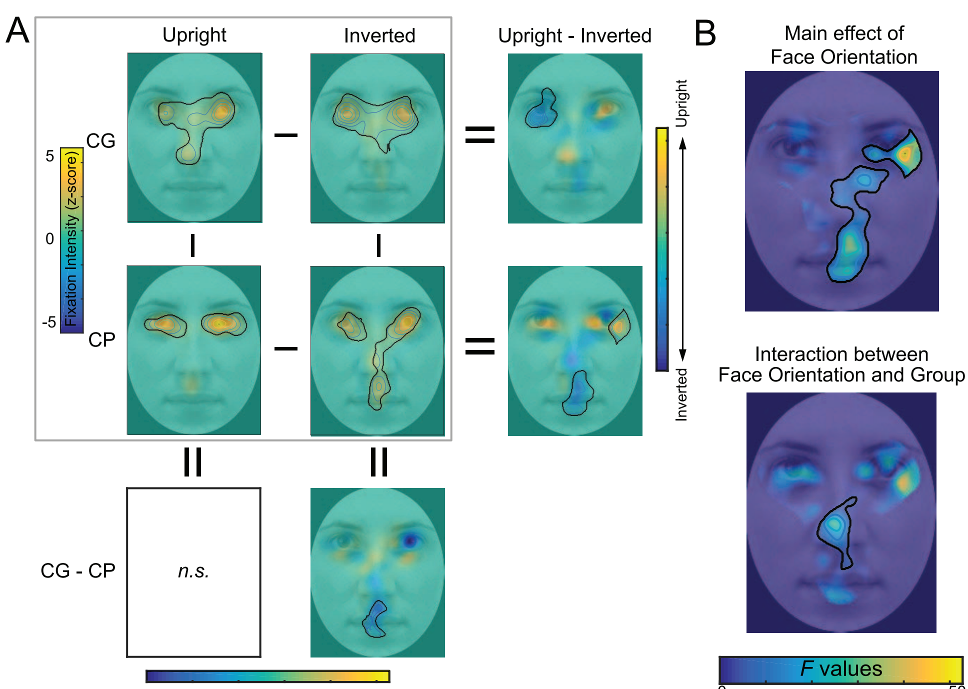

Figure 4. iMap4 results of the spatial fixation pattern. (A) Conditional z score fixation duration map estimated from the linear mixed model: control group (CG) viewing upright and inverted faces, and congenital prosopagnosics (CP) viewing upright and inverted faces. Linear contrasts of the conditional fixation maps were performed for all the possible 2 × 2 combinations. Significant clusters are outlined with black lines in the map (cluster corrected $p < .05$). (B) ANOVA result output from iMap4: F value map of the significant main effect of Group and significant interaction of Group and Face Orientation. *n.s.* = not significant. See the online article for the color version of this figure.

the upright condition, they were heavily biased toward the eye region only. Moreover, as shown in Figure 1 of the online supplemental material, the significant Group × Face Orientation interaction around the nose region (F_{max} [1, 280] = 27.93, and F_{min} [1, 280] = 3.88, within the significant cluster; $p < .05$ cluster corrected) was driven by the higher fixation duration in the upright condition compared with the inverted one in CG, and the reverse pattern in CP.

Discussion

The aim of the present study was to test whether the SFA showed by congenital prosopagnosics in an indirect task (Malaspina et al., 2016) could also be detected by asking participants an explicit recognition of their face, and, if so, whether this advantage would be reflected by a specific gaze behavior, distinct from the one characterizing the exploration of unfamiliar faces. In the present study, we asked the participants to explicitly discriminate the face stimuli and to judge them as "me"/"not me," whereas previous evidence of the advantage in congenital prosopagnosics was obtained by means of a matching task in which the discrimination between the self- and other-faces was indirectly required. In particular, in order to study the possible presence of the SFA during this explicit task, we took advantage of both behavioral and eye movement measurements because although the former could confirm the presence of the advantage also during explicit self-face recognition, the latter could provide us information about how efficiency and distribution of gaze could account for its possible existence.

As a first result, our data confirm previous evidence (Malaspina et al., 2017; Schmalzl et al., 2008; Schwarzer et al., 2007) proving that, overall, individuals with CP show abnormal gaze behavior compared with good recognizers during the exploration of facial stimuli. Indeed, congenital prosopagnosics needed more time to explore the face, making more and shorter fixations. These results seem to suggest that individuals with CP need to sample more information to encode the stimulus properly compared with good recognizers. In particular, the difference between the two groups in the first fixation duration might be crucial; indeed, previous evidence (e.g., Hsiao & Cottrell, 2008) suggested that the first fixation is the most crucial during face recognition, with the second fixation providing a little more evidence about face identity. Accordingly, in order to maximize the amount of information extracted, usually the first fixation is placed in the center of the stimulus, that is, the area between the eyes (Hsiao & Cottrell, 2008; Sadr, Jarudi, & Sinha, 2003; Vinette, Gosselin, & Schyns, 2004). Thus, the fact that congenital prosopagnosics made shorter first fixations and that, especially in the upright condition, they never focused on the central areas might suggest that these individuals are not able to extract information easily enough within the first fixation. As a consequence, all their fixations are shorter and they quickly move their gaze within single features in order to encode the face stimulus. However, despite these differences, the analyses on the spatial distribution of the fixations failed to reveal a significant main effect of the group in the upright condition, whereas congenital prosopagnosics tended to fixate more on the mouth area compared with controls in the inverted condition. The lack of difference between controls and congenital prosopagnosics when faces are presented upright might be quite surprising considering previous evidence showing that individuals with prosopagnosia have a more dispersed gaze distribution compared with controls (Malaspina et al., 2017; Schmalzl et al., 2008; Schwarzer et al., 2007). However, a critical difference between previous studies and the present one lies in the duration of the stimulus presentation: Whereas in the present study the eye movements were recorded from the appearance of the face stimulus to the participant's response (and the total scan time averaged around 700 ms for both groups), in the other studies the face stimulus was presented for a fixed and longer amount of time (1,500 ms in Malaspina et al., 2017; 5,000 ms in Schmalzl et al., 2008; and 7,000 ms in Schwarzer et al., 2007).

Thus, it seems possible that the different presentation times could play a critical role in determining the different results reported in the literature on upright faces, and that the difference in the spatial distribution of the fixations between congenital prosopagnosics and controls could emerge as the stimulus duration increases. In particular, we believe that when congenital prosopagnosics have more time to explore the facial stimulus, they tend to make more dispersed fixations, probably in the attempt to sample more information in order to properly encode the face. By contrast, the difference between individuals with congenital prosopagnosics and controls in the fixation features (i.e., the tendency to make more and shorter fixations in the prosopagnosic population) seems to be present independently of the stimulus duration, as it has been demonstrated in both the present and previous studies (Malaspina et al., 2017; Schmalzl et al., 2008; Schwarzer et al., 2007).

Finally, congenital prosopagnosics tended to fixate more on the mouth area compared with controls in the inverted condition, and this result seems to confirm that these individuals tend to process the face stimulus by focusing on single features and not on the central area. This tendency seems more evident when faces are presented upside-down and might be because face inversion disrupts not only long-range spatial relations but also low-range spatial relations across different facial features (Sekunova & Barton, 2008).

A newer and significant result of this study concerns face inversion. Indeed, in accordance with previous evidence (Barton, Radcliffe, Cherkasova, Edelman, & Intriligator, 2006; Farah et al., 1995), for all participants, upright faces were easier to recognize compared with inverted faces and required fewer fixations and shorter scanning time. Surprisingly, in this case, individuals with CP showed an IE similar to controls both in terms of accuracy and RTs. However, despite congenital prosopagnosics typically showing lack of IE, and, thus, a similar performance between upright and inverted faces (de Gelder & Rouw, 2000; Righart & de Gelder, 2007), it is worth mentioning that the studies reporting this effect in these individuals usually have used only unfamiliar faces as stimuli. By contrast, in this case, both the inclusion of the self-face in the experimental paradigm, and, thus, the presence of a SFA in the congenital prosopagnosic group, might have played as a confound factor, preventing the absence of an IE in these individuals. Moreover, the analysis on the spatial fixation mapping revealed that face inversion affected the two groups differently.

In particular, controls tried to encode both upright and inverted faces in a similar way, that is, by focusing their fixations on the eyes and nose areas in both conditions. This is in accordance with previous evidence showing that the eye region contains the most diagnostic information for face identification (Hsiao & Cottrell, 2008; Sadr et al., 2003; Vinette et al., 2004), and that good Western recognizers look mostly at the eyes and scan the upper half-face more than the lower half when recognizing faces (Barton et al., 2006; Blais, Jack, Scheepers, Fiset, & Caldara, 2008; Henderson, Williams, & Falk, 2005; Miellet, Vizioli, He, Zhou, & Caldara, 2013). However, previous evidence in good recognizers has also shown that the face IE is not strictly a consequence of anomalous eye movements (Williams & Henderson, 2007), whereas it might be linked to a different efficiency in the extraction of information between the two conditions (Sekuler, Gaspar, Gold, & Bennett, 2004), and our data seem to point in the same direction. In fact, in our experiment, the control group did not show any anomalous eye movement pattern with inverted faces, but continued to focus on the same eye region, and because this area does not seem to be so informative in this specific orientation, they showed behaviorally a typical IE.

By contrast, our CPs changed their fixation pattern between the upright and inverted conditions, focusing only on each one of the eyes, in the first case, but extending their exploration to the nose and mouth areas in the latter one. Despite that face inversion is one of the most powerful arguments used to support the presence of face-specific impairment in CP, to the best of our knowledge, only one study investigated in detail how face inversion affects the gaze behavior of congenital prosopagnosics (Malaspina et al., 2017). Specifically, results from that study showed that individuals with CP tended to explore both upright and inverted faces in a very similar way, that is, by focusing only on facial features. Despite some differences, probably related to the additional inclusion of the self-face and the different timing of the stimulus exposure here, the results of both studies seem coherent. Indeed, during this task, overall, the congenital prosopagnosic group directed their eyes on the single features of the face (eye, nose, or mouth) while ignoring the region between the eyes, crucial for expert holistic processing. In particular, as also suggested by a previous study (Righart & de Gelder, 2007), the use of a same feature-based strategy with both upright and inverted faces could partially explain why congenital prosopagnosics often show a similar accuracy in recognizing upright and inverted faces. Specifically, whereas the feature-based strategy could also be optimal in the inverted condition, the same is not true for upright faces, which require holistic processing, and even though face recognition can be achieved also by using a feature-based strategy, this kind of processing is typically less efficient, requires more time, and could explain why congenital prosopagnosics struggle so much with upright faces.

Regarding the processing of the self-face, our behavioral data corroborated previous findings (Keyes & Brady, 2010; Malaspina et al., 2016; Ma & Han, 2010) showing that the SFA is detectable both in people with good recognition abilities and individuals with CP, with both groups performing better and faster in the self-face condition. In particular, although congenital prosopagnosics performed significantly worse than controls with unfamiliar faces, their performance was comparable with controls with the self-face, suggesting that the SFA may act as a compensatory process to overcome their face recognition impairment. It should be mentioned that a small set of stimuli was used for both the own and the other- conditions; because previous studies (Burton, 2013; Jenkins, White, Van Montfort, & Burton, 2011; White, Rivolta, Burton, Al-Janabi, & Palermo, 2017) have shown that increasing within-person variability can affect the performance of both normal recognizer and individuals with CP in face recognition tasks, the results might change when a larger sample of stimuli for both conditions are used. Nevertheless, we might expect to find a quantitative but not qualitative change in the pattern of results, as both groups appear to be affected by the increased within-person variability. Furthermore, we used only gray-scale images, which could reduce the texture information contained in the images. Previous studies (Andrews, Baseler, Jenkins, Burton, & Young, 2016; Itz, Golle, Luttmann, Schweinberger, & Kaufmann, 2017) have shown that texture information is critical in both face matching and recognition tasks, and that poor face recognizers rely less on this kind of information than good recognizers. It follows that using gray-scale images might decrease the differences between the two groups by impoverishing the performance of the control group. However, this should be true for both the own- and the other-face conditions, so that the choice of discarding color information did not introduce any qualitative distortion on the results.

Our results on the self-face are also in accordance with a previous study showing that individuals with CP have also normal neural responses (N250 and P600f components) to the identity of the own face (Parketny, Towler, & Eimer, 2015). Moreover, both groups exhibited an SFA in their gaze behavior; indeed, all our participants required less time and fewer fixations in order to recognize their self-face compared with the unfamiliar face. Interestingly, this advantage was not associated with a different spatial distribution of their fixations, suggesting that, whereas the information from the self and other was sampled in a similar way (same spatial fixation mapping), the processing of the information extracted within each fixation must have been different in the two conditions in order to give the different behavioral results. This evidence seems to support the idea that what is special about the self could be not "what" is processed but "how" efficiently the information sampled is processed. Indeed, even though the exploration of familiar faces is usually characterized by a different distribution of fixations (i.e., more sampling of the internal areas) compared with unfamiliar faces in good recognizers (Heisz & Shore, 2008; Stacey, Walker, & Underwood, 2005), in our study, the distribution of scanning during the recognition of the self-face was similar to the one of the unfamiliar face. Moreover, despite congenital prosopagnosics usually do not show any familiarity effect in terms of eye movements during the visual exploration of faces, here, we could still detect a different gaze behavior (fewer fixations and less scan time) in the case of the self-face. Taken together, both these results allow us to discard the possibility that overexposure to the self-face during life could play a critical role in determining the SFA we found in both behavioral and eye movement data.

Accordingly, the possibility that the self-face could be characterized by a specific processing has been already addressed in the literature, but the evidence collected so far is mixed. Indeed, whereas some studies found that the SFA might be part of a right-dominated neural network devoted to the processing of self-information (Devue et al., 2007; Platek, Keenan, Gallup, & Mohamed, 2004; Platek et al., 2006; Uddin, Kaplan, Molnar-Szakacs, Zaidel, & Iacoboni, 2005), other studies have provided evidence for a specific bilateral representation of one's own face, suggesting that the advantage might be related to a more robust representation of the global and local aspects of the self-face across the brain

(Brady et al., 2004; Brady, Campbell, & Flaherty, 2005; Keyes & Brady, 2010). In particular, according to this last hypothesis, although the right hemisphere would be responsible for the global aspects of the self-face, the left hemisphere might contribute by emphasizing the local aspects of it (Keyes & Brady, 2010). The results of the present study seem to support the first hypothesis emphasizing that the self-face could be characterized by an enhanced processing of self-information, and, in particular, we believe that the SFA could reflect a more general enhanced processing of self-related information. In fact, the advantage for the self-face affected the performance of controls and congenital prosopagnosics similarly in terms of behavioral and eye movement data, and, because of the face recognition impairment characterizing the latter ones, this lack of difference between the two groups seems to suggest that the advantage could be not related to any face-specific mechanisms. Accordingly, if the SFA was face-specific, we would have expected a different modulation of it in the two groups, which we could not find. Furthermore, although some authors (Brady et al., 2004, 2005; Keyes & Brady, 2010) interpreted the presence of the SFA in both upright and inverted faces as proof of the more robust and bilateral representation of the local and global aspects of the face, we believe that this evidence could actually support the opposite hypothesis. In fact, it is well accepted that face inversion disrupts the expert face recognition processing and that, when inverted, faces are processed like any other object, that is, feature by feature (Tanaka & Farah, 1993); thus, for this reason, the presence of an advantage for the self-face in the inverted condition does not seem to be attributable to a face-specific mechanism, but, by contrast, it seems more in favor of a generic self-advantage. In particular, as suggested by others (Blanke, 2012; Frassinetti et al., 2011; Frassinetti, Maini, Romualdi, Galante, & Avanzi, 2008), the self-advantage may rely upon the integration of multisensory signs of the self-body involving a frontoparietal network in the right hemisphere, and, in our case, this multisensory representation of the self could act as a compensatory process to overcome the face recognition impairment in individuals with CP at least when they have to recognize their own face. However, additional studies will be needed to further investigate whether the SFA is face-specific or linked to self-related material in general; specifically, because previous studies have demonstrated that prosopagnosics can be impaired in body and body motion perception (Kolers, 1968; Lange et al., 2009; Moro et al., 2012; Righart & de Gelder, 2007; Rivolta, Lawson, & Palermo, 2017), it might be critical to investigate whether these individuals show also a self-advantage for their body parts, and, if so, if this advantage differs from the one characterizing the self-face. Lastly, because previous studies suggested that the SFA could be linked to the preference for the right half of the face (Brady et al., 2004; Malaspina et al., 2016), another aim of this study was to investigate whether the right perceptual bias described in the literature in both good recognizers and congenital prosopagnosics would be detectable also in terms of eye movements. However, the analyses on the chimeras did not prove any influence of the type of chimeric stimulus on the behavioral performance of the two groups in the self-condition, so that no preference for one specific half of the self-face was found. In particular, we could not find a right perceptual bias in the behavioral or eye movement results of the two groups. Nevertheless, the lack of right perceptual bias is still very informative about, at least, two aspects: (a) Because neither of the two groups showed a preference for the right-half of the self-face despite showing a significant SFA, this could suggest that the two effects are independent of each other and further support the hypothesis that the SFA can be related to a more general enhanced processing of self-related information; and (b) furthermore, the lack of right perceptual bias in a task requiring a direct and explicit recognition of the self-face could also suggest that the bias toward the right-half of the self-face could be sensitive to the task demand. Indeed, whereas the previous studies demonstrating the existence of the rightward bias have used indirect tasks, not requiring an explicit recognition of the self-face (Brady et al., 2004; Malaspina et al., 2016), in this study, participants had to explicitly judge the face stimulus as "me"/"not me." Accordingly, a previous study that used an explicit task to test self-face recognition failed to observe a right perceptual bias in good recognizers (Brady et al., 2005), suggesting that the rightward bias characterizing the self-face might be detectable only during indirect tasks, probably because they require maintaining a short memory representation of the self-face, which might elicit a different exploration of this stimulus.

In conclusion, the present study further corroborated the presence of an SFA in both congenital prosopagnosics and good recognizers during an explicit recognition task, and both in the case of upright and inverted face processing; in particular, the SFA was not related to any change in the spatial fixation distribution, suggesting that it could be related to a more general enhancement of the self-information processing, instead of being related to face-specific mechanisms. However, contrary to what found in previous studies (Malaspina et al., 2016; Brady et al., 2004, 2005), the SFA was not driven by the preference to the right-half face, suggesting that these two effects are separate and independent of each other, and that the right perceptual bias characterizing the self-face is sensitive to the task demand, being more evident when an explicit recognition of the self-face is not required. Finally, we showed that face inversion differently affects controls and congenital prosopagnosics. On the contrary, of controls who mostly explored the eyes and the area between them in both conditions of orientation, congenital prosopagnosics made more distributed fixations in the noncanonical inverted condition, by focusing more on the nose and the mouth in this orientation. This observation could explain why congenital prosopagnosics sometimes perform even better with inverted compared with upright faces. Altogether, our data revealed a new oculomotor signature of the congenital face processing deficit.

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