



Self-face and self-body advantages in congenital prosopagnosia: evidence for a common mechanism

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Abstract

Prosopagnosia is a disorder leading to difficulties in recognizing faces. However, recent evidence suggests that individuals with congenital prosopagnosia can achieve considerable accuracy when they have to recognize their own faces (self-face advantage). Yet, whether this advantage is face-specific or not is still unclear. Here, we aimed to investigate whether individuals with congenital prosopagnosia show a self-advantage also in recognizing other self body-parts and, if so, whether the advantage for the body parts differs from the one characterizing the self-face. Eight individuals with congenital prosopagnosia and 22 controls underwent a delayed matching task in which they were required to recognize faces, hands and feet belonging to the self or to others. Controls showed a similar self-advantage for all the stimuli tested; by contrast, individuals with congenital prosopagnosia showed a larger self-advantage with faces compared to hands and feet, mainly driven by their deficit with others' faces. In both groups the self-advantages for the different body parts were strongly and significantly correlated. Our data suggest that the self-face advantage showed by individuals with congenital prosopagnosia is not face-specific and that the same mechanism could be responsible for both the self-face and self body-part advantages.

Keywords Prosopagnosia · Face recognition · Body recognition · Self-recognition

Introduction

Face recognition is a fundamental skill that allows us to identify others and recover their biographical information, as well as to understand their feelings and intentions. For most people, the recognition of a face is an automatic process that is achieved almost immediately. However, for other people faces represent challenging visual stimuli so that most of the times the whole recognition process is not straightforward and does not end successfully. Those last people are sometimes affected by prosopagnosia, which is the inability to

recognize the identity of faces (Bodamer 1947). The impairment has been typically described following a brain lesion, mainly to the ventral occipito-temporal cortex, limited to the right hemisphere (De Renzi and di Pellegrino 1998) or bilaterally (Sergent and Signoret 1992). Some individuals, though, can exhibit face recognition impairment from birth, without suffering any acquired brain damage. Those individuals are affected by the developmental form of prosopagnosia, which represents the failure to develop normal face recognition skills despite intact perceptual and intellectual functioning and in the context of normal exposure to faces throughout their lives (Schmalzl et al. 2008). After initial studies on the familiar heritability of the impairment (e.g., Schmalzl et al. 2008), the idea that developmental prosopagnosia could be genetically influenced has been recently supported also by one genetic study, which provided preliminary data in favor of the involvement of genetic variants of the oxytocin receptor gene in a group of individuals with prosopagnosia (Cattaneo et al. 2016). For this reason, here we will refer to this condition in terms of “congenital prosopagnosia” CP, McConachie (1976).

CP is an heterogeneous disorder, both in its features and in the severity of the deficit itself (de Gelder and Rouw

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2000; Duchaine et al. 2007; Schmalzl et al. 2008): some individuals with CP are able to detect faces among other stimuli and to perform simple face matching tasks (de Gelder and Rouw 2000; Humphreys et al. 2007; McKone et al. 2011), while others cannot (Behrmann et al. 2005; Bentin et al. 1999; Garrido et al. 2008; Kress 2003); some are impaired in extracting non-identity information from a face, such as expression, gender and age (De Haan and Campbell 1991; Duchaine et al. 2006; Kress and Daum 2003), while other individuals with CP can perform those tasks (Duchaine et al. 2003; Jones and Tranel 2001; Kress and Daum 2003). Despite this heterogeneity, the hallmark of CP is the inability to recognize familiar faces or to learn new faces (Barton and Corrow 2016; Dalrymple and Palermo 2016).

However, recent studies on individuals with CP (Malaspina et al. 2016, 2018) found in these individuals preserved recognition of one particular familiar face: the self-face. Accordingly, one electrophysiological study found that some individuals with CP show normal neural responses (N250 and P600f components) to the identity of the self-face (Parketny et al. 2015). Moreover, one study on an acquired prosopagnosic patient also showed preserved trait inference from the self-face but not from familiar faces (Klein et al. 2008). These results mimic a well-known effect, that is the self-face advantage (SFA), which has been described in typically developed individuals and consists of faster reaction times when participants have to recognize their own face compared to unfamiliar or familiar faces (Ma and Han 2010; Sugiura et al. 2005). The existence of an advantage in self-face recognition is consistent with the idea that the processing of the self-face is distinct from the processing of other-faces (Brady et al. 2004, 2005; Keyes and Brady 2010), but the results on whether this advantage reflects face-specific mechanisms or a more general enhanced processing of self-information are still mixed (Devue et al. 2007; Frassinetti et al. 2011; Kircher et al. 2000; Uddin et al. 2005). However, the existence of a SFA also with inverted faces (Keyes and Brady 2010; Malaspina et al. 2018) seems to disprove the idea of the advantage being face specific: in fact, it has already been shown that face inversion disrupts the expert mechanism characterizing specifically face recognition (Farah et al. 1995). Similarly, the SFA found in typically developed individuals and individuals with CP does not seem to be associated with a change in the spatial fixation distribution, and this might suggest that the advantage could be related to a more general enhancement of the self-information processing, instead of being attributable to face-specific mechanisms (Malaspina et al. 2018).

To further investigate the hypothesis that the SFA could be independent of the specific mechanisms characterizing face processing, here we investigated whether the advantage could be due, instead, to a more general mechanism

involved in the recognition of self body-parts, in both individuals with CP and typically developed.

To this aim, we recruited a group of individuals with CP and a control group, who underwent a delayed matching task involving the presentation of face and body-part stimuli (hands and feet), belonging to the participant or to two unfamiliar gender-matched controls. According to our hypothesis, if the SFA is not due to face-specific mechanisms but to a more general mechanism underlying self-recognition, then we will expect both groups to show a similar advantage during the recognition of both self-face and other self body-parts. By contrast, if the self-face advantage is linked to mechanisms specific to face recognition, then participants should show an advantage in recognizing their own faces but not necessarily their body parts, or the advantage characterizing the self-face should differ significantly from the one characterizing the other body parts.

Finally, since previous evidence (Brady et al. 2004; Malaspina et al. 2016) have suggested that the SFA could be linked to a rightward bias (i.e., a preference for the right part of the self-face, which falls in the observer's right visual field when looking in the mirror), in this study we also wanted to investigate the possible presence of such bias during the recognition of other body parts. For this reason, we used chimeric stimuli of faces, hands and feet created from the original picture of each participant (i.e., a composite made of two right half-faces or two right hands/feet, and a composite made of two left half-faces or two left hands/feet) in addition to the original and mirror-reversed pictures of all these stimuli. In particular, we were expecting the right perceptual bias to be detectable as increased performance in the presence of the right self-hemi-face, the right hand and the right foot.

Materials and methods

Participants

All participants had normal or corrected-to-normal vision and reported no neurological or neurophysiological damage. Each participant provided written permission for the use of their photographs for the purposes of this study. Informed consent was also obtained from all participants before the onset of the experiment. The study was carried out in accordance with ethical guidelines of the Declaration of Helsinki and was approved by the ethical committee of the University of Milan-Bicocca (protocol number RM-2016-44). Participants received university course credit for taking part in the study.

Congenital prosopagnosics

Eight individuals with CP (seven females, all right-handed, mean age of 24.9 ± 1.8 , age range 23–28) participated in the study and composed our experimental group (CP group). Six of them were recalled from previous studies (Cattaneo et al. 2016; Malaspina et al. 2016, 2018, 2017), while the last two individuals with CP were undergraduate students recruited from the University of Milan-Bicocca. All individuals with CP underwent a semi-structured interview, to assess the presence of CP in these individuals and to exclude possible alternative explanations for their face recognition impairment. They all reported no known history of brain damage. As the controls, the eight individuals of the CP group underwent a battery of tests investigating face and object recognition (see below).

Control participants

Twenty-two undergraduates from the University of Milan-Bicocca were recruited through the University of Milan-Bicocca Sona System© and composed our control group (11 males, all right-handed, mean age of 23.5 ± 2.3 years old, age range 20–30). The recruitment of these people was based on the absence of perceived life-long face recognition impairment, as assessed by a short interview at the beginning of the testing session, and as confirmed by the neuropsychological battery (see below).

Face and object recognition abilities assessment

All participants underwent a screening session assessing their face and object recognition abilities. In particular, our battery was composed of two tests assessing participants' ability to recognize newly learned Cambridge Face Memory Test, CFMT; Duchaine and Nakayama (2006) and famous faces Famous Faces Recognition Test, FFRT; Malaspina et al. (2017), two tests on visual object recognition Boston Naming Test, BNT; Kaplan, Goodglass, and Weintraub (1983); Famous Monuments Recognition Test, FMRT; Cattaneo et al. (2016) and a self-rating report on face recognition ability PI20; Shah, Gaule, Sowden, Bird, and Cook (2015). In addition to these tests, we calculated an additional index from the CFMT, that is the inversion effect IE; Yin (1969). The inversion effect was defined as the difference between the total score of the upright and inverted versions of the CFMT and was included because it represents a qualitative index of face processing (Behrmann and Avidan 2005), which can be used as a further indicator to diagnose congenital prosopagnosia (Albonico et al. 2017).

The scores obtained in these tests by the 22 controls formed the sample for the calculation of z-scores for the CP participants. The mean scores for each test (\pm SD)

were as follows: 56.86 ± 7.03 for the upright version of the CFMT, 41.77 ± 5.56 for the inverted version of the CFMT, 15.09 ± 7.06 for the inversion effect, 33.59 ± 5.18 for the FFRT, 24.04 ± 3.55 for the FMRT and 57.27 ± 1.98 for the BNT. The individual raw scores and z-scores for each CP are reported in Table 1. In addition, to further confirm the presence of prosopagnosia in the CP group, CFMT and IE z-scores were compared with those obtained by a larger sample of 217 controls for this test (Albonico et al. 2017).

All 8 individuals composing the CP group proved face recognition impairment; indeed, they all performed poorly (i.e., 2 SDs below the mean of the control group) in the upright version of the CFMT and in the FFRT. Furthermore, these participants showed a reduced inversion effect compared to controls and, particularly, 6 of them had an inversion effect score 2 SDs lower than the control group. Four CPs also showed a PI20 score greater than the cut-off score of 65, which is indicative of mild and moderate impairment (Shah et al. 2015). The fact that not all individuals with CP had elevated scores in the PI20 is in accordance with the reports from our semi-structured interviews and not surprising; indeed, previous studies have shown that results from self-reports have to be interpreted with caution as individuals with face recognition impairment are often not well aware of their deficit (Bowles et al. 2009; De Haan 1999; Grueter et al. 2007). All individuals with CP performed in the normal range in the two tests investigating visual object recognition abilities (FMRT and BNT), demonstrating the absence of difficulties in general visual processing. None of the controls showed any impaired performance in any tests.

Stimuli

Since the experiment was composed of three different conditions involving the presentation of three different body parts (face, hands and feet), three unique stimuli sets were created for each participant. Each set included the participant's own face, hands and feet and two additional people's faces, hands and feet that were used as control stimuli consistently across the experiment (i.e., two female models for all female participants and two male models for all male participants).

To create each unique stimulus set, the participant and the two gender-matched controls, unknown to the participant, were photographed under symmetrical ambient light on a white background. In the case of the face, participants were required to look directly at the camera (Nikon d5100) with a neutral expression, whereas in the case of hands and feet they were asked to place those on a specific position outlined on a white cardboard. All photographs were then converted into greyscale using Adobe Photoshop CS4®. Prior to the construction of the chimeric stimuli, the mean luminance and contrast of the three original pictures belonging to the participant and two matched controls were also equalized

Table 1 Demographic details and raw and z-scores of the 8 individuals with CP at the neuropsychological tests, and average scores for the control group (CG)

Participant	CR	EC	LS	MB	PV	RB	SE	VT	CG mean (\pm SD)
Gender	F	F	M	F	F	F	F	F	
Age	28	25	24	23	27	25	23	24	
P120	79	73	45	46	44	69	64	76	
CFMT upright									
Raw score	36 ^a	40 ^a	40 ^a	34 ^a	38 ^a	40 ^a	37 ^a	37 ^a	56.86 \pm 7.03
z score	-2.97 ^a	-2.40 ^a	-2.40 ^a	-3.26 ^a	-2.69 ^a	-2.40 ^a	-2.83 ^a	-2.83 ^a	
z score ^b	-2.49 ^a	-2.02 ^a	-2.02 ^a	-2.73 ^a	-2.26 ^a	-2.02 ^a	-2.37 ^a	-2.37 ^a	
CFMT inverted									
Raw score	30 ^a	41	39	37	33	44	44	38	41.77 \pm 5.56
z score	-2.12 ^a	-0.14	-0.50	-0.86	-1.58	0.40	0.40	-0.68	
z score ^b	-1.92	-0.10	-0.43	-0.76	-1.42	0.39	0.39	-0.59	
IE									
Raw score	6	-1 ^a	1 ^a	-3 ^a	5	-4 ^a	-7 ^a	-1 ^a	15.09 \pm 7.06
z score	-1.29	-2.28 ^a	-2.00 ^a	-2.56 ^a	-1.43	-2.71 ^a	-3.13 ^a	-2.28 ^a	
z score ^b	-1.35	-2.30 ^a	-2.03 ^a	-2.58 ^a	-1.48	-2.71 ^a	-3.12 ^a	-2.30 ^a	
FFRT									
Raw score	13 ^a	21 ^a	21 ^a	18 ^a	19 ^a	12 ^a	12 ^a	18 ^a	33.59 \pm 5.18
z score	-3.98 ^a	-2.43 ^a	-2.43 ^a	-3.01 ^a	-2.82 ^a	-4.17 ^a	-4.17 ^a	-3.01 ^a	
FMRT									
Raw score	18	21	28	27	28	18	24	21	24.04 \pm 3.55
z score	-1.70	-0.86	1.11	0.83	1.11	-1.70	-0.01	-0.86	
BNT									
Raw score	58	54	56	58	57	55	57	57	57.27 \pm 1.98
z score	0.37	-1.65	-0.64	0.37	-0.14	-1.15	-0.14	-0.14	

CFMT Cambridge Face Memory Test, IE Inversion Effect, FFRT Famous Face Recognition Test, FMRT Famous Monuments Recognition Test, BNT Boston Naming Test

^aPathological score (< 2SD below the mean of the control group)

^bz-score based on the normative data in Albonico et al. (2017)

using the SHINE toolbox for Matlab (Willenbockel et al. 2010), to minimize potential low-level confounds.

Faces were then cropped into an oval shape so that external features such as hair, were excluded, and 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 to obtain the right and left sides of the face which were afterwards duplicated and mirror-reversed, to create four facial stimuli for each participant. In the case of hands and feet we used the left and right hands, as well as the left and right feet singularly, to create the four chimeric stimuli. In this latter case, the single body parts were arranged side by side in the picture, horizontally aligned at a fixed distance of 4 pixels for the distance between the thumbs of two hands, and 40 pixels for the distance between the soles of the two feet. Thus, for each participant's body parts four chimeric stimuli were created: an original L_R stimulus, a reversal R_L stimulus, a composite L_L stimulus made by two left half-faces or the two left hands or feet and a composite R_R stimulus made by two right half-faces or two

right hands or feet. The final face stimuli were fully included in a 288 \times 384 pixels rectangle (approximately 9° \times 14.5° of visual angle), whereas hands' images were 446 \times 384 pixels (approximately 14.5° \times 14.5° of visual angle), and feet images were 326 \times 384 pixels (approximately 10.5° \times 14.5° of visual angle).

Summarizing, all the steps resulted in four stimuli of the body parts of each participant (participant and two gender-matched models) for a total of 12 images in each unique stimulus set—four images of the participant's body parts and 8 belonging to matched models (see Fig. 1 for an example of the stimuli used in the three conditions).

Apparatus and procedure

Participants sat in a comfortable chair approximately 57 cm from the monitor (40.5 cm \times 30.5 cm, 1280 \times 800 pixels) in a dark silent room with their head supported with a chin rest. The experiment was controlled by OpenSesame 3.1.1 Software (Mathôt et al. 2012) and a keyboard was used to collect participant's response. The instructions of the task

Fig. 1 Example of the stimuli used in the three conditions: hands, feet and faces. All the three pictures depict L_R stimuli



were displayed using a self-paced presentation on the screen at the beginning of the experiment.

The experiment was composed of three conditions, one for each body part: condition “A” for faces, condition “B” for hands and condition “C” for feet. The three conditions were further divided into two blocks each and administered according to an ABC CBA scheme, to prevent any possible presentation-order effects. Within each block, each trial (see Fig. 2 for an example) started with a fixation cross at the centre of the screen, replaced after 1 s from one of the possible stimuli (face, hands, or feet) for 200 ms; the exposure time of the target stimulus was decided in accordance with previous studies investigating body recognition in prosopagnosia; Rivolta, Lawson, and Palermo (2017). Immediately after that, two stimuli (the target and a distractor) appeared at the centre of the screen, vertically aligned, one above the other, to avoid any spatial compatibility response bias. All images were presented on a grey background. Participants were asked to press the “↑” key if the target stimulus appeared in the upper half of the screen, or the “↓” key if the target stimulus appeared in the lower half of the screen. Participants were asked to be as accurate and as fast as possible. The test stimuli remained on the screen until the participant provided a key-response. There were no inter-stimulus intervals in this paradigm and participant’s response triggered the presentation of the next trial.

Within each block, each of the four participant’s stimuli described above appeared as the target stimulus 12 times, while the four stimuli of the two controls appeared as target stimulus six times each (resulting in 48 “self” target stimuli and 48 “other” target stimuli) for a total of 96 trials per single block, and 192 for each condition (i.e., face, hands, and feet). On each trial, the distractor stimulus was chosen pseudo-randomly from the 8 images of the remaining two identities so that all pictures were used as distractor stimulus an equal number of times. Target stimulus and distractor stimulus always depicted different identities. The target stimulus appeared half of the time in the upper part of the screen and the remaining half in the lower part, randomly.

Before the first block of each condition, to familiarize the participant with the brief presentation time of the target stimulus and to practise key press responses, all participants

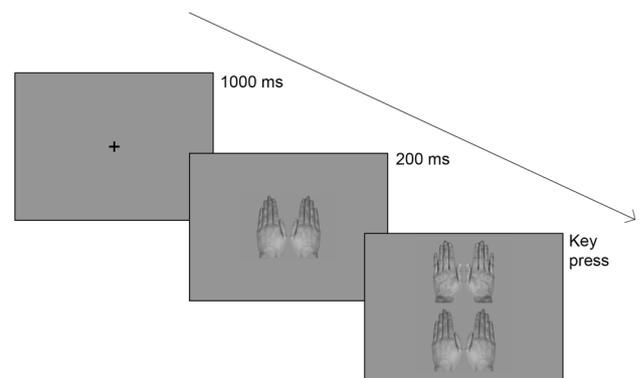


Fig. 2 Example of an experimental trial. Trials began with a fixation cross for 1 s. Then, participants were presented with a target stimulus (face, hands, or feet depending on the block) for 200 ms, followed by a test screen in which they were asked to indicate which of two stimuli was the target. The trial ended when the participant pressed a key, indicating their response

performed some practice trials following the same procedure of the actual experiment, but employing unknown participants’ stimuli. The practices were composed of 12 trials each. These trials were not counted for statistical analysis.

Results

Comparison between groups

Proportion of correct responses and response times (RTs) from correct trials were analysed. RTs were measured from the stimulus onset until participant’s response. RT outliers (2.5 SDs above or below the mean for each participant) were discarded and not analysed. In order to provide a better summary of our findings, we also analysed the inverse efficiency score (IES), defined as RT/accuracy (Bruyer and Brysbaert 2011). Indeed, it has been shown that focusing not only on accuracy is critical to detect differences between typical and atypical populations (Duchaine and Garrido 2008).

The accuracy, RTs and IES data from the control and CP groups were analysed using repeated measures

ANOVAs in IBM SPSS Statistics 22 (IBM Corp, Armonk, NY, USA)¹. A first series of ANOVAs were run on accuracy, RTs and IES data including as within-subjects factors Identity (Self vs. Other) and Condition (Face vs. Hands vs. Feet) and as between-subject factor Group (control group vs. CP group). Then, within each condition and for the self stimuli only (i.e., in the familiar stimulus condition, since no effect should be expected in the case of an unfamiliar stimulus), a second series of ANOVAs were run, to investigate any possible effects of the four stimuli (L_L, L_R, R_L, and R_R) on participants' performance. Thus, in these ANOVAs the within-subjects factor included was Stimulus (L_L, L_R, R_L, and R_R), and the between-subjects factor was Group (control group and CP group). Significant differences were further explored by Bonferroni post-hoc multiple comparisons (corrected p -values are reported). The effect sizes in the ANOVAs were also measured by computing the Partial Eta Squared (η_p^2).

Results from the first series of ANOVAs revealed that the triple interaction between Group, Condition and Identity was significant on accuracy, $F(2.56) = 25.13$, $p = .000$, $\eta_p^2 = 0.48$, and IES data, $F(2.56) = 18.67$, $p = 0.000$, $\eta_p^2 = 0.40$ (Fig. 3). Post-hoc comparisons showed that individuals with CP performed worse than controls only when they had to recognize unfamiliar faces (accuracy CP group: $M = 0.72$, $SE = 0.02$; accuracy control group: $M = 0.94$, $SE = 0.01$; $p = 0.000$; IES CP group: $M = 1064$ ms, $SE = 75$ ms; IES control group: $M = 851$ ms, $SE = 45$ ms; $p = 0.021$), while they performed similar to controls in recognizing their self faces (accuracy CP group: $M = 0.96$, $SE = 0.01$; accuracy control group: $M = 0.96$, $SE = 0.01$; $p = 0.970$; IES CP group: $M = 721$ ms, $SE = 44$ ms; IES control group: $M = 756$ ms, $SE = 26$ ms; $p = 0.493$) and in recognizing feet and hands, in both the "self" and "other" conditions (all $ps > 0.05$). Second, while accuracy data revealed a significant self-advantage only for faces in the CP group (self condition: $M = 0.96$, $SE = 0.01$; other

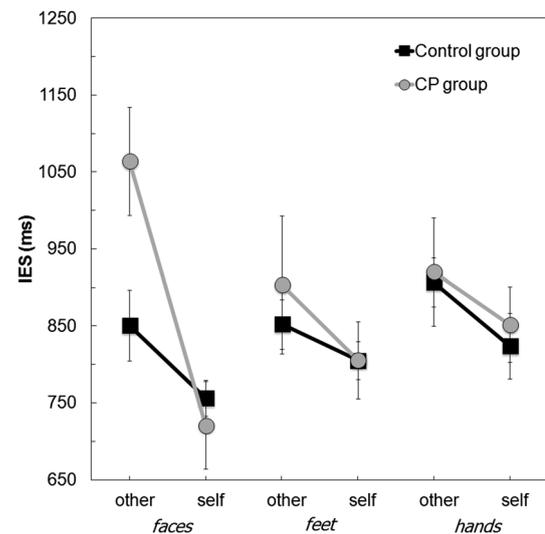


Fig. 3 Mean inverse efficiency score of the control group and congenital prosopagnosia group for the Other/Self in the different stimulus conditions. Vertical lines indicate ± 1 SE

condition: $M = 0.72$, $SE = 0.02$; $p = 0.000$), IES data showed the presence of a significant self-advantage for both faces and feet in the CP group (self face condition: $M = 721$ ms, $SE = 44$ ms; other face condition: $M = 1064$ ms, $SE = 75$ ms, $p = 0.000$; self feet condition: $M = 806$ ms, $SE = 43$ ms; other feet condition: $M = 904$ ms, $SE = 64$ ms, $p = 0.019$; self hands condition: $M = 852$ ms, $SE = 66$ ms; other hands condition: $M = 920$ ms, $SE = 58$ ms; $p = 0.273$) and for all stimuli in controls (self face condition: $M = 756$ ms, $SE = 26$ ms; other face condition: $M = 851$ ms, $SE = 45$ ms, $p = 0.006$; self feet condition: $M = 805$ ms, $SE = 26$ ms; other feet condition: $M = 852$ ms, $SE = 39$ ms, $p = 0.05$; self hands condition: $M = 824$ ms, $SE = 40$ ms; other hands condition: $M = 907$ ms, $SE = 35$ ms; $p = 0.032$). Third, in the "other" condition, controls showed significantly higher accuracy for faces compared to feet ($p = 0.005$) and hands ($p = .013$) in the "other" condition, while individuals with CP showed lower accuracy for faces than for feet ($p = .001$) and hands ($p = .000$). Individuals with CP also had a better performance with faces than feet ($p = .011$) in the "self" condition. No differences among faces, hands and feet stimuli were found in the IES data (all $ps > 0.05$).

The interaction between Group and Identity, $F(1.28) = 11.07$, $p = .002$, $\eta_p^2 = 0.28$, and the interaction between Group and Condition, $F(2.56) = 11.86$, $p = 0.000$, $\eta_p^2 = 0.30$, were also significant on accuracy. Post-hoc comparisons of the interaction between Group and Identity showed that individuals with CP (other condition: $M = 0.83$, $SE = 0.02$; self condition: $M = 0.93$, $SE = 0.02$) performed significantly worse than controls (other condition: $M = 0.91$, $SE = 0.01$, $p =$

¹ Since previous papers have suggested that females tend to outperform males in different tests of face recognition (Herlitz and Lovén 2013; Herlitz and Yonker 2002; Rennels and Cummings 2013) we first verified whether there was any difference in performance between female and male participants in both the control and CP groups. For each one of our conditions, independent samples t-test between female and male participants were run on the accuracy, RTs and IES data of the control participants, while the performance of the male individual with CP was compared to the one of the female individuals with CP by using single-subject statistics (Crawford and Garthwaite 2002). No significant differences were found between female and male controls in any of the conditions (all $ps > 0.05$). Similarly, in the CP group, the performance of the male individual was comparable to the one of the females in all conditions (all $ps > 0.05$). Given these results, we decided to exclude the participant's genders from the factor list in all subsequent analyses.

0.003; self condition: $M = 0.94$, $SE = 0.01$, $p = 0.775$) in the “other” condition but not in the “self” one. Moreover, both groups showed a significantly higher accuracy in the “self” condition compared to the “other” condition (CP group: $p = 0.000$; control group: $p = 0.042$). The interaction between Group and Condition, instead, revealed that individuals with CP performed significantly worse than controls when they had to recognize faces (CP group: $M = 0.84$, $SE = 0.02$; control group: $M = 0.95$, $SE = 0.01$; $p = 0.000$), but performed similar to controls with hands (CP group: $M = 0.92$, $SE = 0.02$; control group: $M = 0.91$, $SE = 0.01$; $p = 0.661$) and feet (CP group: $M = 0.88$, $SE = 0.02$; control group: $M = 0.91$, $SE = 0.01$; $p = 0.245$). Furthermore, both individuals with CP and controls had significantly different performances in the face and hands conditions, pointing in opposite directions: in fact, while the CP group showed better performance with faces than hands, the control group showed the opposite trend (CP group: $p = 0.007$; control group: $p = 0.019$).

The interaction between Identity and Condition was significant on both accuracy, $F(2.56) = 25.53$, $p = .000$, $\eta_p^2 = 0.48$, and IES data, $F(2.56) = 27.56$, $p = 0.000$, $\eta_p^2 = 0.50$. Post-hoc comparisons revealed that accuracy in the self-face condition ($M = 0.96$, $SE = 0.01$) was significantly higher than the accuracy in the other-face condition ($M = 0.83$, $SE = 0.01$, $p = 0.000$) and that accuracy for faces was significantly higher than accuracy for feet (self condition: $M = 0.91$, $SE = 0.01$; other condition: $M = 0.89$, $SE = 0.02$) and hands (self condition: $M = 0.92$, $SE = 0.01$; other condition: $M = 0.90$, $SE = 0.02$) (self condition, respectively $p = 0.000$ and $p = 0.012$; other conditions, respectively $p = 0.024$ and $p = 0.003$). By contrast, post-hoc comparisons for the IES data showed a significantly better performance with the self stimuli compared to the other stimuli (face self condition: $M = 739$ ms, $SE = 26$ ms; face other condition: $M = 957$ ms, $SE = 44$ ms, $p = 0.000$; feet self condition: $M = 805$ ms, $SE = 25$ ms; feet other condition: $M = 878$ ms, $SE = 38$ ms, $p = 0.004$; hands conditions self condition: $M = 838$ ms, $SE = 38$ ms; hands other condition: $M = 914$ ms, $SE = 34$ ms, $p = .043$), but no differences were found among faces, feet and hands stimuli, neither in the “self” nor in the “other” condition (all $ps > 0.05$).

The main effect of the Group was significant on the accuracy data, $F(1.28) = 5.13$, $p = 0.03$, $\eta_p^2 = 0.15$, showing that overall individuals with CP ($M = 0.88$, $SE = 0.02$) showed lower accuracy compared to controls ($M = 0.92$, $SE = 0.01$). The main effect of the Identity was significant on accuracy, $F(1.28) = 30.39$, $p = 0.000$, $\eta_p^2 = 0.52$, RTs, $F(1.28) = 7.96$, $p = 0.009$, $\eta_p^2 = 0.22$, and IES, $F(1.28) = 20.05$, $p = 0.001$, $\eta_p^2 = 0.42$, highlighting that both groups had a better performance in recognizing their self body-parts compared to the ones belonging to others (accuracy self: $M = 0.93$, $SE = 0.01$; accuracy other: $M = 0.87$, $SE = 0.01$; RTs self: $M = 737$ ms, $SE =$

16 ms; RTs other: $M = 787$ ms, $SE = 22$ ms; IES self: $M = 794$ ms, $SE = 21$ ms; IES other: $M = 916$ ms, $SE = 30$ ms).

Finally, the results from the second series of ANOVAs (i.e., the one investigating the effect of the different chimeras) failed to reveal any significant effect of the type of stimulus (L_L, L_R, R_R and R_R) in all conditions (face, hands, and feet), neither as main effect nor in interaction with the group factor (all $ps > 0.05$).

Comparing the self-advantage in the different conditions

Our results confirmed previous findings showing that the self-face advantage is detectable both in typically developed individuals and individuals with CP and that the self-face advantage showed by the CP group is so effective to lead their performance to be comparable to the one of controls in the self-face condition (Keyes and Brady 2010; Malaspina et al. 2016, 2018). Furthermore, these results suggest that both groups show a similar advantage in recognizing self body-parts compared to unfamiliar ones. However, to further investigate if there were any relations among the self-advantages showed in the different conditions, for each participant we calculated a self-advantage score for faces, hands and feet separately. For accuracy data, the self-advantage score was computed as the difference between the accuracy in the self-condition minus the accuracy in the other-condition, while for RTs and IES data as the difference between the other- and the self-conditions.

The self-advantage scores obtained were first submitted to one-sample t -tests to test whether the advantages in recognizing the self-stimuli for the different body parts were significantly larger than zero (one-tailed). Controls (see Table 2) showed the presence of a significant self-advantage for face, hands, and feet in both RTs and IES data. Only the self-face advantage was significant on accuracy data, though However, the lack of a significant advantage in the latter might be due to a ceiling effect in this group; this is also in accordance with previous studies on typically developed individuals showing that the advantage in recognizing self body-parts is detectable mainly in terms of RTs data (Ma and Han 2010; Sugiura et al. 2005). On the other side, individuals with CP (see Table 2) showed a significant self-advantage for faces only in the accuracy data, and for faces and feet in the IES data.

Afterwards, the self-advantage scores were compared across conditions within each group separately, using paired samples t test. Within the control group (see Table 3), the self-advantages for face, hands and feet did not differ from each other in accuracy, RTs or IES. In the CP group, instead, the self-advantage in the face condition was significantly larger than the feet and hands ones in both accuracy and IES

Table 2 Means (M) and standard errors (SE) for the self-advantages in the three conditions (faces, feet and hands) for both the control group and the individuals with CP. Significant self-advantages are indicated with bold text

	Individuals with CP			Control group		
	M (SE)	<i>t</i> (7)	<i>p</i> -value	M (SE)	<i>t</i> (21)	<i>p</i> -value
Accuracy						
Faces	0.242 (0.030)	8.11	0.000	0.026 (0.013)	1.95	0.032
Feet	0.036 (0.027)	1.34	0.111	0.016 (0.013)	1.23	0.115
Hands	0.013 (0.018)	0.72	0.248	0.031 (0.020)	1.58	0.064
RTs						
Faces	59 (52)	1.14	0.145	63 (24)	2.65	0.007
Feet	47 (28)	1.69	0.067	28 (15)	1.83	0.041
Hands	48 (33)	1.49	0.090	51 (24)	2.16	0.021
IES						
Faces	343 (52)	6.54	0.000	94 (32)	2.96	0.004
Feet	98 (47)	2.08	0.038	47 (22)	2.16	0.021
Hands	68 (45)	1.53	0.085	83 (40)	2.10	0.024

Table 3 Self-advantages comparison for both the control group and the individuals with CP

	Individuals with CP			Control group		
	M (SE)	<i>t</i> (7)	<i>p</i> -value	M (SE)	<i>t</i> (21)	<i>p</i> -value
Accuracy						
Faces-feet	0.205 (0.034)	4.74	0.002	0.010 (0.016)	0.62	0.545
Faces-hands	0.229 (0.034)	6.71	0.000	−0.006 (0.019)	−0.31	0.763
Feet-hands	0.023 (0.017)	1.34	0.222	−0.015 (0.018)	−0.86	0.398
RTs						
Faces-feet	13 (45)	0.28	0.786	35 (21)	1.63	0.118
Faces-hands	11 (40)	0.27	0.791	12 (19)	0.63	0.533
Feet-hands	−50 (18)	−2.69	0.031	4 (23)	0.18	0.856
IES						
Faces-feet	245 (28)	8.86	0.000	47 (23)	2.07	0.051
Faces-hands	275 (33)	8.43	0.000	11 (21)	0.51	0.612
Feet-hands	30 (23)	1.30	0.234	−35 (30)	−1.19	0.245

Significant self-advantages are indicated with bold text

data (see Table 3). Self-hands advantage was also larger than the self-feet advantage, but on the RTs data only.

Finally, the self-advantages were correlated across the three conditions, separately for each group (see Fig. 4). In the control group, the self-hands advantage was significantly correlated with the self-feet advantage in accuracy ($r=0.442$, $n=22$, $p=.039$), RTs ($r=0.437$, $n=22$, $p=.042$) and IES data ($r=0.660$, $n=22$, $p=.001$). The self-face advantage, instead, was significantly correlated with the self-feet (IES: $r=0.703$, $n=22$, $p<.001$; RTs: $r=0.473$, $n=22$, $p=.026$) and the self-hands advantage (IES: $r=0.843$, $n=22$, $p<.001$; RTs: $r=0.677$, $n=22$, $p=.01$) in the IES and RTs data. A similar pattern of correlation was also found in the group of individuals with CP: the self-feet advantage was significantly correlated with the self-hands advantage in accuracy ($r=0.776$, $n=8$, $p=.024$), RTs ($r=0.737$, $n=8$, $p=.037$) and IES data ($r=0.878$, $n=8$, $p=.004$). In the IES data, the self-face advantage was also significantly

correlated with the self-feet ($r=0.851$, $n=8$, $p=.007$) and self-hands advantages ($r=0.786$, $n=8$, $p=.021$).

Discussion

The aim of the present study was to test whether the self-face advantage (SFA) showed in previous studies by individuals with CP (Malaspina et al. 2016, 2018) and typically developed individuals (Ma and Han 2010; Sugiura et al. 2005) is face-specific or relies on a more general mechanism underlying self-recognition. For this reason, we investigated whether people affected by face recognition impairment (i.e., CP group) and healthy controls show a similar advantage for the self-face and body-parts, using a delayed visual matching task in which participants had to match a previously seen stimulus to one of two possible choices. Furthermore, since previous studies (Brady et al. 2004; Malaspina et al. 2016)

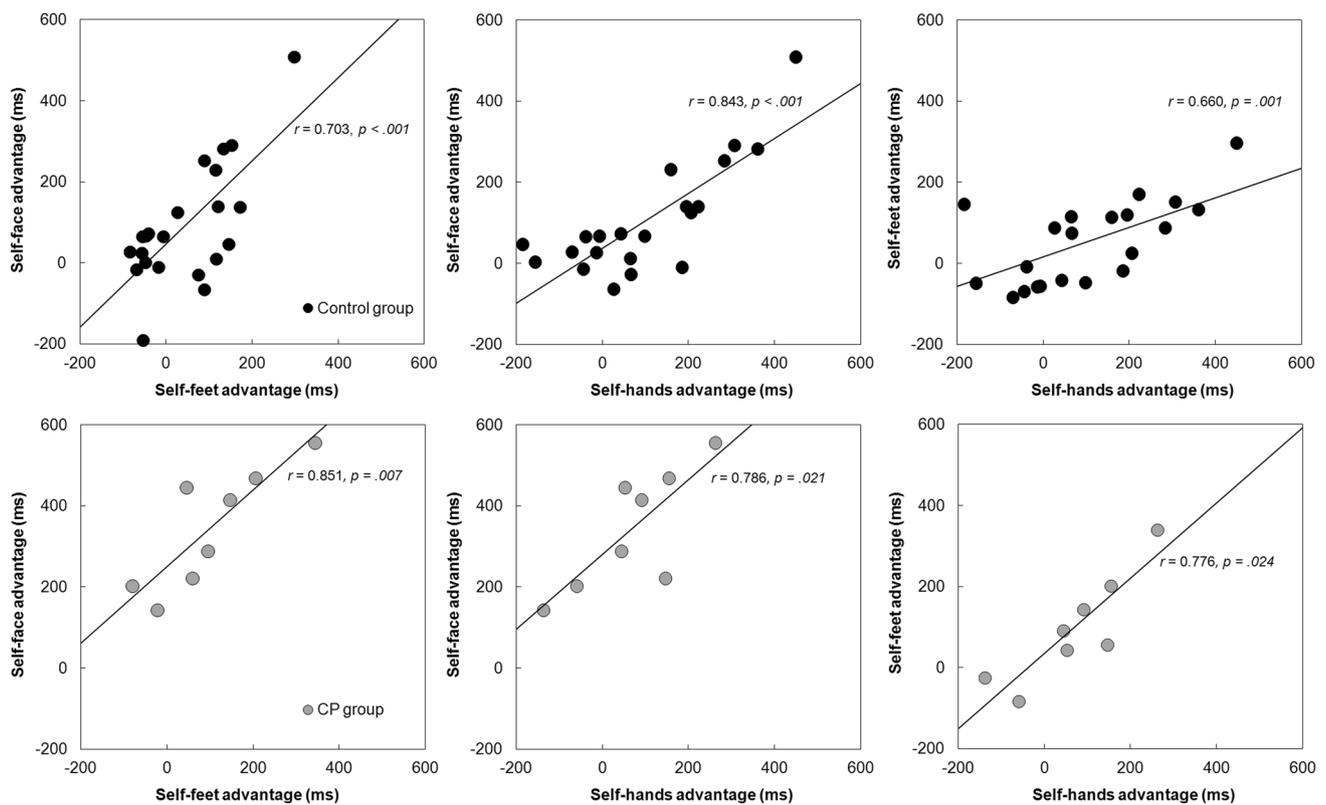


Fig. 4 Bivariate correlation of the self-advantages among the three conditions (face, hands and feet). Only results from the IES data are reported. Top row reports the results for the control group, whereas bottom row the results for the individuals with congenital prosopagnosia

suggested that a preference for the right part of the self-face might be at the origin of the self-face advantage, here we used self and unfamiliar face, hands and feet chimeric stimuli to investigate if a similar right bias is present also for other body parts.

First, in accordance with a previous study showing preserved recognition abilities during a hand-matching task in developmental prosopagnosia (Shah et al. 2015a, b), our data highlight that individuals with CP do not show difficulties in recognizing body parts. These results seem in contrast with some recent evidence suggesting that both individuals with acquired and congenital prosopagnosia can be impaired in whole body perception (Biotti et al. 2017; Moro et al. 2012; Rivolta et al. 2017), atypical body motion perception (Lange et al. 2009) and show abnormalities in cortical areas specialized for body processing (Jiahui et al. 2018; Righart and de Gelder 2007). However, one difference between our study and the ones mentioned above concerns the set of stimuli used: in fact, while the studies that found impaired performance and abnormal activation employed stimuli depicting the whole body, here, for the first time to our knowledge, we used different and defined self- and other body parts (face, hands and feet). Thus, the different results might have arisen from the different stimuli used and, interestingly, might leave

open the possibility of a dissociation between body-parts and whole body recognition in this population. In particular, some studies have suggested that holistic processing might not be specific to faces, but it could also apply to some other kinds of visual stimuli, such as bodies and objects belonging to the same class (Behrmann et al. 2005; Damasio et al. 1982; Farah et al. 1995a, b; Robbins and Coltheart 2012). In support of this hypothesis, it has been shown that body-recognition can be affected by inversion as well: when typically developed individuals are asked to recognize bodies, they are better with upright than inverted ones, and this “inversion effect” looks comparable to the one shown for faces (Minnebusch et al. 2009; Reed et al. 2003). Thus, the existence of a similar inversion effect for both bodies and faces might suggest that face and body processing could relate to similar cognitive and, eventually, neural processing (Rivolta et al. 2017; Robbins and Coltheart 2012). In particular, the comparison between the results of this study and the evidence already present in the literature might suggest that the holistic processing could be applied also to bodies (Robbins and Coltheart 2012): accordingly, individuals with CP would be impaired in recognizing the whole body, as they are in recognizing faces, but would show spared performance in recognizing the single parts composing the body, as they are

in recognizing local aspects of a face, such as nose, mouth and eyes. We suggest that the similarities between face and body processing could be due to the fact that both faces and bodies are complex social stimuli (Rivolta et al., 2016), relevant for person identification. Indeed, previous studies have demonstrated that when we are looking at a person, we strongly rely on face and the whole body for identification, with the face being the predominant cue (Burton et al. 1999), but with the weight of the whole body increasing under difficult viewing conditions (Rice et al. 2013). The similarities between faces and bodies might be also due to the physical proximity of the brain regions that process those stimuli; indeed, both body-tuned (fusiform body area; Downing et al. 2001) and face-tuned regions (fusiform face area; Kanwisher et al. 1997) are localized in the ventral temporal cortex. It is possible that the neurodevelopment of those regions might follow similar principles and trajectories. Accordingly, some studies have shown that face and body recognition have similar progress during childhood (Bank et al. 2015). However, further investigation is needed to explore the similarities and differences between face and body holistic processing.

Finally, another possibility worth considering is that body perception deficits could affect only a subset of the congenital prosopagnosic population. This latter hypothesis would be in accordance with the heterogeneity that characterizes CP and would also account for the normal body perception (Duchaine et al. 2006; Susilo et al. 2013) and normal activation of the body-selective brain regions (Van den Stock et al. 2008) that some individuals with prosopagnosia showed in other studies. Either way, further studies are needed to investigate whether body and face recognition impairments simply co-occur in individuals with prosopagnosia or rely on the same cognitive and neural processes.

Second, we found that typically developed individuals showed a self-advantage for all the three categories of stimuli (face, hands, and feet). This result is in accordance with previous findings showing that typically developed individuals can have enhanced performance in processing their own body-parts compared to other people's body-parts (Frassinetti et al. 2008, 2009, 2010) (Ma and Han 2010). However, in our study we also found that the advantage shown by controls with the self-material was of similar magnitude in all the three body-parts conditions (i.e., face, hands, and feet). Furthermore, we found strong correlations among self-advantages in the three stimuli conditions. Taken together, these results could prove the existence of a common mechanism underlying the processing of the self-face and self body-parts, leading to a general advantage for the recognition of the self-body. In particular, in our opinion this advantage and the mechanism underlying self-recognition are strictly tied to the multi-source nature of the self-related information. Indeed, while most of our experience of the others is visually related, information on the self-body

comes not only from visual input, but also from kinaesthetic, tactile, vestibular and proprioceptive sources. Our suggestion is that the integration of such multisensory information could determine a more complete and robust representation of the self-body that, in individuals with typical development, leads to a quantitative advantage (higher accuracy and faster responses), while it compensates for a missing or distorted input in individuals with CP; for this reason, the recognition of self-related information would be associated with lower thresholds compared to the information related to others. Accordingly, one study (Cook et al. 2012) has shown that individuals are able to visually recognize their own body motion better than that of familiar people, even though we rarely have visual experience of our own bodies in motion. Different studies have also suggested that the processing of self-information is related to activity of a right fronto-parietal network (Devue et al. 2007; Platek et al. 2004, 2006; Uddin et al. 2005). Within this network, two brain regions, which are the right anterior insula and the right anterior cingulate, seemed to play a role in the integration of self-information independently of the stimulus domain, resulting in a more abstract representation of the self-information (Devue et al. 2007). It is possible that such a multi-modal representation supported by those two brain regions could be responsible for the self-advantage we found with different body parts in all our participants. However, additional studies are required to further investigate the mechanisms underlying the self-advantage.

Similarly to controls, individuals with CP showed an advantage in recognizing their own body-parts compared to unfamiliar ones and, in particular, in this population the self-advantage was larger in the case of faces compared to hands or feet. Despite this result might support the face-specificity of the self-face advantage, we believe that the observed pattern could lead to another more plausible interpretation. Indeed, these individuals performed similarly with the self-face and body parts, while significantly worst with unfamiliar faces compared to unfamiliar body parts. Hence, the larger self-advantage with faces compared to hands and feet looks mainly driven by their lower performance with unfamiliar faces. Furthermore, the existence of a face-specific mechanism responsible for a self-face advantage in a population characterized by a selective face recognition impairment seems unlikely. By contrast, it seems more reasonable that the enhancement of the processing of self-material could underlie both the self-face and self body-part advantages, as further proved by the strong correlations we found among the self-advantage across the face, hands and feet conditions. In particular, the multisensory representation of the self-material would allow individuals with CP to recognize the self-face despite their characteristic face recognition impairment. Indeed the visual information related to face stimuli can be considered somehow poorer in individuals with CP

compared to controls, because of their atypical face recognition abilities, which would not allow them to process faces with the same specific and expert processing of typically developed individuals. However, it is possible that inputs from other modalities could obviate for this impoverished processing of the visual input and allow them to correctly identify at least the self-face.

It is worth mentioning that in each trial of the experiment the same picture was used for the study and test phases and that a limited number of exemplars were used as face, hands and feet stimuli (i.e., one depicting the self-body and two depicting unknown body-parts). While it is possible that the use of the same image might have made the task easier for all participants, we do not believe that our pattern of results can be simply explained by the use of image matching strategies. Indeed, if the results had been simply driven by participants' ability to rely on matching strategies, then we would not have found differences between self and unfamiliar stimuli. Furthermore, it has been shown that image matching strategies are particularly useful for individuals who struggle to create a view-invariant form of the visual stimulus (Longmore et al. 2008). However, if our participants with CP had taken advantage of those strategies, then they would have been able to complete the task in all three conditions, including unfamiliar faces. By contrast, the CP group struggled in the unfamiliar face condition, but not in the hands or feet ones, suggesting that the task used here was sensitive enough to detect the face recognition impairment of these individuals and further possible deficits with hands or feet. Regarding the number of exemplars used, instead, one could argue that the use of a limited number of stimuli exemplars might have decreased the task demands and influenced our results. However, our analyses revealed that even control individuals showed a significantly different performance among the three stimulus types in the "other" condition (with hands and feet being harder than faces). In particular, this would confirm that, despite the relatively easy demands, our task was sensitive enough to detect difference among the different body-parts and between the two groups. Finally, the experimental paradigm used in the present study is very close to those of previous studies (Rivolta et al. 2017; Moro et al. 2012) that did find impaired body perception in prosopagnosia, suggesting that task demands were not a key factor in determining our results.

Finally, since previous evidence (Brady et al. 2004; Malaspina et al. 2016) suggested that the self-face advantage shown by both typically developed individuals and individuals with CP could be linked to a preference for the right-half of the face, in this study we used chimeric stimuli to test whether a similar bias was detectable also during the recognition of other body-parts. However, analyses on the different chimeric stimuli failed to reveal any preference for any of them. In particular, here we could not find any rightward bias, neither for

faces nor for hands or feet stimuli. Nonetheless, we believe that the lack of a right perceptual bias can be still informative in two ways. First, it might suggest that the right perceptual bias could be sensitive to task demands. Indeed, the first report of a right perceptual bias for the self-face comes from a study in which participants were required to judge the likeness of chimeric faces to the memory representation of the self-face (Brady et al. 2004). A subsequent study that has introduced a reference face to which compare the chimeric faces failed to report such bias (Brady et al. 2005). Even in Malaspina et al. (2016), where the right perceptual bias was described in the individuals with CP, no bias was found in typically developed individuals in both accuracy and response times; again, in that study the response screen with the chimeric faces was preceded by a reference face. Thus, the present results, together with those of previous studies, seem to suggest that the right asymmetry characterizing the processing of the self-face could interest specifically the mnemonic representation of one's own face but not its perceptual representation; indeed, when more perceptual task are used, a preference for the right-half of the self-face does not emerge. Second, the fact that both the control group and the individuals with CP showed significant self-advantages, despite not exhibiting a preference for the right-half of the face or body-part stimuli, could further suggest that those two effects are independent of each other (Malaspina et al. 2018). In fact, if the self-advantage depended on the preference for the right-half of the body-parts, the lack of a right bias should automatically translate into a lack of self effects. By contrast, our results showed the opposite pattern: a significant self-advantage for all the body-parts in the absence of any right bias. Taken together, these results seem to suggest an independency between the two biases. In particular, while the self-advantage might arise from the multi-modal nature of the self-related information, possibly supported by an activity in the right anterior insula and the right anterior cingulate, the right-perceptual bias might involve the long-term memory representation of the self-body.

In conclusion, the present study shows that self body-part recognition is spared in individuals with CP, suggesting that body-parts and whole-body processing might be dissociable in this population. Moreover, we further confirmed the presence of a self-face advantage in both individuals with CP and typically developed individuals. In particular, while the self-face advantage was comparable to those showed with other body parts (e.g., hands and feet) in typically developed individuals, the CP group showed a larger self-advantage for faces compared to hands and feet, due to their poor performance with others' faces. Furthermore, we found a strong relation among the self-advantages in the different conditions in both groups, indicating that the same mechanism could be responsible for both self-face and self body-parts recognition. This enhancement of the self-information processing might be due to the integration of multisensory signs of the self-body relying on a

fronto-parietal network. Finally, we could not find any rightward bias in the recognition of self body-parts, further confirming that the right perceptual bias characterizing self-face recognition is independent of the self-advantage.

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