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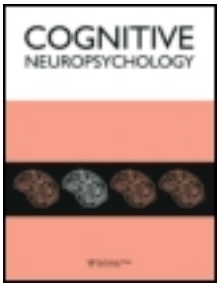

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General holistic impairment in congenital prosopagnosia: Evidence from Garner's speeded-classification task

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General holistic impairment in congenital prosopagnosia: Evidence from Garner's speeded-classification task

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Congenital prosopagnosia (CP), a lifelong impairment in face processing in the absence of brain damage, is often ascribed to impairment in holistic processing. It is still debated whether such difficulties are restricted to faces or whether they can also be observed for nonfacial stimuli. Here, we investigate this issue by examining CP individuals and their controls on two variations of the Garner speeded classification task tailored to assess holistic processing of nonfacial stimuli. In Experiment 1, participants were asked to judge the width of visually presented rectangles while ignoring their irrelevant height, or to judge changes in width while height remained constant. Critically, while controls exhibited the expected Garner interference, no such interference was observed for the CPs, indicating impaired holistic processing of integral, nonfacial shape dimensions. Experiment 2, utilized the same Garner paradigm, but here participants were asked to judge integral dimensions that are unrelated to shape (colour). Importantly, both CPs and controls exhibited the same level of Garner interference, indicating intact integral processing of colour dimensions. This dissociation between the performance on the two Garner tasks indicates that CPs do not exhibit a general local processing bias or impaired integration of any perceptual dimensions, but rather a deficit that is restricted to tasks requiring holistic integral perception of shape dimensions. Taken together, these results provide evidence for the existence of a general impairment in holistic shape perception in CP, which may be related to the mechanisms underlying this disorder.

Keywords: Face perception; Holistic processing; Shape perception; Impaired integration.

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Impaired holistic processing in prosopagnosia

Prosopagnosia is a condition in which face perception is highly impaired either due to a brain lesion (acquired prosopagnosia: AP) or congenitally (CP), in the absence of brain damage and given intact sensory and intellectual functions (Barton, 2008, 2009; Behrmann & Avidan, 2005; Lobmaier, Bölte, Mast, & Dobel, 2010; Rivest, Moscovitch, & Black, 2009). Many studies on prosopagnosic individuals reveal disrupted holistic processing of faces (for example, see the following papers in AP: Barton, 2009; Barton, Zhao, & Keenan, 2003; Busigny, Joubert, Felician,

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Ceccaldi, & Rossion, 2010; Busigny & Rossion, 2010; Ramon, Busigny, & Rossion, 2010; CP: Avidan, Tanzer, & Behrmann, 2011; Behrmann, Avidan, Marotta, & Kimchi, 2005; Bentin, DeGutis, D'Esposito, & Robertson, 2007; Kimchi, Behrmann, Avidan, & Amishav, 2012; Lange et al., 2009; Palermo et al., 2011; Susilo, McKone, & Edwards, 2010).[1] These studies used well-established tasks designed to examine holistic perception and its disruption under various experimental manipulations (e.g., inversion effect, Farah, Tanaka, & Drain, 1995; Freire, Lee, & Symons, 2000; Yin, 1969; part–whole effect, Gauthier & Tarr, 2002; Tanaka & Farah, 1993; and the composite effect, Boutet, Gentes-Hawn, & Chaudhuri, 2002; Farah, Wilson, Drain, & Tanaka, 1998; Gauthier, Curran, Curby, & Collins, 2003; Young, Hellawell, & Hay, 1987). Critically, it was shown that both CP and AP differ from their matched controls in their response pattern under these different manipulations. For example, both CP and AP failed to show the part–whole face advantage—that is, better perception of a face feature when this feature is embedded within the entire face than perception of the same feature when it is presented in isolation (Boutsen, & Humphreys, 2002; DeGutis, Chatterjee, Mercado, & Nakayama, 2012; DeGutis, Cohan, Mercado, Wilmer, & Nakayama, 2012; Ramon et al., 2010; Stephan, Breen, & Caine, 2006). Similarly, unlike the typical advantage for upright faces exhibited by normal observers, prosopagnosic individuals showed equal, or even superior, performance for inverted compared to upright faces (Avidan et al., 2011; Behrmann et al., 2005; Busigny & Rossion, 2010; Gauthier, Behrmann, & Tarr, 1999; Schmalzl, Palermo, & Coltheart, 2008). Moreover, in the composite face paradigm, in which two composite faces are presented, and participants are instructed to make same/different decisions based only on the top part of the face, normal participants are more prone to judgement errors when the top and bottom part of a face are aligned than when they are misaligned (Le Grand et al., 2006; Young et al., 1987). Contrary to this typical effect, both CP and AP individuals were shown to be less affected by this manipulation (Avidan et al., 2011; Palermo et al., 2011; Ramon et al., 2010). Finally, and of much relevance for the present investigation, using the Garner paradigm, Kimchi et al. (2012) showed that, unlike controls, CP individuals (CPs) were able to process information about facial features regardless of irrelevant changes in configural information and vice versa—that is, process information about facial configuration, regardless of irrelevant changes in features. These results provide further evidence for impairment in holistic face processing in these individuals.

In contrast to these results, some studies do not show such evidence for impaired holistic face processing in prosopagnosic individuals and rather report normal inversion and composite effects among CPs (Le Grand et al., 2006; Schmalzl et al., 2008; Susilo et al., 2010), as well as intact holistic processing and reliance on configural information while recognizing face gender (DeGutis, Chatterjee, et al., 2012). We return to these inconsistencies and their possible accounts in the Discussion section.

The relation between holistic perception and face recognition abilities

But what is the relation between holistic face perception and face recognition abilities? Previous studies imply a clear association between these two abilities. For example, performance in holistic face perception, as measured by the composite and part–whole tasks, predicted better face recognition ability (DeGutis, Wilmer, Mercado, & Cohan, 2012; Richler, Wong, & Gauthier, 2011; Wang, Li, Fang, Tian, & Liu, 2012). Likewise, in CPs, Avidan et al. (2011) showed a positive correlation between the severity of the face recognition impairment, as evident by the performance

[1] We note that the ongoing theoretical debate on what exactly constitutes holistic processing is beyond the scope of the current paper (for further discussion on this issue see Behrmann, Richler, Avidan, & Kimchi, 2013).

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on two diagnostic tests (Cambridge Face Memory Test, CFMT, and a famous faces questionnaire) and the extent of the local bias in the composite task. Moreover, not only may holistic face processing and face recognition be associated but several studies also imply that the latter is related to general holistic processing abilities in healthy individuals. For example, Darling, Martin, Hellmann, & Memon (2009) reported that global superiority, as measured by the Navon task (Navon, 1977) is positively correlated with better performance on a face identification task. The same task was also positively correlated with the face inversion effect, such that individuals who had a larger global bias were more prone to the face orientation manipulation (Martin & Macrae, 2010).

THE PRESENT STUDY: GENERAL HOLISTIC DEFICIT IN CONGENITAL PROSOPAGNOSIA

The main question that emerges from this review of the literature and is the focus of the present study is whether individuals with prosopagnosia, and here we only focus on the congenital form, would also exhibit deficits in processing other visual stimuli in which holistic perception is required. That is, are the holistic deficits exhibited by these individuals, which are associated with their face recognition impairment, only restricted to faces or can they be revealed for other nonfacial stimuli that require holistic perception? This question has important theoretical bearings as it implies a general deficit in holistic perception as a possible mechanism underlying CP.

There are several studies that examined holistic perception of nonface stimuli in CP (Avidan et al., 2011; Behrmann & Avidan, 2005; Behrmann et al., 2005; Bentin et al., 2007; Duchaine, Yovel, & Nakayama, 2007; Lange et al., 2009; Le Grand et al., 2006; Schmalzl et al., 2008). Here, we lay out some of the existing, often conflicting findings in CP, and we return to the possible interpretation of these discrepancies in the Discussion section. Thus, for example, Avidan et al. (2011) and Behrmann et al. (2005) found that individuals with CP exhibited a disruption in holistic processing for nonfacial stimuli, using the Navon global/local compound letter identification task (Navon, 1977). Specifically, CP individuals, contrary to a group of matched controls, showed a clear local bias as evident by faster local than global letter identification and greater local to global interference (Avidan et al., 2011; Behrmann et al., 2005). Notably, a similar local bias was also reported in Bentin et al. (2007). Finally, some CP individuals also show abnormal processing of biological motion, a deficit that, similarly to face perception, was attributed to the reliance on configural processing (Lange et al., 2009). Such findings provide additional evidence for a more general holistic perception deficit in CP. Again, not all studies report such deficits in holistic processing of nonfacial stimuli. Specifically, CP participants in these studies exhibited the typical global superiority in the Navon task (Duchaine, Yovel, et al., 2007), were impaired in configural processing of faces but not of houses, and had normal sensitivity to global form and motion (Le Grand et al., 2006).

Thus, there is still an ongoing debate as to whether congenital prosopagnosia is a face-specific impairment or whether this deficit can be accounted for by a more general impairment in holistic processing. Such inconsistencies may stem from the different tasks and stimuli employed across studies. For example, the Navon compound letters task, commonly used as a tool to distinguish between holistic compared to more analytic processing, while being very popular, has two major limitations. First, the goal of the experiment (i.e., contrasting global vs. local processing) is embedded within the explicit instructions given to participants, thus inducing prior expectations that might bias the results. Second, and perhaps more critically, this task can be determined by relying on the high and low spatial frequencies components of the small and large elements, respectively, rather than exerting specific global or local attentional mechanisms (Dakin & Frith, 2005). We note that, despite these limitations, we also employ this task in the present study to allow direct comparison of our new findings to the existing literature (see Experiment 3).

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To overcome these limitations, in the present study we aimed to further examine the extent to which CP individuals exhibit a general holistic processing deficit using the classic Garner's speeded-classification task (Garner, 1974, and see above). This paradigm is specifically tailored to assess holistic processing by measuring participants' ability to attend to a single dimension of an object while ignoring an irrelevant dimension belonging to the same object (Garner, 1974). In the main experiment (Garner shape paradigm, Experiment 1), we used rectangles as the experimental stimuli, as they are simple, basic, two-dimensional objects that have been previously found to be processed in an integral, holistic fashion using the Garner paradigm (Felfoldy, 1974; Ganel & Goodale, 2003; Kunde, Landgraf, Paelecke, & Kiesel, 2007). Specifically, participants were asked to classify such rectangles on the basis of their width (decide whether they are wide or narrow) in two different conditions. In the *baseline* condition, the relevant dimension (width) varied on a trial by trial basis, while the irrelevant dimension (height) was kept at a constant value. In the *filtering* condition, both the relevant and irrelevant dimensions varied on a trial-by-trial basis (Figure 1a). Equal performance in the baseline and filtering conditions indicates perfect selective attention to the relevant dimension, and the dimensions are considered *separable*. Poorer performance in the filtering than in the baseline condition—*Garner interference*—indicates that participants could not selectively attend to one dimension without being influenced by irrelevant variation in another dimension, despite being task irrelevant, and the dimensions are considered *integral*. As mentioned above, normal observers performing this task cannot ignore the irrelevant dimension (height) of the rectangles, and hence they exhibit Garner interference.

In a control experiment (Garner colour paradigm, Experiment 2), we wanted to examine a corollary question, and that is whether CP individuals would exhibit a deficit in the integration of any perceptual dimensions, or whether their holistic deficit is restricted only to integration of dimensions that constitute a shape. Using the same Garner paradigm and the rectangle stimuli as those in Experiment 1, we now focused on colour rather than shape as the perceptual dimension. Importantly, colour perception is composed of three dependent, integral dimensions (i.e., hue, brightness, and saturation), rendering it impossible to judge one of these dimensions without being influenced by the other dimensions (Burns & Shepp, 1988). Most critically however, contrary to the width and height of the rectangles judged in Experiment 1, here, the integration of the colour dimensions of the rectangles (and we focus on hue and brightness) does not involve shape perception.

Thus, the specific tailoring of the experimental stimuli (width and height of rectangles vs. hue and brightness of coloured rectangles) in tandem with the Garner paradigm provides a basic psychophysical measure of holistic perception. If, as predicted based on previous findings, CP individuals indeed exhibit difficulties in holistic *shape* perception, we expect that, in Experiment 1, they would be able to process the rectangles' width and height in a separable manner and would not show shape-related Garner interference as opposed to controls. In contrast, if indeed their holistic deficit is restricted to shape dimensions, we expect to find the same level of Garner interference in both groups in Experiment 2. This pattern of results will stress the notion that CPs do not simply tend to focus their attention on local elements but, rather, they exhibit a specific deficit in holistic processing that is restricted to configural requirements related to shape perception.

Method

Participants

All participants had normal or corrected-to-normal vision and provided written informed consent to a protocol approved by the Ethics committee of the Psychology Department at Ben-Gurion University of the Negev. Handedness was determined by self-report.

Congenital prosopagnosia group. Twelve healthy individuals diagnosed with CP (two males, one

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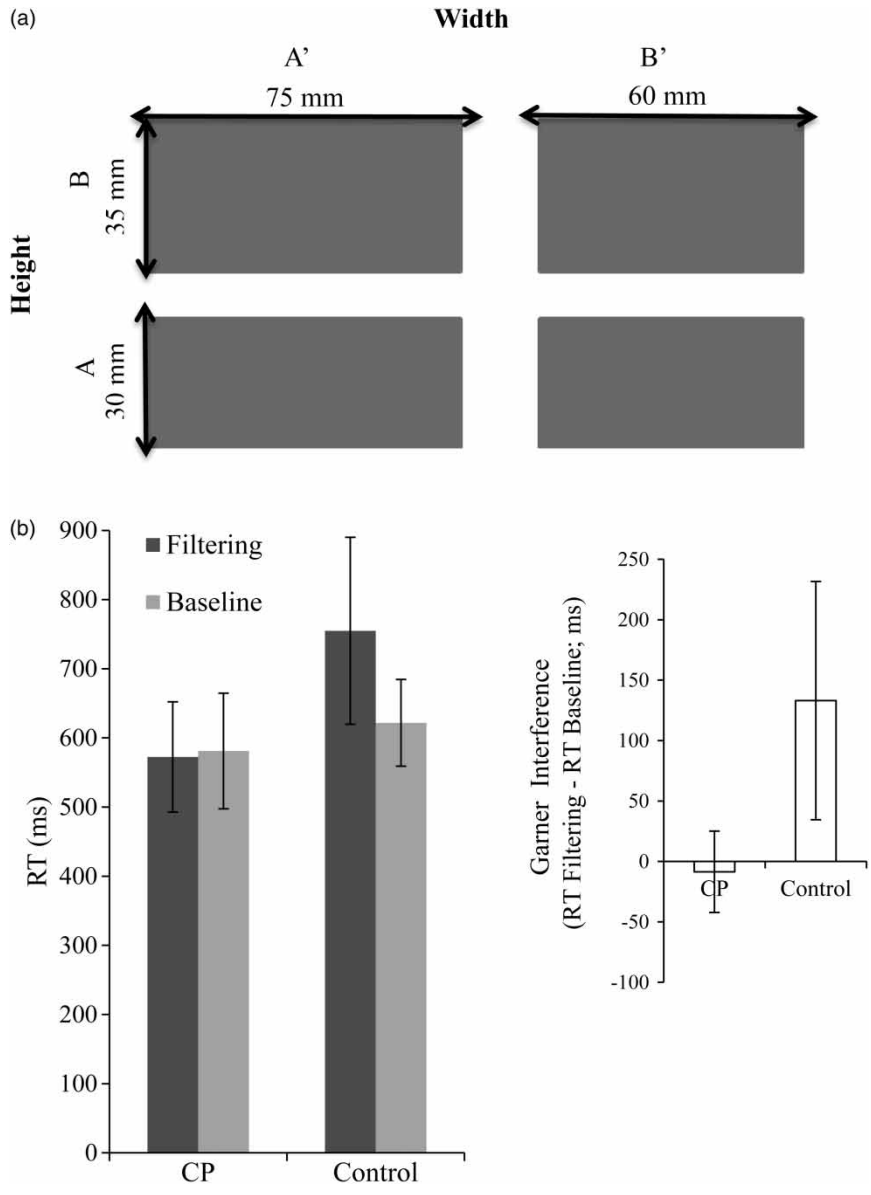

Figure 1. *(a) Stimuli used in the Garner shape experiment (Experiment 1): A set of four grey rectangles is shown; two were classified as "wide" (width 75 mm) and differed in height (35 or 30 mm: BA′ and AA′, respectively), and two were classified as "narrow" (width 60 mm) and again differed by the same height (BB′ and AB′). (b) Reaction time (RT) in ms obtained in Experiment 1 for congenital prosopagnosia (CP) participants and their age-matched controls on the "filtering" and "baseline" conditions. Note the lack of difference in RT between the filtering and baseline conditions in the CP group, indicating that CPs did not exhibit a Garner interference effect (graph on the right). Error bars denote inferential confidence intervals (ICIs) that were calculated based on the method devised by Tryon and Lewis (2008).*

left-handed) participated in this study; age range was 22–67 years (mean ± *SD* = 43.5 ± 17.2; see Table 1). All CP participants reported experiencing substantial life-long difficulties with face processing and were thoroughly interviewed to exclude other conditions that may

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account for their difficulty. Moreover, as previously reported in Avidan et al. (2011), in order to establish objective diagnostic criteria for CP individuals, we used four different experiments previously reported in the literature (e.g., the famous face questionnaire; the Cambridge Face Memory test, CFMT, Duchaine & Nakayama, 2006a; the Cambridge Face Perception test, CFPT, Duchaine, Germine, & Nakayama, 2007; and a task measuring discrimination of unfamiliar upright and inverted faces). We calculated *z*-scores for each participant based on data obtained from large control groups (for more details see Avidan et al., 2011). We included only participants with clear impairments (more than 2 *SD*s) on at least two of these four diagnostic measures as per standards commonly used in this literature (DeGutis, Chatterjee, et al., 2012; Duchaine, Germine, et al., 2007; Duchaine, Yovel, et al., 2007; Duchaine & Nakayama, 2006b; Rivolta, Palermo, Schmalzl, & Coltheart, 2011; Yovel & Duchaine, 2006). For brevity, we provide detailed performance only for the famous face questionnaire and the CFMT, which are commonly used across studies and were diagnostic for nine of the 12 CP participants. For the remaining three, we also provide indication of performance on the upright/inverted face discrimination to allow full assessment of their diagnosis (see Table 1). Eight CPs participated in the Garner shape paradigm (Experiment 1), and eight in the colour Garner (Experiment 2); four CPs participated in both Experiment 1 and Experiment 2. All CPs participated in the *Navon compound letter global/local (GL) task* (Experiment 3). Note that six of the CP

Table 1. *Demographic details of CP individuals and performance (raw values and z-scores) on the famous faces questionnaire and the CFMT*

			Famous faces questionnaire		*CFMT (total)*	
Participant	*Sex*	*Age*	*% corr.*	*z-score*	*Score*	*z-score*
JF[a]	F	63	46%	**−2.88**	51	*−1.13*[c]
EM	M	67	29%	**−4.20**	27	**−4.30**
SI[b]	F	66	37%	**−3.53**	45	***−1.92***
JT[b]	F	37	52%	**−2.4**	32	**−3.63**
OH	F	22	52%	**−2.4**	37	**−2.97**
ID[b]	F	41	37%	**−3.53**	37	**−2.97**
SW[ab]	F	50	55%	**−2.18**	48	*−1.53*[c]
TZ[ab]	F	62	70%	*−1.1*[c]	43	**−2.18**
UT	F	30	39%	**−3.93**	45	***−1.92***
FG	F	24	46%	**−2.85**	42	**−2.31**
OG	M	29	21%	**−4.77**	36	**−3.1**
SS	F	31	44%	**−2.68**	39	**−2.71**
CP (average ± sd)		43.5 ± 17.2	44% ± 12	**−3.21 ± 0.8**	40.2 ± 6.8	**−2.8 ± 0.8**
Matched Control (n=14) (average ± sd)		47.7 ± 16.8	88% ± 0.1		55.9 ± 11.4	

Note: Raw data and z-scores. CP − Congenital prosopagnosia; CFMT = Cambridge Face Memory Test; F = Female; M = Male; % corr = % correct answers. Code for the z-score: *Italic* = −1SD below control performance; ***Bold Italic*** = −1.6SD below control performance; **Bold** = −2SD below control performance. Note that in the famous faces questionnaire and the CFMT, abnormal performance is indicated by a negative z-score.

[a]These CPs also participated in Kimchi et al., (2012). [b]These CPs also participated in Avidan et al., (2011); data on the Navon compound letter task for these individuals is also reported in this reference. [c]These CPs exhibit borderline deficit on the CFMT or famous faces questionnaire but importantly, they also show abnormal performance (>2SD) on an upright/inverted face discrimination task which is part of our diagnostic battery and hence adhere to our inclusion criteria (see Methods for more details).

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individuals also participated in previous studies (Avidan et al., 2011; Kimchi et al., 2012), and during the current experimental sessions they all also took part in additional experiments that are not related to the present study.

Control group

All control participants were healthy community volunteers. A matched control group was used for each of the Garner experiments (Experiments 1 and 2), and for the Navon compound letter GL task (Experiment 3) we used a group of age-matched controls subselected from a large control group previously reported in Avidan et al. (2011).

Matched control group. A total of 14 healthy community volunteers participated in the Garner experiments and were compensated for their participation, age range 25–67 years (mean $\pm$ *SD* = 47.7 $\pm$ 16.8); *t*-test analysis revealed that the CP and control group did not differ in age ($t = -0.10$, $p = .90$). Participants were matched according to their age, gender, and dominant hand. They all completed two standard diagnostic face processing tests to confirm normal face perception (famous faces questionnaire and CFMT; see below for details of tasks and Table 1 for group performance). Eight of these matched controls participated in the Garner shape paradigm (Experiment 1), and eight in the colour Garner (Experiment 2); two participated in both Experiment 1 and Experiment 2.

Control for the Navon compound letter global/local (GL) task. Twelve healthy participants, subselected based on age and gender from a larger control group previously reported (Avidan et al., 2011), were included. Age range was 22–68 years (mean $\pm$ *SD* = 43.5 $\pm$ 18.1); *t*-test analysis revealed that the CP and control group did not differ in age ($t = 0.01$, $p = .90$).

Stimuli and experimental design

Participants were tested individually; they were seated at a viewing distance of approximately 60 cm from a computer screen. All tests except for the famous faces questionnaire were run on either a laptop (if testing occurred outside the lab due to participants' necessities) or a desktop PC in the lab.

Diagnostic tests

Famous faces questionnaire

The questionnaire consisted of photographs of faces of 56 celebrities, randomly intermixed with 56 photos of faces of unknown individuals (celebrities who are famous in other countries). Face images were inserted into a table printed on paper or presented on a computer screen, and participants had to indicate the name of the individual, provide some contextual information (e.g., occupation) or respond "do not know". Participants were allowed unlimited time to fill out this questionnaire. Correct responses included either the correct name of a person or a detailed correct context (e.g., female American actress who played in the movie "Gentlemen Prefer Blondes" in response to a picture of Marilyn Monroe), and we calculated a *z*-score for each participant based on previously reported control data (Avidan et al., 2011). To the best of our knowledge, none of the anonymous "celebrities" is famous in our country, and this was confirmed in pilot studies. Moreover, the average rate of indicating "I don't know" for these face stimuli by both CPs and their matched control was above 95%, and those faces that were named were falsely recognized.

Cambridge Face Memory Test (CFMT)

This test was developed by Bradley Duchaine who kindly provided us with the test, and it was run using a Java script. Detailed description of the procedures can be found in Duchaine, Germine, et al. (2007) and Duchaine and Nakayama (2006a). Briefly, the CFMT is designed to examine short-term memory of unfamiliar faces and has been widely used in recent years in the congenital/developmental prosopagnosia literature. The *z*-score for each participant was calculated using data of 20 controls (aged 45.1 $\pm$ 9.1) that were used in previous studies for diagnostic purposes of individuals with developmental prosopagnosia (Duchaine,

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Germine, et al., 2007) and were provided by Bradley Duchaine.

EXPERIMENTAL TESTS

Method

All experiments were programmed using E-prime software (Psychology Software Tools, Inc.), and both reaction time and accuracy were recorded.

Experiment 1: The Garner shape paradigm

Stimuli were a set of four grey rectangles; two were classified as "narrow" (width 60 mm) and differed in height (30 or 35 mm), and two were classified as "wide" (width 75 mm) and differed by the same height (Figure 1a). Prior to testing, participants were familiarized with all four rectangles and confirmed that they could discriminate between the height/width variations. They were asked to learn the two categories (wide or narrow) to allow classification of these stimuli. In each trial, participants saw only one rectangle presented for unlimited exposure duration and were instructed to press one of two designated keys on the keyboard. The experiment was composed of a total of 160 trials divided into four blocks (40 trials in each block; two filtering blocks and two baseline blocks). The first eight trials in each block were considered as practice and were discarded from further analysis. In the *baseline* blocks, the relevant dimension (width) varied from trial to trial while the irrelevant dimension (height) was held constant. In the *filtering* blocks, both dimensions varied. The order of the blocks was counterbalanced across participants in each group (i.e., half of the participants were randomly allocated to start with the baseline blocks, and the other half started with the filtering blocks); each matched control performed the experiment in the same order as their respective CP. Previous studies using the Garner paradigm with similar stimuli have used a full design (i.e., judging width while height was irrelevant and vice versa) and reported symmetric effects (Cant, Large, McCall, & Goodale, 2008; Dykes, 1979). Given these previous reports and the limited availability of the CP individuals, we only used the shorter, partial Garner task (judging width but not height, see Ganel & Goodale, 2003; Kunde et al., 2007).

Experiment 2: The Garner colour paradigm

All stimuli were created and coloured using Adobe Photoshop software. The experimental structure is identical to the shape Garner experiment, with the following exceptions: Two rectangles were classified as "bright" (100% brightness) and differed in hue (red or pink), and two were classified as "dark" (85% brightness) and differed by the same hue (Figure 2); saturation was held constant for all rectangles. Prior to testing, participants were familiarized with all four rectangles and confirmed that they could discriminate between the hues and brightness levels. In the baseline blocks, the relevant dimension (brightness) varied from trial to trial while the irrelevant dimension (hue) was held constant. In the filtering blocks, both dimensions varied.

Experiment 3: The Navon compound letter global/local (GL) task

All CP individuals completed the Navon compound letter global/local (GL) task (Figure 3a). Stimuli included four hierarchical letters of two types: consistent letters, in which the global and the local letters shared identity (a large H made of smaller Hs and a large S made of small Ss), and inconsistent letters in which the letters at the two levels had different identities (a large H made of small Ss and a large S made of small Hs). Dimensions of the global letter were $3.2 \times 3^{\circ}$, and those of the local letter were $0.44 \times 0.53^{\circ}$. Participants identified the letter at either the global or local level in separate blocks of trials in which consistent and inconsistent letters were randomized. Each block ($n = 96$ trials) was preceded by instructions to identify the letter at the local or global level. Participants pressed one of two keys on the keyboard to indicate a response of "S" or "H". A trial was initiated with a central fixation cross of 500-ms duration, which was immediately replaced by one of the four possible stimuli. Participants pressed one of

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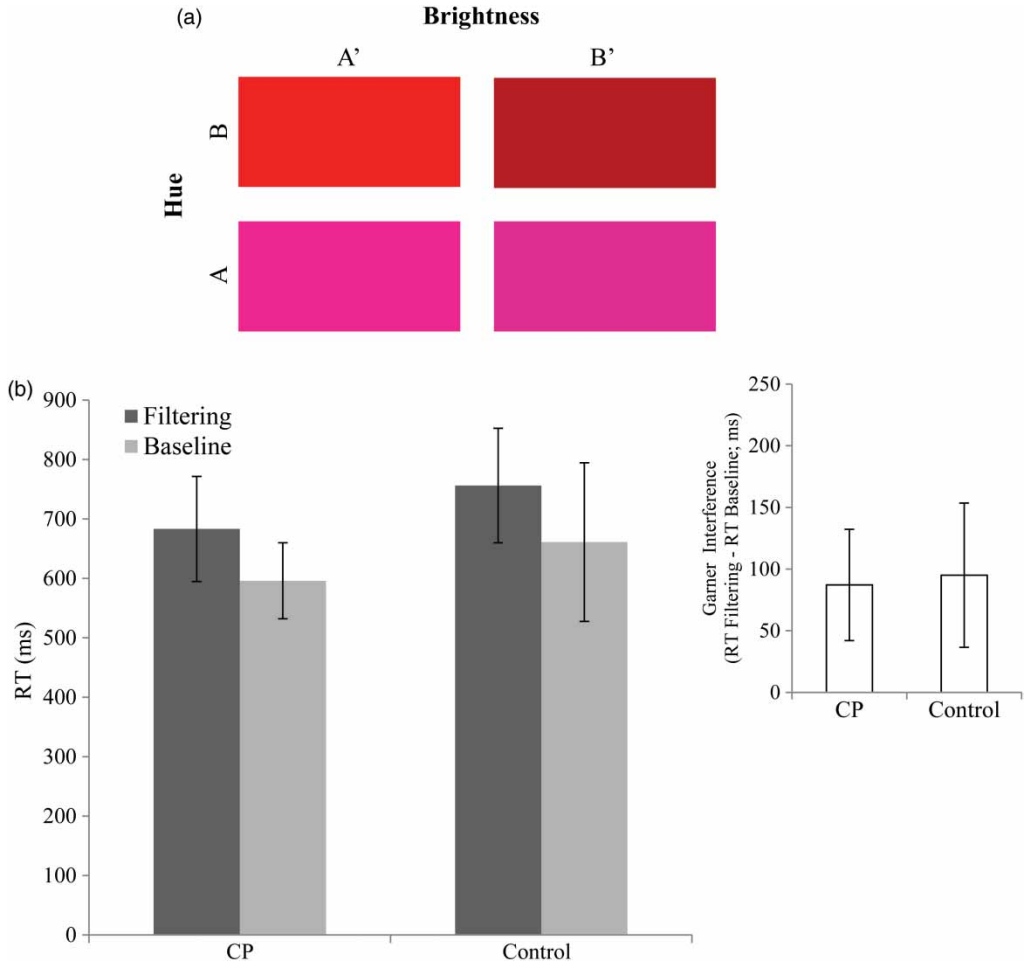

Figure 2. *(a) Stimuli used in the Garner colour experiment (Experiment 2): A set of four rectangles is shown; two rectangles were classified as "bright" (100% brightness) and differed in hue (red or pink: BA′ and AA′, respectively), and two were classified as "dark" (85% brightness) and differed by the same hue (BB′ and AB′, respectively). To view this figure in colour please see the online version of this journal. (b) Reaction time (RT) in ms obtained in Experiment 2 for congenital prosopagnosia (CP) participants and their age-matched controls on the "filtering" and "baseline" conditions. Note that both groups showed a similar RT difference between the filtering and baseline conditions, indicating a Garner interference effect (graph on the right). Error bars were calculated as in Figure 1.*

two keys on the keyboard to indicate a response of "S" or "H". The stimuli remained visible until subjects responded.

Results

Diagnostic tests

We first compared CPs and controls (all CPs vs. all matched controls who participated in Experiments 1 and 2) on the diagnostic tests using a *t*-test for independent groups. These comparisons revealed that the two groups (control vs. CP) significantly differed on the famous face questionnaire (average percentage correct: 44% vs. 88%; $t = -10.01$, $p < .001$) as well as on the CFMT (average score: 40.2 vs. 55.9; $t = -4.17$, $p < .001$; see Table 1). Importantly, the data used for diagnostic purposes of the CPs as detailed in

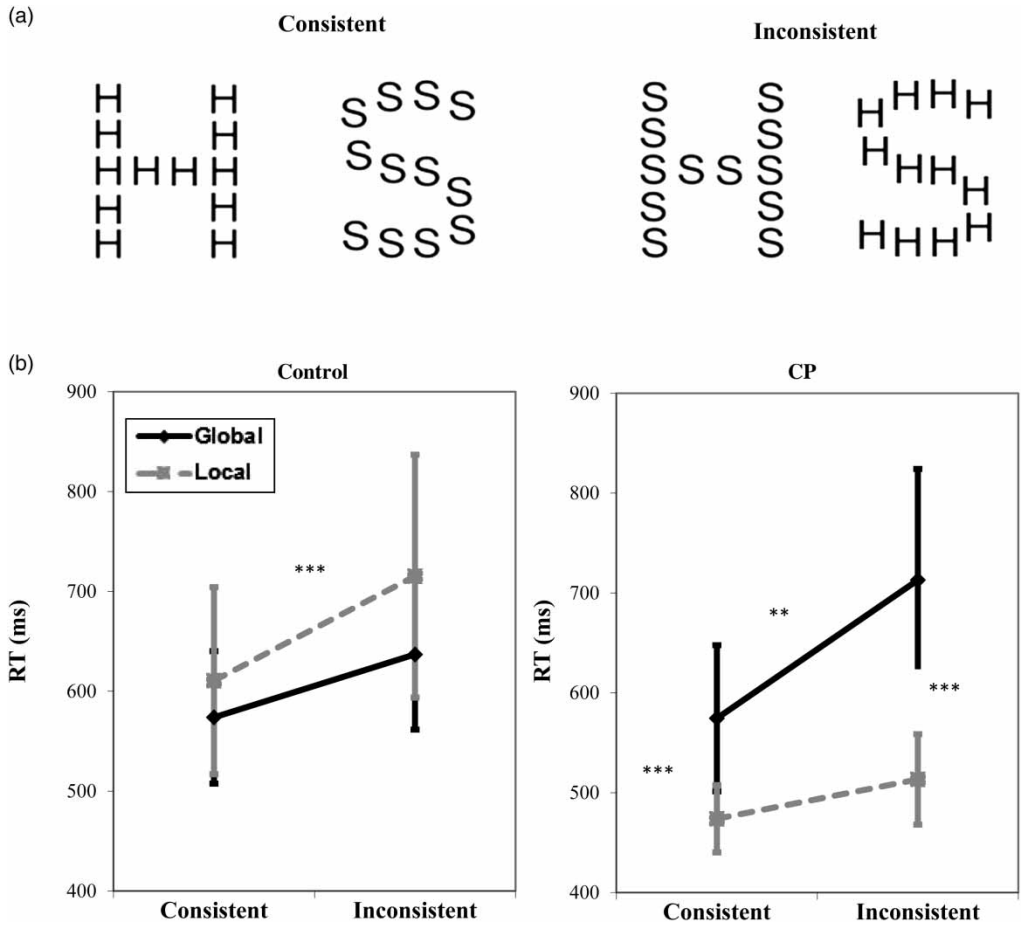

Figure 3. *(a) Stimuli used in the compound letter global/local task (Experiment 3). (b) Reaction time (RT) in ms on the global/local task for the congenital prosopagnosia (CP) participants and a group of matched control participants (these control data were also included in Avidan et al., 2011). CPs do not exhibit the expected global advantage and, instead, evince a local advantage and local-to-global interference. Asterisks denote significance level:* $^{**}p < .005$ $^{***}p < .0005$. *Error bars were calculated as in Figure 1.*

Table 1 did not include the data of these matched controls, and hence this comparison across groups provides a separate confirmation of their diagnosis.

Experiment 1: Garner shape paradigm

All reaction time (RT) summaries and analyses (see Table 2) are based on participants' mean RTs for correct responses. RTs less than or greater than 2.5 standard deviations were discarded from the analysis (average of 3% of the trials per participant in both groups). Overall error rate was 2.49% (control group 2.83%, and CP group 2.14%).

To test our a priori hypothesis that CP would exhibit reduced Garner interference compared to controls, we used a one-tailed mixed-design analysis of variance (ANOVA) on RTs with group (CP vs. control) as a between-subject factor and condition (baseline vs. filtering) as a within-subject factor. This analysis revealed a significant interaction between group and condition, $F(1, 14) = 3.55$, $p < .05$, $\eta_p^2 = .20$. Further analysis using planned comparisons indicated that while the control group

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Table 2. *Individual data and group average of CP participants and group average of the control group on the three experimental tasks*

	Garner shape paradigm (Experiment 1)			*Garner colour paradigm (Experiment 2)*			*Navon compound letter global/local (GL) task (Experiment 3)*	
	RT (ms)			*RT (ms)*			*RT inconsistent − RT consistent*	
Participant	*Filtering*	*Baseline*	*Garner interference*	*Filtering*	*Baseline*	*Garner interference*	*Local to global interference*	*Global to local interference*
S.I.	646.89	584.55	62.33	—	—	—	212.65	30.77
J.T.	448.65	434.34	14.31	—	—	—	53.27	34.92
O.H.	390.11	362.35	27.75	—	—	—	62.89	10.68
I.D.	434.38	415.96	18.42	—	—	—	616.32	224.59
S.W.	712.87	702.49	10.37	672.15	566.37	105.78	60.28	3.64
T.Z.	642.23	797.14	−154.91	701.98	669.28	32.69	265.61	38.66
J.F.	422.44	485.51	−63.06	1021.38	731.05	290.33	69.48	38.73
E.M.	882.38	865.79	16.58	943.34	785.61	157.72	77.20	−1.98
U.T.	—	—	—	515.92	416.56	99.35	25.69	57.54
O.G.	—	—	—	613.14	653.72	−40.57	38.59	23.99
F.H.	—	—	—	697.42	619.06	78.35	57.78	18.46
S.S.	—	—	—	472.75	454.43	18.31	114.52	37.07
Average ± *SD*	575.49 ± 175	581.02 ± 188	−8.52 ± 68	683.11 ± 201	595.92 ± 137	92.74 ± 100	137.85 ± 167	43.08 ± 59
Control average ± *SD* (*n*)	754.87 ± 299 (8)	621.76 ± 143 (8)	133.1 ± 201 (8)	756.12 ± 219 (8)	661.03 ± 286 (8)	95.09 ± 132 (8)	63.04 ± 69 (12)	104.85 ± 66 (12)

Note: CP = congenital prosopagnosia; RT = reaction time. In Experiments 1 and 2, Garner interference is derived from RT filtering − RT baseline (in ms). Global to local/local to global interference is calculated as RT inconsistent − RT consistent (in ms).

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exhibited a clear Garner interference, as evident by the significance difference in RT between the filtering and baseline conditions (754.87 ms vs. 621.76), $F(1, 14) = 6.28$, $p < .05$, $\eta_p^2 = .30$, the CP group did not exhibit such an effect (572.49 ms vs. 581.01 ms), $F(1, 14) < 1$, indicating no evidence for Garner interference. Importantly, there was no evidence for a group difference in the RT obtained for the baseline condition (control 621.76 ms vs. 581.01), $F(1, 14) < 1$, emphasizing that the significant difference between the groups is derived from the filtering-baseline interference exhibited by the controls and the lack of such interference in CP (see Figure 1b).

To further confirm the patterns of differences and similarities across CPs and controls, we adopted a method for calculating inferential confidence intervals (ICIs) (Tryon, 2001; Tryon & Lewis, 2008) and applied this statistical approach to our data (see Avidan et al., 2013, for a recent study using this approach with CP individuals). This method addresses some of the problems of traditional null hypothesis testing and enables one to infer statistical differences, but also, and even more critically, statistical equivalence between two groups (see below in Experiment 2). We separately calculated the 95% ICI (one-tailed) for the Garner interference effect (i.e., filtering RTs − baseline RTs) in each group and then compared the values across the two groups. Importantly, this comparison revealed nonoverlapping ICIs of the Garner effect across the two groups (see Figure 1), indicating a significant difference between the groups and further confirming the results of the ANOVA. A similar analysis using accuracy level as the dependent variable in a repeated measures ANOVA revealed no significant group interaction ($F < 1$). Applying the ICI method to the interference index calculated based on accuracy revealed statistical equivalence between the two groups (at 95% ICI; one-tailed), again confirming the results of the standard ANOVA.

Further comparisons were carried out to rule out speed–accuracy trade-offs in each group. Specifically, in the matched control group, participants were less accurate in the filtering than in the baseline condition, indicating Garner interference in accuracy, $F(1, 14) = 5.98$, $p < .05$ (95.90% vs. 98.44%), which is consistent with the RT effect and hence excludes speed–accuracy trade-offs. The same comparison conducted for the CP group did not reveal a Garner interference in accuracy, $F(1, 14) = 1.27$, $p = .27$ (97.26% vs. 98.44%), which is consistent with the absence of such an effect in RT in this group and excludes the possibility of speed–accuracy trade-offs.

Experiment 2: Garner colour paradigm

All RT summaries and analyses (see Table 2) are based on participants' mean RTs for correct responses. Trials with RTs less than or greater than 2.5 standard deviations were discarded from the analysis (average of 2% per participant for both groups). Overall error rate was 4.8% (control group 4.9%, and CP group 4.6%).

To test our a priori hypothesis that CP would exhibit the same Garner interference as controls, we used a mixed-design ANOVA on RTs with group (CP vs. controls) as a between-subject factor and condition (baseline vs. filtering) as a within-subject factor. No statistically significant interaction between group and condition was found ($F < 1$), and there was a main effect of condition, $F(1, 14) = 9.44$, $p < .01$, $\eta_p^2 = .40$, indicating that both groups exhibit Garner interference as evident by the significance difference in RT between the filtering and baseline conditions (CPs, 683 ms vs. 595 ms; control, 756 ms vs. 661 ms). Critically, applying the ICI method to the interference index revealed statistical equivalence between the two groups (at 95% ICI; one-tailed), again confirming the results of the standard ANOVA.

A similar analysis using accuracy level as the dependent variable revealed no significant interaction ($F < 1$) nor main effect, $F(1, 14) = 1.61$, $p = .22$. Again, the ICI method calculated based on the accuracy interference index confirmed the result of the standard ANOVA and showed statistical equivalence (at 95% ICI; one-tailed).

Experiment 3: The Navon compound letter task

Several previous studies, including our own (Avidan et al., 2011; Behrmann et al., 2005),

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which examined general holistic deficits in CP, used the Navon compound letter task (Figure 3a). To allow examination of consistency with these previous results, we also tested the participants of the present study on the same task in addition to the tasks described in Experiments 1 and 2 (see Table 2). Note that some of the data reported here were already included in our previous publication (specifically, the data for the age-matched controls subselected from a larger control group included in the original paper, and the data of five of the 12 CPs; see Table 1 and Avidan et al., 2011); these data are brought here again to allow comparison with the results of the present study. To examine the performance on this task, we used a mixed-design ANOVA on RTs with group (CP vs. control) as a between-subjects factor, and task (local vs. global) and consistency (consistent vs. inconsistent) as within-subject factors. A statistically significant three-way interaction between group, task, and consistency was found, $F(1, 22) = 14.31$, $p < .01$, $\eta_p^2 = .39$. Probing of this interaction revealed a two-way interaction of task and group, $F(1, 22) = 22.65$, $p < .001$, $\eta_p^2 = .51$. These results reveal that in contrast to controls, CPs do not exhibit the expected global advantage (see Figure 3b). Instead, they evince a local advantage as reflected in an overall faster RT in the local condition than in the global one, and greater global to local interference (see Avidan et al., 2011; Behrmann et al., 2005, for a similar finding).

Correlations across tasks

Finally, contrary to previous findings that reported association between holistic processing and face perception abilities in CP (Avidan et al., 2011), there were no correlations between the Garner interference index and performance in the different face diagnostic tasks (CFMT and famous faces questionnaire), nor between the Garner interference index and the Navon global index. However, this null effect might be attributed to the relatively small number of participants ($n = 8$ in each group) and/or to the mixed order of blocks (i.e., starts from baseline or filtering) inherent to the Garner paradigm, which might have masked any such correlations.

GENERAL DISCUSSION

The aim of the present study was to further explore the intriguing ongoing debate on *general* versus *face-specific* holistic impairments as a possible mechanism underlying face perception deficits in CP. Here we tested CP individuals and controls on two variations of the classic Garner's speeded-classification paradigm (Garner, 1974), designed to assess holistic processing. The first experiment, which is the critical one, was designed to assess holistic, integral shape processing. A second, follow-up experiment (Experiment 2) was aimed to assess whether CP would be impaired at the perception of any integral dimensions, or whether their deficit is restricted to the integration of dimensions that are related to shape per se. Specifically, in Experiment 1 (Garner shape paradigm), participants were required to judge the width, while ignoring the height, of simple 2D rectangles, which are probably among the most basic examples of nonfacial stimuli that are known to be processed holistically (Ganel & Goodale, 2003). In Experiment 2 (Garner colour paradigm), participants were requested to judge the brightness of coloured rectangles (rather than their shape dimension), while ignoring their hue. Importantly, these two dimensions were repeatedly shown to be processed as integral dimensions but, critically, they are unrelated to shape (Burns & Shepp, 1988).

In Experiment 1, we showed that while controls failed to ignore variations along the irrelevant shape dimension, consequently exhibiting Garner interference, the CP group was unaffected by manipulation of the irrelevant dimension (height) and demonstrated no such interference. The marked difference in performance observed for the CP group compared to controls is particularly intriguing given previous findings demonstrating robust Garner interference in similar paradigms in normal participants (Cant et al., 2008; Ganel & Goodale, 2003; Macmillan & Ornstein, 1998). In contrast, in Experiment 2, both CPs and controls showed a Garner interference effect when integral processing was related to colour rather than to shape perception. These findings indicate that the lack of holistic

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perception, typical to CPs, is not due to a general failure in integration or a general overfocused local attentional bias that allows them to ignore information from any irrelevant dimension. Rather, the deficit in holistic processing is evident only when the task requires configural shape integration. Consistently with these novel findings and in accordance with our previous reports (Avidan et al., 2011; Behrmann et al., 2005), we also showed that these CP individuals display a local bias in the Navon compound letter task (Experiment 3), a pattern that markedly deviates from the typical global superiority exhibited by controls. Taken together with the results of Experiments 1 and 2, this pattern of results implies that the impaired holistic performance can be demonstrated across a number of tasks with different characteristics, pertaining that the relevant dimensions to be integrated are related to holistic shape processing.

These results are consistent with previous findings indicating that CP exhibit difficulties in deriving holistic perception of nonface stimuli (Barton, 2009; Bentin et al., 2007; Lange et al., 2009; Palermo et al., 2011). Note, however, that the usage of the Garner shape paradigm resolves some critical limitations that have been attributed to the Navon compound letters task commonly used in other studies. For example, in the Navon task, participants are explicitly being told, prior to the task, to focus on the global or the local form of the letter, and hence their performance might be biased by prior expectations. But, more critically, participants' decision in this task can be determined by relying solely on the high and low spatial frequency components of the small and large elements, respectively, rather than exerting a specific global or local attentional mechanism (Dakin & Frith, 2005). Hence, a central goal of the present study was to devise an alternative task, using the simplest possible shapes to assess holistic perception, and this is precisely what the Garner classification task permits.

As outlined above, despite the converging evidence stemming from the existing literature, some studies failed to find more general holistic impairments in prosopagnosia and rather reported normal holistic processing of nonfacial stimuli (AP, Barton, 2009; Busigny et al., 2010; Busigny & Rossion, 2010; CP, Duchaine & Nakayama, 2006b; Duchaine, Yovel, et al., 2007; Susilo et al., 2010; Yovel & Duchaine, 2006; and in some participants, Le Grand et al., 2006). Such behavioural inconsistencies were explained by the divergence across studies in terms of diagnostic criteria (Avidan et al., 2011) and more intriguingly in possible inherent heterogeneity in the characteristics of the CP population (Avidan et al., 2011; Behrmann & Avidan, 2005; Bentin et al., 2007; Duchaine & Nakayama, 2006b; Duchaine, Yovel, et al., 2007; Stollhoff, Jost, Elze, & Kennerknecht, 2011). Clearly, the issue of the heterogeneity of the behavioural and related neural profile of CP is very important (Furl, Garrido, Dolan, Driver, & Duchaine, 2011; Garrido et al., 2009). Uncovering possible subtypes of the disorder may certainly advance our understanding, not only of CP but also of face perception more generally and perhaps even of other neurodevelopmental disorders (for a recent review see Avidan & Behrmann, in press). At present, given the small number of participants in this and other behavioural and imaging studies, we can only speculate on this issue.

The present results provide evidence for a more *general* impairment in holistic shape processing in CP. We note that we were not able to show direct correlation between holistic shape processing and holistic face processing, probably due to the relatively small number of participants or the inherent properties of the Garner experimental design. However, in light of the existing literature implying that general holistic processing and face perception are associated (Avidan et al., 2011; Darling et al., 2009; Martin & Macrae, 2010), we suggest that the present results may imply that at least some of the face processing deficits in these individuals might be attributed to this difficulty. One possible prediction stemming from these results is that CPs should exhibit deficits in other object categories in addition to faces as was also suggested previously in AP (Barton, 2009; Behrmann et al., 2005; Gauthier et al., 1999). While there are reports indicating impairments in object processing in CP, these difficulties are

not evident in all participants (Behrmann et al., 2005; Duchaine & Nakayama, 2005; Stollhoff et al., 2011) and are not as severe as the face impairments. Further research in CP is clearly warranted in order to unequivocally establish the relation between impairments in holistic face perception and the general holistic impairments in shape perception reported here; such research should also account for a possible relation between the latter deficit and deficits in object processing.

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