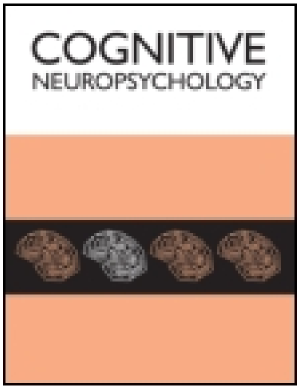

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Perceptual separability of featural and configural information in congenital prosopagnosia

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The deficit in face recognition in individuals with prosopagnosia has often been attributed to an underlying impairment in holistic processing. Exactly what constitutes holistic processing has remained controversial, however. Here, we compare how configural information and featural information interact during face processing in a group of individuals with congenital prosopagnosia (CP) and matched controls. We adopted Amishav and Kimchi's version of Garner's speeded classification task, in which observers classify upright faces based on configural (intereyes and nose–mouth spacing) or featural (shape of eyes, nose, and mouth) information while the other dimension remains constant or varied randomly. We replicated the finding that normal observers evince symmetric Garner interference—failure to selectively attend to features without being influenced by irrelevant variation in configuration, and vice versa—indicating that featural and configural information are integral in normal face processing. In contrast, the CPs showed no Garner interference: They were able to attend to configural information without interference from irrelevant variation in featural information, and they were able to attend to featural information without interference from irrelevant variation in configural information. The absence of Garner interference in CP provides strong evidence that featural information and configural information are perceptually separable in CP's face processing. These findings indicate that CPs do not perceive faces holistically; rather, they process featural and configural information independently.

Keywords: Configural processing; Congenital prosopagnosia; Dimensional integrality; Dimensional separability; Faces; Face perception; Featural processing; Holistic processing.

Adults' expertise in face recognition has been attributed to their ability to engage in holistic or configural processing. Evidence to support this claim comes from multiple studies showing that face perception engages a representation that goes beyond the sensitivity to features of

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the face. Converging evidence is gleaned from investigations of individuals with prosopagnosia who, along with the difficulty in face recognition, are also impaired at holistic/configural processing. Although holistic or configural processing is considered a hallmark of face perception, there is an ongoing debate as to what exactly constitutes this form of processing (e.g., Maurer, Le Grand, & Mondloch, 2002). Here, we revisit this debate by laying out several theoretical proposals stipulating what might be computed during holistic processing, and, based on these proposals, we set out some predictions regarding the nature of the impairment in prosopagnosia. We then review existing studies that demonstrate the nature of the impairment in prosopagnosia. Finally, we present empirical evidence obtained from individuals with congenital prosopagnosia (CP) using a speeded classification paradigm that can help adjudicate between the various theoretical claims. Based on these findings, we conclude that whereas featural and configural information are integral during normal face processing, these two types of information are separable in CP. These findings both support and challenge existing accounts in that we observe no specific impairment in processing configural information, but rather a deficit in holistic processing, which is manifested as a failure to process featural information and configural information integrally.

What is holistic versus configural processing?

Holistic/configural processing is commonly contrasted with analytic or part-based processing, and although the terms "configural" and "holistic" are sometimes used interchangeably, they often refer to different kinds of processing (see also, Tanaka & Gordon, 2011). The *holistic view* posits that faces are perceived and represented as unified wholes, in which featural information (individual facial features such as eyes, nose, and mouth) and configural information (spatial relations between facial features) are fused together (e.g., Farah, Wilson, Drain, & Tanaka, 1998; Tanaka & Farah, 1993; Tanaka & Sengco, 1997; Young, Hellawell, & Hay, 1987). In its extreme version, this view assumes that faces are not decomposed into parts at all. On such a view, there is mandatory perceptual integration across the entire face region (McKone, 2008), or similarly, mandatory interactive processing of all facial information (e.g., Yovel & Kanwisher, 2004).

Several empirical findings, in particular the part–whole effect and the composite face effect, have been interpreted as supporting the holistic view. The part–whole effect (Tanaka & Farah, 1993) refers to the finding that a particular facial feature (e.g., the nose) is recognized more accurately when tested in the context of the entire studied face than when tested in isolation. In the original composite face effect (Young et al., 1987), aligning two half faces of different familiar individuals makes it difficult to recognize the person in the top half compared with a condition in which the two halves are misaligned. The effect is also readily observed for unfamiliar faces in a same/different discrimination paradigm (e.g., Richler, Bukach, & Gauthier, 2009). Both the part–whole and the composite effects are absent for inverted faces and are much weaker or absent for nonface objects (e.g., Carey & Diamond, 1994; Donnelly & Davidoff, 1999; Gauthier & Tarr, 2002; Robbins & McKone, 2007; Tanaka & Farah, 1993; Young et al., 1987).

The *configural view* posits that both features and configural information are explicitly represented in faces, but that configural information dominates upright face processing (e.g., Bartlett & Searcy, 1993; Cooper & Wojan, 2000; Diamond & Carey, 1986; Leder & Bruce, 2000; Maurer et al., 2002; Rhodes, 1988; Rhodes, Brake, & Atkinson, 1993; Searcy & Bartlett, 1996). Specifically, spacing of the facial features relative to each other, often referred to as 'second-order spatial relations', are assumed to be critical for the processing of individual faces. They are distinguished from 'first-order spatial relations', which refer to the basic arrangement of the features (i.e., the eyes above the nose and the mouth below the nose) and are critical for discriminating faces from other object classes (Diamond & Carey, 1986; Maurer, et al., 2002).[1]

Several studies have demonstrated that even very small changes to the spacing between features can be perceived when faces are upright (Haig, 1984; Hosie, Ellis, & Haig, 1988; Kemp, McManus, & Pigott, 1990). The main support for the configural view comes from studies demonstrating that inversion disrupts the processing of configural information, whereas the processing of featural information is relatively immune to inversion (e.g., Freire, Lee, & Symons, 2000; Leder & Bruce, 2000; Leder et al., 2001; Mondloch, Le Grand, & Maurer, 2002; Murray, Yong, & Rhodes, 2000).

Both views, however, have not gone unchallenged. For example, in contrast to the part–whole effect, which is considered a marker for holistic processing, there are findings demonstrating that facial features are not identified or discriminated better in the context of the whole face than in isolation (Gold, Mundy, & Tjan, 2012; Homa, Haver, & Schwartz, 1976; Kimchi & Amishav, 2010). Also, in contrast to the findings of differential effect of inversion on the processing of configural versus featural information, which are considered evidence for the configural view, some findings show that the processing of both types of information can be *equally* affected by face inversion (Riesenhuber, Jarudi, Gilad, & Sinha, 2004; Yovel & Duchaine, 2006; Yovel & Kanwisher, 2004), and other findings suggest that the inversion effect reflects reduced efficiency rather than a qualitative change in face processing (Sekuler, Gaspar, Gold, & Bennett, 2004). Furthermore, contrary to both views, there is substantial evidence that facial features themselves play an important role in face processing (e.g., Cabeza & Kato, 2000; Collishaw & Hole, 2000; Harris & Nakayama, 2008; Martelli, Majaj, & Pelli, 2005; Miellet, Caldara, & Schyns, 2011; Rotshtein, Geng, Driver, & Dolan, 2007; Schwarzer & Massaro, 2001).

An alternative approach for understanding the nature of face representation and processing, and the one taken here, is to examine how featural and configural information interact in face processing using methodologies that are linked to theoretical distinctions, such as Garner's (1974) distinction of dimensional separability/integrality, and that have been successfully applied to the domain of object perception. *Separable* dimensions can be selectively attended to without interference from the unattended dimension or property and are processed independently. *Integral* dimensions cannot be selectively attended to and processed independently of each other. Stimuli composed of separable dimensions are processed analytically, by their dimensional values; stimuli composed of integral dimensions are processed holistically, as unified wholes. A powerful method to assess dimensional interaction is Garner's (1974) speeded-classification paradigm. Garner's paradigm examines whether perceivers can attend to one dimension of an object without experiencing interference from irrelevant variation in another dimension and provides a rigorous test of perceptual separability between stimulus dimensions (Maddox, 1992).

Amishav and Kimchi (2010) used the Garner's paradigm to examine directly how featural and configural information interact during face processing. They asked whether observers can selectively attend to facial features while configural information is ignored, and vice versa. Participants classified a set of upright faces (varying in features and configuration) on a relevant dimension (e.g., features) while ignoring variation on an irrelevant dimension (e.g., configuration), in two conditions. In the baseline condition, the irrelevant dimension was held at a constant value, and only the relevant dimension varied from trial to trial. In the filtering condition, both the relevant and the irrelevant dimensions varied from trial to trial in a random fashion. The relationship between the two

[1] It is important to note that although some researchers define configural information as local interfeature distances (e.g., Leder, Candrian, Huber, & Bruce, 2001), in our view, configuration is a consequence of the spatial relations between the facial features; it does not reside in a single interfeature distance, although a common way to manipulate configuration is to alter individual interfeature distances.

dimensions is inferred from the performance in these two conditions. 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, and the dimensions are considered integral. Amishav and Kimchi found that normal participants exhibited symmetric Garner interference: They could not selectively attend to the features without interference from irrelevant variation in the configuration, nor could they attend to the configuration without interference from irrelevant variation in the features, and both "interference" effects were comparable in magnitude. This finding indicates that featural information and configural information are perceptually integral in processing of upright faces. Performance with inverted faces, on the other hand, showed asymmetric Garner interference—selective attention to features but not to configural information, implying dominance of featural information in processing inverted faces. These results provide refined characterizations of the nature of face processing, specifying holistic face processing as the perceptual integrality of featural and configural information.

Holistic and configural processing in congenital prosopagnosia

As noted above, one existing explanation for the impairment in face processing in individuals with prosopagnosia is that they fail to integrate the disparate local elements of a face into a coherent unified representation (for review, see Barton, 2009; Rivest, Moscovitch, & Black, 2009). Indeed, it has been suggested that all patients with acquired prosopagnosia (AP) are unable to derive a unified perceptual representation from the multiple features of an individual face (Rossion, 2008). Similar claims have been made about individuals with congenital prosopagnosia (CP; e.g., Avidan, Tanzer, & Behrmann, 2011; Behrmann, Avidan, Marotta, & Kimchi, 2005; Palermo et al., 2011), and it appears that the patterns of impairment in face perception are generally similar across the two groups (although performance in perceiving emotional expression may differ, e.g., Humphreys, Avidan, & Behrmann, 2007). Here, we review some of the extant data exploring this holistic/configural impairment in prosopagnosia. We do not differentiate between AP and CP for this review although the novel empirical data we present below is only from CP individuals.

Many investigations have compared the ability of prosopagnosic individuals and controls on various face tasks. For example, Rouw and de Gelder (2002) showed not only that a prosopagnosic individual, R.P., showed a paradoxical inversion effect (better performance on inverted than upright stimuli) but that he also performed more poorly on normal than on scrambled faces, thus exhibiting an impairment in holistic processing. Similarly, Ramon, Busigny, and Rossion (2010) showed that AP patient, P.S., did not exhibit the superiority of the whole over the parts in the part–whole paradigm and, also, did not show the normal composite face effect. Several other studies have also reported that prosopagnosic (both AP and CP) individuals show reduced interference from the unattended part of the face in the composite face paradigm (Avidan et al., 2011; Palermo et al., 2011; Ramon et al., 2010). Additionally, many prosopagnosic individuals do not show the normal superiority for processing upright over inverted faces, and some even show an "inversion superiority" effect in which the individual performs better with inverted than with upright faces (e.g., Avidan et al., 2011; Behrmann et al., 2005; Busigny & Rossion, 2010; Duchaine, Yovel, Butterworth, & Nakayama, 2006; Farah, Wilson, Drain, & Tanaka, 1995; also see de Rouw and de Gelder, 2002, and de Gelder & Rouw, 2000a, 2000b, for paradoxical inversion effect for faces and nonface objects). This latter inversion superiority effect is attributed to the unfettered access to the parts of a face in the inverted case in the absence of any interference from configural information.

A review of the findings exploring spatial distance sensitivity in prosopagnosia also reveals an impairment in the ability to represent the spatial relations between facial features. For example, Ramon and Rossion (2010) reported that patient P.S. performed poorly on a task that required matching unfamiliar faces in which the faces differed with respect to either local features or inter-feature distances, over the upper and lower areas of the face. P.S. was impaired at matching when the relative distances between the features differed, and this was true even when the location of the features was held constant (and uncertainty about their position was eliminated). Consistent with this, prosopagnosic individuals performed more poorly when deciding which of three faces was "odd" when the interocular distance or the distance between the nose and mouth was altered as well as when the relative distances between features were changed (Barton & Cherkasova, 2005; Barton, Press, Keenan, & O'Connor, 2002).

The review presented above suggests that there is consensus about the fact that prosopagnosic individuals are impaired at some aspect of holistic processing. Closer scrutiny, however, reveals several counterexamples. For example, Le Grand et al. (2006) reported that, of the eight CPs who participated in their study, surprisingly, only one showed an abnormal composite effect. Additionally, Susilo et al. (2010) reported that the CP in their study showed a composite effect across three different tasks (naming and two same/different judgements). Also, Schmalzl, Palermo, and Coltheart (2008) tested a family of seven developmental prosopagnosia (DP) individuals (spanning four generations) and reported that only four failed to show the normal composite effect, and, finally, Williams, Berberovic, and Mattingley (2007) found a normal composite effect in a case of DP.

Such a disparity of findings may reflect heterogeneity across the population of CPs, but they may also cast some doubt on the view that an impairment in face perception is related to the difficulty in holistic/configural processing. Some authors have also entertained the possibility that the deficit in prosopagnosia may potentially arise from difficulty in part-based processing. For example, acquired prosopagnosic D.C. demonstrated intact within-class object recognition yet could not discriminate isolated face parts (Rivest et al., 2009), and Susilo et al. (2010) confirms this feature-based account as a possible explanation for the impairment in face perception in their participant, S.P.

In light of the mixed set of findings and the fact that holistic and/or part-based impairments may contribute to prosopagnosia, here, we explore this issue further by examining the interplay between features and configuration in CP. To this end, we use an experimental methodology that is specifically designed to explore the perceptual separability and integrality of stimulus dimensions.

THE PRESENT STUDY

In the present study, we examined how featural information and configural information interact (i.e., whether they are separable or integral) during face processing in a group of 10 individuals diagnosed with CP, using Garner's speeded-classification paradigm.

The stimulus set, created by Amishav and Kimchi (2010), consisted of four faces made by orthogonally combining featural and configural information. Featural information was manipulated by the shape of facial features (eyes, nose, mouth), and configural information was manipulated by intereyes and nose–mouth distances (Figure 1). On each experimental trial, participants classified a face on either features (featural judgements) or configuration (configural judgements). In the baseline condition, participants made speeded classification of the relevant dimension (e.g., features), while the values of the irrelevant dimension (e.g., configuration) were held constant. For example, for featural judgements, the baseline block consisted of either Faces A and C or Faces B and D (see Figure 1): The features varied from trial to trial, but there was no variation in the configuration. In the filtering condition, the participant's task was identical, but the values of the irrelevant dimension varied, so that the

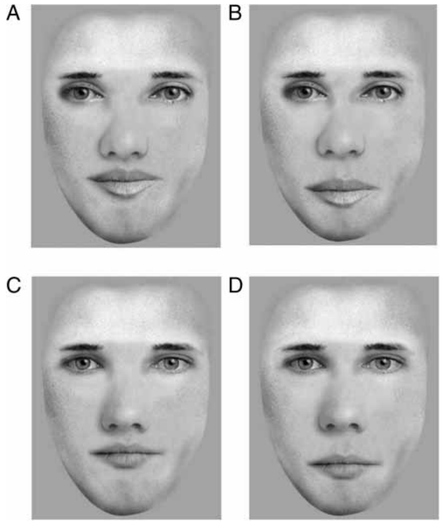

Figure 1. *The stimulus set used in the experiment. Faces in each row (Faces A and B and Faces C and D) have the same features (eyes, nose, and mouth) but vary in their configuration (differ in intereyes and nose–mouth distance). Faces in each column (Faces A and C and Faces B and D) vary in their features (eyes, nose, and mouth) but have the same configuration (same intereyes and nose–mouth distance). From "Perceptual integrality of componential and configural information in faces", by R. Amishav and R. Kimchi, 2010,* Psychonomic Bulletin & Review, 17*(5), p. 744. Copyright 2010 by Psychonomic Society, Inc. Reprinted with permission.*

filtering block consisted of all four faces. For example, for featural judgements, although configuration was irrelevant, it still varied randomly from trial to trial.

The ability of participants to selectively attend to one dimension while ignoring an irrelevant dimension is measured by comparing performance in the filtering condition to performance in the baseline condition. Worse performance in the filtering than in the baseline condition—Garner interference—indicates that the irrelevant dimension interferes with efficient processing of the relevant dimension, implying integral dimensions. Equal performance in the baseline and filtering conditions indicates perfect selective attention to the relevant dimension, implying that the dimensions are separable. Note that equal discriminability of the two dimensions is critical for Garner interference to reflect a genuine violation of separability (Garner, 1974).

As noted above, normal observers evince integrality of featural and configural information under such conditions, indicated by symmetric Garner interference (Amishav & Kimchi, 2010). If the impairment in face perception in CP is related to the failure to process faces holistically, as predicted by the holistic view, then, when tested in Garner's speeded-classification task, individuals with CP should show no Garner interference. Specifically, the prediction is that the CP individuals should show no interference from the irrelevant variation in configuration when classifying faces by their features and should show no interference from the irrelevant variation in featural information when classifying faces by their configuration. If, however, the impairment in face perception in CP is related to impairment in processing one type of information but not the other, asymmetric Garner interference should be observed. That is, if CP individuals are impaired only in processing configural information, as predicted by the configural view, irrelevant variation in featural information is expected to interfere with classification of faces by their configuration, but classification of faces by their features is not expected to be influenced by variation in configuration; if CP individuals are impaired only in processing featural information, irrelevant configural information is expected to interfere with classification of faces by their features, but not vice versa.

Method

Participants

All participants provided informed consent to a protocol approved by the Institutional Review Boards of Carnegie Mellon University or by the Ethics committees of the Psychology Departments at Ben-Gurion University and at University of Haifa. All participants had normal or corrected-to-normal visual acuity.

Control participants. Ten healthy individuals (8 females) between 21 and 71 years of age (mean $\pm$ *SD*, 47.2 $\pm$ 18.97), none of whom had a history of neurological or psychiatric illness, served as age- and gender-matched controls for the CP participants. The control participants were community volunteers who were paid for their participation and undergraduate students who participated in the study in return for course credit.

Congenital prosopagnosics. Ten individuals who were diagnosed with CP took part in the study (8 females), ranging in age from 21 to 74 years (mean ± *SD*, 47.8 ± 18.72). Six were tested in Israel, and four were tested in the US. CP individuals completed two diagnostic tasks: a questionnaire consisting of photographs of famous individuals to assess their face recognition, and a standardized measure, the Cambridge Face Memory Test (CFMT). The scores for each individual CP on the two measures, as well as the *z* scores calculated for each individual CP against data from a group of control participants, are shown in Table 1, along with biographic detail for each CP and information about their prior participation in other studies.

1. *Famous faces questionnaire*. All participants were tested on a famous faces questionnaire (Avidan & Behrmann, 2008) consisting 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 printed on paper, and participants indicated the name of the individual, provided some contextual information (e.g., occupation), or responded "do not know". Participants were allowed unlimited duration to complete this questionnaire. We created two versions of this questionnaire, one suitable for US participants and the other suitable for Israeli participants. A total of 58 control participants (age range 20–70 years) completed one or the other form of this questionnaire (Avidan & Behrmann, 2008; Behrmann et al., 2005). Performance on these two versions of the questionnaire did not differ (mean ± *SEM*: 83.4% ± 2.7; 84.9% ± 2.3, for 30 US and 28 Israeli participants,

Table 1. *Demographic details of CP individuals and performance on famous faces questionnaire and CFMT diagnostic tests*

			Famous faces questionnaire		*CFMT*	
Participant	*Sex*	*Age (years)*	*% corr.*	*z-score*	*Score*	*z-score*
K.E.[a,b,c]	F	74	42.86	-3.12^{+}	40	-2.58^{+}
O.N.[c]	F	48	60.71	$-1.77^{\#}$	35	-3.24^{+}
E.M.	M	67	28.57	-4.21^{+}	27	-4.29^{+}
O.F.	F	21	51.79	-2.45^{+}	37	-2.97^{+}
S.W.[a]	F	50	55.35	-2.18^{+}	48	-1.53^{*}
T.D.[a,c,d]	F	38	46.42	-2.85^{+}	41	-2.45^{+}
W.A.[a,c,d]	F	24	45.71	-2.91^{+}	40	-2.58^{+}
F.F.	M	31	60.71	$-1.77^{\#}$	38	-2.84^{+}
J.F.	F	63	46.43	-2.85^{+}	51	-1.13^{*}
T.Z.[a]	F	62	69.64	-1.1^{*}	43	-2.18^{+}
CP mean ± *SD*		47.80 ± 18.72	50.82 ± 11.52	−2.52 ± 0.87	40.0 ± 6.68	−2.59 ± 0.88
Controls mean ± *SD*			84.1 ± 13.2		59.6 ± 7.6	
Age range (years)						
Famous faces		20–70				
CFMT		45 ± 9.1				

Note: CFMT = Cambridge Face Memory Test. F = female. M = male. CP = congenital prosopagnosia. Performance: raw values and z scores. Note that in the famous faces questionnaire and the CFMT, abnormal performance is indicated by a negative *z* score. * z-scores 1-1.6 SD below control mean, # z-scores 1.6-2 SD below control mean, and + z-scores 2 SD or more below control mean. Some of these CP participants also took part in previous studies, and their famous faces and CFMT data have been reported.
[a]Avidan et al., 2011. [b]Avidan et al., 2013. [c]Thomas et al., 2009. [d]Nishimura, Doyle, & Behrmann, 2010.

respectively, $p = .67$). We calculated z scores for each CP participant based on the control data (see Table 1).

2. *Cambridge Face Memory Test*. The CFMT is designed to examine short-term memory of unfamiliar faces and has been widely used in the congenital/developmental prosopagnosia literature in recent years (Duchaine, Germine, & Nakayama, 2007; Duchaine, Yovel, & Nakayama, 2007). A z score for the datum from each individual CP was calculated using data from 20 controls (aged 45.1 ± 9.1 years) kindly provided to us by Bradley Duchaine. These data have been used in previous studies for diagnostic purposes for individuals with developmental prosopagnosia (Duchaine, Germine et al., 2007; Duchaine, Yovel, et al., 2007).

Stimuli

Stimuli were a set of four faces used by Amishav and Kimchi (2010, Experiment 1). The stimuli were generated using computerized facial composite software (*FACES 3.0*; IQ_Biometrix). The set of four faces (see Figure 1) was created by orthogonally combining two sets of features (eyes, nose, and mouth) with two sets of configural information (intereyes and nose–mouth distances). To minimize the possibility that altering features' shape would result in changes in spacing, features were similar in size and were carefully pasted in the exact locations of the face. Images were black and white and appeared on a grey background. Each face subtended approximately 11.5 × 8 cm. Intereyes distance was defined as the distance between the centres of the pupils (44 mm or 38 mm); nose–mouth distance was defined as the distance between the upper contour of the mouth and the lowest contour of the nose (6 mm or 12 mm). Spacing was employed by Adobe Photoshop, Version 8. The experiment was run either on a laptop or on a desktop PC with screen resolution 1,024 × 768.

Design and procedure

On each experimental trial, participants classified a face on either features (*featural judgements*) or configuration (*configural judgements*). Experimental trials were divided into separate blocks of *baseline* and *filtering* conditions. The baseline conditions required speeded classification of just two faces: Participants judged one dimension (e.g., configuration) while the irrelevant dimension was held at a constant value (e.g., both faces had the same features). The filtering conditions required speeded classification of all four faces: Participants again judged one dimension (e.g., configuration), but the faces now differed along the irrelevant dimension (e.g., faces differed in their features). For each judgement task, there were two baseline conditions and one filtering condition. For the featural judgements, one baseline condition required discriminating Face A from Face C (Figure 1), and the second baseline condition required discriminating Face B from Face D. The filtering condition required discriminating Faces A and B from Faces C and D. For the configural judgements, one baseline condition required discriminating Face A from Face B, and the second baseline condition required discriminating Face C from Face D. The filtering condition required discriminating Faces A and C from Faces B and D. Each condition appeared on a separate block of 32 trials, preceded by 12 practice trials (which were discarded from the analyses), with each stimulus occurring on an equal number of trials. Because the filtering condition involved four stimuli whereas the baseline conditions involved two, there were two blocks of filtering condition for each task, differing only in the random ordering of the stimuli within the block.

Participants performed the three conditions (two baselines and one filtering) of each task as a set; the order of task (featural judgements first, configural judgements first) and the order of condition within task (baseline first, filtering first) were counterbalanced across participants. Stimulus order of presentation was randomized for each participant.

Participants were tested individually. At the beginning of each block, participants were presented with photos of the to-be-classified faces and were instructed which response key should be pressed for each face. Each trial started with a fixation point presented for 500 ms. After a 500-ms interval, a face appeared and remained on the screen until response or for a maximum of 3,500 ms. An incorrect response was followed by an auditory tone, and the trial was re-presented (up to three times) at the end of the block.

Results

All reaction time (RT) summaries and analyses are based on participants' mean RTs for correct responses. RTs shorter than 250 ms and longer than 3,000 ms were discarded (0.3% and 0.08% of all trials in the CP and control group, respectively). Preliminary analyses showed that the two baseline conditions of each task were equivalent (Fs < 1); therefore, their data were pooled.

Mean RTs and error rates (ERs) in the baseline and filtering conditions for featural and configural judgements for the control and CP groups are presented in Figure 2. Also displayed are the results of the 32 college-age participants from Amishav and Kimchi's (2010) study, which serve as a further benchmark.

We first describe the performance of the matched control group to confirm that the pattern of results for this group was similar to that reported by Amishav and Kimchi (2010)—that is, symmetric Garner interference in judgements of featural and configural information (see Figure 2)—and then we compare the CP group with the matched controls.

Matched control group

Overall error rate was 5.56%, and there was no evidence of a speed–accuracy trade-off. A 2 (task: featural judgements, configural judgements) × 2 (condition: baseline, filtering) repeated measures analysis of variance (ANOVA) conducted on the RT data showed no difference between the featural judgements and the configural judgements, $F < 1$. Planned comparisons examining the RT difference between the baseline conditions of the two judgement tasks confirmed the equal discriminability of the featural and configural information, $F(1, 9) = 1.84$, $p > .20$. Most importantly, the analysis revealed a significant effect of condition, $F(1, 9) = 8.95$, $p < .02$, indicating a symmetric Garner interference effect, which was, on average, 114 ms: RTs in the filtering condition were longer than RTs in the baseline condition by 132 ms for the featural judgements and by 95 ms for the configural judgements (see Figure 2). The difference in the magnitude of interference for the two tasks was not significant, as indicated by the nonsignificant interaction between task and condition, $F < 1$.

The ER data showed a similar pattern of results (see Figure 2), but none of the effects reached statistical significance.

Thus, our group of matched controls performed similarly to the college-age participants (age range 19–25 years) in Amishav and Kimchi's (2010) study, exhibiting symmetric Garner interference: When classifying upright faces, the participants could not selectively attend to featural information without being influenced by irrelevant variation in configural information, and vice versa. The symmetric Garner interference indicates that featural and configural information are integral during face processing.[2]

CP group

The overall error rate was 3.56%, and there was no evidence of a speed–accuracy trade-off. As shown in Figure 2, the pattern of performance of the CP group is quite different from that of the control groups. We first analysed the data from the CP group alone. The 2(task) × 2(condition) repeated measures ANOVAs performed on the RT and ER data yielded significant effects for RTs only. The CPs tended to be faster in the configural than in

[2] On the surface, it appears as though the matched control group shows greater interference than the young controls tested by Amishav and Kimchi (2010). A direct comparison of these data is somewhat problematic because there are twice as many young controls as matched controls and because of the large difference in the age range. Nevertheless, a statistical comparison of the two groups reveals no significant interaction between group, task, and condition ($F < 1$), reflecting the presence of symmetric Garner interference in both groups

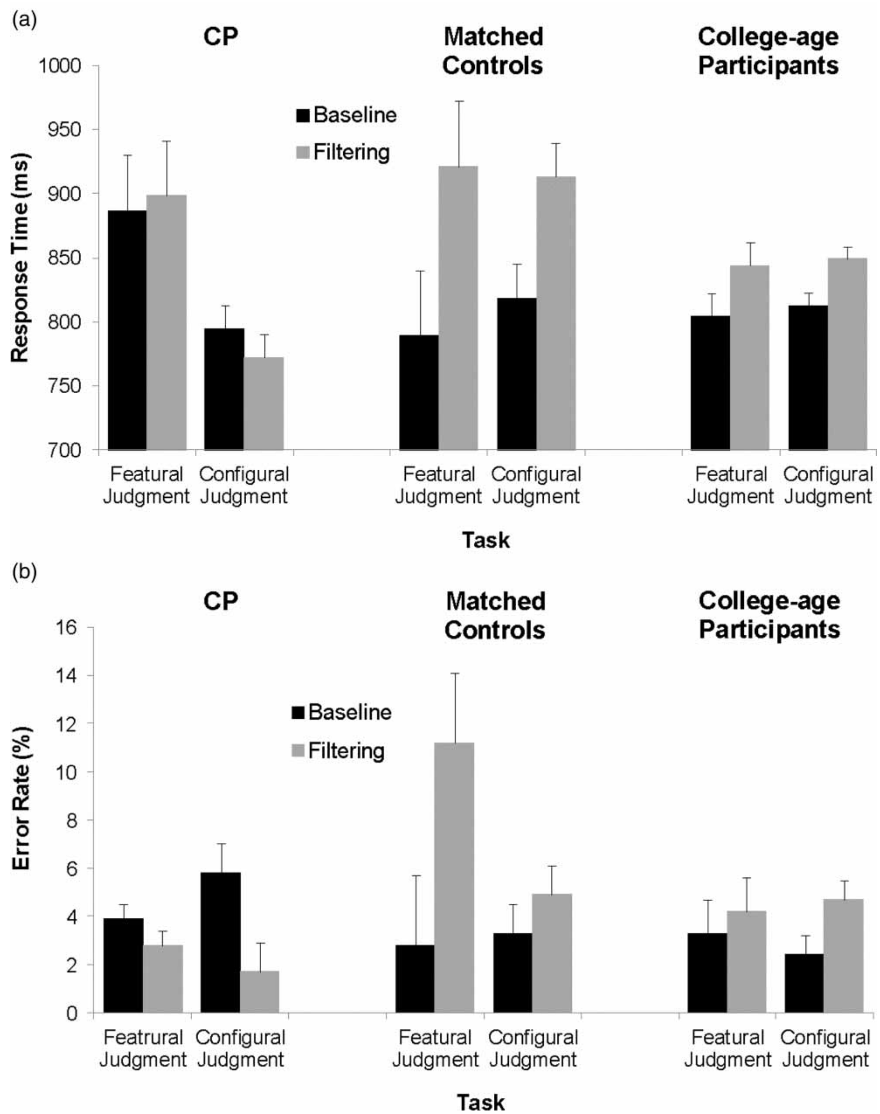

Figure 2. *(A) Mean reaction times (RTs) and (B) error rates as a function of task (featural judgements, configural judgements) and condition (baseline, filtering) for the congenital prosopagnosia (CP) participants and matched controls. The results for the college-age participants are from Amishav and Kimchi (2010, Experiment 1). Error bars represent the standard error of the difference between responses in the baseline and filtering tasks.*

the featural judgements, $F(1, 9) = 4.07$, $p < .08$, but the difference between the baseline conditions of the two judgement tasks, although evident numerically, was not statistically significant, $F(1, 9) = 1.76$, $p > .21$. Importantly, there was no indication of Garner interference. RTs in the filtering condition were no longer than RTs in the baseline condition both in the featural judgement task and in the configural judgement task: The effect of condition and the interaction between condition and task were not significant, Fs < 1. Overall interference averaged -6 ms, with an average interference of -24 ms in the configural judgements ($F < 1$) and 12 ms in the featural judgements ($F < 1$).

These results suggest that when classifying faces, the CPs could selectively attend to features without interference from irrelevant variation in configural information, and vice versa.

To compare the performance of the CPs to the matched controls directly, we performed ANOVAs on the RT and ER data with task (featural judgements, configural judgements) and condition (baseline, filtering) as within-subject factors and group (CP, matched control) as a between-subject factor. The analyses showed no main effect of group, $F < 1$, $F(1, 18) = 1.04$, $p > .32$, for RT and ER, respectively. These results indicate that the overall RT ($M = 838$ ms) and the overall ER ($M = 3.56\%$) of the CPs did not differ from those of controls (RT: $M = 860$ ms; ER: $M = 5.56\%$). There was no significant effect of task, $F(1, 18) = 1.95$, $p > .17$, $F < 1$, for RT and ER, respectively, and no significant Task × Group interaction, $F(1, 18) = 2.81$, $p > .11$, $F < 1$, for RT and ER, respectively. The difference between the groups in the baseline condition of the featural judgement task, although evident numerically (see Figure 2), was not significant, $F(1, 18) = 1.28$, $p > .27$. There was a main effect of condition, $F(1, 18) = 4.77$, $p < .0424$, for RT only, which did not interact with task, $F < 1$. Most importantly, the analyses revealed a significant Condition × Group interaction, $F(1, 18) = 5.83$, $p < .0267$, $F(1, 18) = 7.04$, $p < .0162$, for RT and ER, respectively, but no Condition × Task × Group interaction, Fs < 1, for both RT and ER. These results confirmed the different pattern of results regarding Garner interference observed for the two groups. That is, the absence of Garner interference (in both judgement tasks) in the CP group clearly diverges from the symmetric Garner interference observed in the matched control group.

Individual overall Garner interference scores [RT(filtering) − RT(baseline)] (averaged across the two tasks) are presented in Table 2. Six of the CPs clearly showed no Garner interference effect, as indicated by the negative values. Figure 3 displays RTs in the baseline and filtering conditions for the configural judgement task (Figure 3A) and the featural judgement task (Figure 3B) for each control and CP participant. As can be seen in Figure 3, in each task, most of the controls (8/10) were above the line of equivalence for baseline and filtering RTs, exhibiting Garner interference, whereas only 3 of the CPs were above this line in the configural judgement task and 4 in the featural judgement task. Garner interference scores in the featural judgement task and in the configural judgement task for each control and CP participant are presented in Figure 4. Although there is variability in both groups, the distribution of the individual scores differs between the groups. As can be seen in Figure 4, only 2 of the CPs showed interference in both tasks, whereas most of the controls (7/10) showed interference in both tasks. Thus, the absence of Garner interference is present at both the group level and the individual subject level in many of the CPs.

Table 2. *Individual overall Garner interference scores of CP individuals and matched controls*

CP		*Matched controls*	
Participant	*Garner interference*	*Participant*	*Garner interference*
K.E.	−197	C.C.	−13
O.N.	−18	S.H.	101
E.M.	−45	A.M.	215
O.F.	44	I.D.	387
S.W.	−65	O.P.	54
T.D.	−69	L.N.	10
W.A.	−5	H.S.	152
F.F.	151	A.B.S.	25
J.F.	23	K.R.	147
T.Z.	121	H.D.	56
Mean	−6	Mean	114
SD	100	*SD*	120
SEM	32	*SEM*	38

Note: Garner interference was calculated for each participant by subtracting participant's mean reaction time (RT) in the baseline condition from mean RT in the filtering condition (averaged across the judgement tasks). Scores in ms. CP = congenital prosopagnosia.

Discussion

The goal of this study was to examine the nature of face processing in CP individuals, with specific

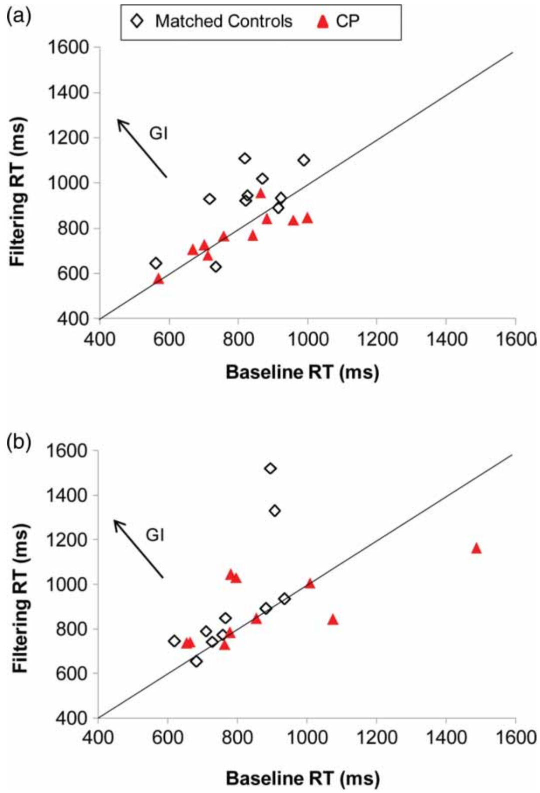

Figure 3. *Individual reaction times (RTs) of congenital prosopagnosia participants (CPs) and matched controls in the baseline and filtering conditions for (A) the configural judgements and (B) the featural judgements. Each point represents one participant. The line running from corner to corner indicates equivalence of baseline and filtering RTs. Data points above the line of equivalence indicate Garner interference (GI; longer RTs in the filtering than in the baseline condition). To view a colour version of this figure, please see the online issue of the Journal.*

emphasis on examining how featural and configural information interact during face processing. Research conducted on normal observers suggests that faces are processed holistically—featural information and configural information are integral during upright face processing (Amishav & Kimchi, 2010). Do CPs process faces in a similar manner, or do they process featural and configural information independently?

To examine the hypothesis that CPs impairment in face perception is related to their difficulty in processing faces holistically (i.e., configural and featural information are not integral during face processing), we tested a group of 10 CP individuals in Garner's speeded-classification task using facial stimuli.

The overall level of performance of the CPs was similar to that of age- and gender-matched controls, both in speed and in accuracy. The pattern of performance, however, differed markedly. The CP group exhibited no Garner interference in either the featural or the configural judgements. When classifying upright faces that varied in features (shape of eyes, nose, and mouth) and configuration (intereyes and nose–mouth spacing), the CPs could attend to configural information and make configural judgements without interference from irrelevant variation in featural information; similarly, they could attend to featural information and make featural judgements without interference from irrelevant variation in configural information. This pattern of performance, which is in clear contrast to the symmetric Garner interference observed in matched controls (and in young controls), indicates that featural information and configural information are separable in CP's upright face processing. That is, CPs do not perceive and process faces holistically. Rather, CPs process facial features and configuration independently.

The finding that individuals with CP process featural and configural information independently is consistent with the findings of the absent or reduced composite face effect and part–whole effect in CP (e.g., Avidan et al., 2011; Palermo et al., 2011; Ramon, Busigny, & Rossion, 2010; de Gelder & Rouw, 2000b). Actually, perceptual separability of featural and configural information can easily account for the absence of the part–whole effect, because the features (i.e., the face parts) can be selectively attended, and, therefore, no difference is expected between recognizing a feature (e.g., nose) in a whole intact face and recognizing a feature in isolation or in a scrambled face. Similarly, the independent processing of features and configuration allows selective attention to features in the top of the composite face while ignoring the overall configuration, resulting in absence of a composite effect.

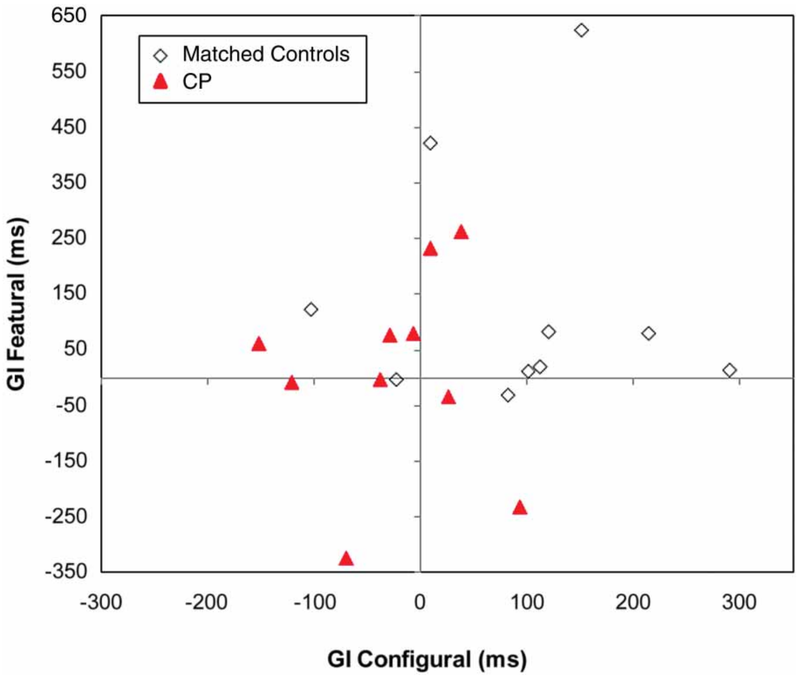

Figure 4. *Individual Garner Interference (GI) scores (in ms) of congenital prosopagnosia participants (CPs) and matched controls for the featural judgements (GI featural) and the configural judgements (GI configural). Each point represents one participant. Data points in the top right quadrant indicate positive interference values in both tasks. To view a colour version of this figure, please see the online issue of the Journal.*

The present results challenge the configural view, which predicts that individuals who suffer from CP will show deficits mainly in processing configural information. Were CPs impaired only in processing configural information, then asymmetrical Garner interference should have been observed—interference from irrelevant variation in featural information when classifying faces by configuration, but not vice versa. Our results, however, showed no Garner interference whatsoever. Furthermore, the CPs were not slower than controls in classification of faces that differed only in configuration (i.e., in the baseline condition of the configural judgements). If anything, there was an insignificant trend for slower performance in the baseline condition of the featural judgements. Actually, the absence of asymmetrical Garner interference for each of the judgement tasks suggests that one type of information does not dominate over the other.

Some of the few studies that directly examined featural versus configural processing in CPs reported that CPs show greater deficit in processing of configural information than processing of featural information (Barton, Cherkasova, Press, Intriligator, & O’Connor, 2003; Lobmaier, Bolte, Mast, & Dobel, 2010), but since there was no attempt in these studies to equate the discriminability of the configural and the featural information, these findings may be confounded with discriminability. Of particular relevance to the present results are the findings of Yovel and Duchaine (2006; see also Duchaine, Yovel, et al., 2007). They tested developmental prosopagnosics in a face discrimination task with faces that differed only in featural information or faces that differed only in configural information and found that the prosopagnosics showed lower performance than controls on both the configural and featural discrimination tasks. The discrepancy between our finding of similar levels of performance of the prosopagnosics and controls and their finding of lower performance of the prosopagnosics than of controls can be attributed to the greater difficulty of their discrimination task, which involved a larger set of faces and limited exposure. Their finding of the prosopagnosics' comparable deficits with configural and featural discrimination, however, converges with our finding in demonstrating that the prosopagnosics' face impairment is not limited to configural information. Our findings further specify the nature of the processing underlying the impairment—the CP's independent processing of featural and configural information.

Interestingly, an informal postexperiment debriefing revealed that CPs tended to focus on just one of the distances and on just one of the features. Presumably, the CPs' featural processing and configural processing were both based on local properties, whereas the processing of the control participants was based on the ensemble of features and on the spatial relations between the facial features. A focus on a single local feature of a face has also been reported in AP patient, P.S., who does not use the optimal eye-region information that contains multiple features to identify familiar faces and, instead, focuses on the relatively isolated mouth (Caldara et al., 2005; Orban de Xivry, Ramon, Lefèvre, & Rossion, 2008).

Note that normal observers may also adopt a local strategy under certain conditions. They seem to focus on a local interfeature distance for discriminating faces that differ only in configural information when they know exactly which property they have to compare (Leder & Bruce, 2000; Leder et al., 2001), and they can selectively attend to a single facial feature for discriminating faces that differ only in features (Kimchi & Amishav, 2010; Sergent, 1984). But when faces vary in both featural and configural information of similar discriminability (as is true of natural faces), these two types of information are integral in normal observers' upright face processing, meaning that they are processed holistically (Amishav & Kimchi, 2010; Kimchi & Amishav, 2010), enabling the observer to distinguish between faces and uniquely identify or recognize an individual face. It is this kind of processing that is dysfunctional in individuals who suffer from CP. Instead, CP individuals process featural and configural information independently and apparently tend to focus locally on a single facial feature or on a single interfeature distance. The question of whether CPs fail to represent integrally only faces, or whether their information processing in general is characterized by independent processing of stimulus dimensions, even dimensions that are considered integral (e.g., hue and brightness, Garner & Felfoldy, 1970; the orientation and length of lines, Dick & Hochstein, 1988), awaits further research.

In sum, the present study provides evidence that individuals with CP do not process faces holistically—they process featural and configural information independently rather than in an integral fashion. This result not only elucidates the underlying perturbation in CP but also confirms that intact face processing is characterized by the integrality of configural and featural information.

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