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Normal composite face effects in developmental prosopagnosia

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Highlights

- Two samples of developmental prosopagnosics (DPs) completed composite face tasks
- The groups completed complementary simultaneous and sequential matching procedures
- In both experiments, the DPs exhibited composite effects comparable with controls
- The whole-face processing indexed by the composite effect seems to be intact in DP

Abstract

Upright face perception is thought to involve holistic processing, whereby local features are integrated into a unified whole. Consistent with this view, the top half of one face appears to fuse perceptually with the bottom half of another, when aligned spatially and presented upright. This ‘composite face effect’ reveals a tendency to integrate information from disparate regions when faces are presented canonically. In recent years, the relationship between susceptibility to the composite effect and face recognition ability has received extensive attention both in participants with normal face recognition and participants with developmental prosopagnosia. Previous results suggest that individuals with developmental prosopagnosia may show reduced susceptibility to the effect suggestive of diminished holistic face processing. Here we describe two studies that examine whether developmental prosopagnosia is associated with reduced composite face effects. Despite using independent samples of developmental prosopagnosics and different composite procedures, we find no evidence for reduced composite face effects. The experiments yielded similar results; highly significant composite effects in both prosopagnosic groups that were similar in magnitude to the effects found in participants with normal face processing. The composite face effects exhibited by both samples and the controls were greatly diminished when stimulus arrangements were inverted. Our finding that the whole-face binding process indexed by the composite effect is intact in developmental prosopagnosia indicates that other factors are responsible for developmental prosopagnosia. These results are also inconsistent with suggestions that susceptibility to the composite face effect and face recognition ability are tightly linked. While the holistic process revealed by the composite face effect may be necessary for typical face perception, it is not sufficient; individual differences in face recognition ability likely reflect variability in multiple sequential processes.

Key words:

Developmental prosopagnosia; Composite face effect; Holistic face processing

Introduction

In recent years, research has revealed substantial individual differences in face processing ability. Whilst ‘super-recognisers’ make up the upper tail (Russell, Duchaine, & Nakayama, 2009), the lower-end of the distribution is composed of individuals with developmental prosopagnosia[1] (DP). DP is a neurodevelopmental condition characterised by difficulties recognising facial identity, despite normal intelligence, typical low level vision, and no history of brain damage (Behrmann & Avidan, 2005; Cook & Biotti, 2016; Duchaine & Nakayama, 2006b). DP was once thought to be extremely rare (McConachie, 1976), but one in every 50 people are now thought to experience lifelong face recognition difficulties severe enough to disrupt their daily lives (Kennerknecht et al., 2006; Kennerknecht, Ho, & Wong, 2008). Individuals with DP typically utilise non-face cues including voice, gait, and hairstyle to recognise others. Consequently, they often experience great difficulties when non-face cues are unavailable or changed, or when familiar people are encountered out of context.

Numerous papers have suggested that diminished holistic face processing may underlie the difficulties seen in DP (Avidan, Tanzer, & Behrmann, 2011; Carbon, Grüter, Weber, & Lueschow, 2007; DeGutis, Cohan, Mercado, Wilmer, & Nakayama, 2012; DeGutis, Cohan, & Nakayama, 2014; Liu & Behrmann, 2014; Lobmaier, Bölte, Mast, & Dobel, 2010; Palermo et al., 2011). Typical face perception appears to involve a rapid parallel analysis, whereby local features are integrated into a unified whole (Farah, Wilson, Drain, & Tanaka, 1998; Maurer, Le Grand, & Mondloch, 2002; McKone & Yovel, 2009; Piepers & Robbins, 2013). Evidence of holistic face perception is provided by the composite face effect, where the top half of one face appears to fuse perceptually with the bottom half of another, when the two halves are aligned and presented upright (Hole, 1994; Young, Hellawell, & Hay, 1987). The resulting illusion-induced interference disrupts observers’ ability to judge the identity (Young et al., 1987), physical resemblance (Hole, 1994), age (Hole & George, 2011), gender (Baudouin & Humphreys, 2006), and attractiveness (Abbas & Duchaine, 2008) of constituent face halves (for reviews see Murphy, Gray, & Cook, 2017; Rossion, 2013). When face halves are inverted, observers show little or no interference (McKone et al., 2013; Susilo, Rezlescu, & Duchaine, 2013). Importantly, the composite effect reveals a tendency to integrate feature information from disparate regions when faces are presented canonically, consistent with holistic theories of face perception

(Farah et al., 1998; Maurer et al., 2002; McKone & Yovel, 2009; Piepers & Robbins, 2013).

The suggestion that DP results from disrupted holistic processing is closely related to the view that the whole-face binding process measured by the composite face effect contributes to face recognition ability (DeGutis, Wilmer, Mercado, & Cohan, 2013; Farah et al., 1998; Maurer et al., 2002; Piepers & Robbins, 2013). However, studies comparing observers' susceptibility to the composite face effect and their face recognition ability have yielded mixed results (Murphy et al., 2017). In cases of acquired prosopagnosia (AP), individuals are left with face recognition difficulties following brain injury. While some APs exhibit reduced composite face effects relative to matched controls (Busigny, Joubert, Felician, Ceccaldi, & Rossion, 2010; Ramon, Busigny, & Rossion, 2009), others exhibit typical susceptibility to the original matching procedure (Finzi, Susilo, Barton, & Duchaine, 2016; Rezlescu, Pitcher, & Duchaine, 2012). Where composite face effects and face recognition ability have been compared in samples drawn from the general population, some authors have observed positive associations (DeGutis et al., 2013; Engfors, Jeffery, Gignac, & Palermo, 2017; Richler, Cheung, & Gauthier, 2011), whilst others have found little or no correlation (Konar, Bennett, & Sekuler, 2010; Rezlescu, Susilo, Wilmer, & Caramazza, 2017; Wang, Li, Fang, Tian, & Liu, 2012).

The literature is also inconsistent with respect to the relationship between individuals' susceptibility to the composite face effect and other putative markers of holistic representation, including the part-whole (Tanaka & Farah, 1993) and face-inversion effects (Yin, 1969). For example, some authors have found associations between susceptibility to the composite face effect and the part-whole effect (DeGutis et al., 2013). However, other studies have found no association between susceptibility to the composite face effect and the part-whole effect (Rezlescu et al., 2017; Wang et al., 2012), or between composite face effects and perceptual decrements induced by face inversion (Rezlescu et al., 2017). These findings cast doubt on the view that a unitary process underlies holistic face processing. Where different measures of holistic processing are unrelated or weakly correlated in the typical population, neuropsychological dissociations might also be seen in the DP population.

Although studies have described a number of individuals with DP who exhibit composite effects comparable with those of matched controls (Le Grand et al., 2006; Schmalzl, Palermo, & Coltheart, 2008; Susilo et al., 2010), three studies have concluded that DP is associated with reduced susceptibility to the composite face effect at the group level (Avidan et al., 2011; Liu & Behrmann, 2014; Palermo et al., 2011). Nevertheless, the case for diminished composite effects in DP remains unconvincing. In at least one study, inspection of single-case data suggests that previously reported group results have been strongly influenced by the presence of outliers in DP samples (Palermo et al., 2011). In other studies, DP samples perform poorly in the baseline ‘misaligned’ condition making it hard to interpret putative differences in composite effect susceptibility (Liu & Behrmann, 2014).

Given the uncertainty about the functional significance of the holistic processes revealed by the composite face effect (Finzi et al., 2016; Konar et al., 2010; Rezlescu et al., 2017; Wang et al., 2012) and the popular view that DP may be caused by diminished holistic representation (Carbon et al., 2007; DeGutis et al., 2012; DeGutis et al., 2014; Lobmaier et al., 2010), obtaining a better understanding of composite face effects in DP is theoretically important. It may also have implications for interventions aimed at improving face recognition in DP (e.g., DeGutis et al., 2014). The present study therefore sought to confirm that DP is associated with reduced composite face effects at the group level. We describe two experiments employing independent samples of DP participants collected in the UK and the USA (N = 16 and N = 24) and complementary paradigms (simultaneous and sequential matching). Contrary to previous group studies (Avidan et al., 2011; Liu & Behrmann, 2014; Palermo et al., 2011), we find no evidence for diminished composite face effects in DP.

Experiment 1

In our first experiment we compared the composite face effects of DPs and matched controls using a simultaneous matching procedure (Hole, 1994). Composite effects seen with upright faces were compared with those seen with inverted faces. Whereas strong effects of alignment are seen when composite faces are presented upright, interference is greatly reduced when composites are constructed from inverted faces (Susilo et al., 2013). This comparison is useful as it addresses the possibility that effects of misalignment found with upright faces are due to general factors rather than face-specific processes (McKone et al., 2013; Rossion, 2013). We also examined composite effects for pseudo-words which resemble the effects found for upright faces (Anstis, 2005). For the sake of brevity, however, details of the procedure and results for pseudo-words are provided as supplementary material.

Methods

Participants

Two groups of observers completed the procedure; 16 individuals with DP (M_{age} = 43.56 years, SD_{age} = 15.09 years, 3 males), and a control group comprising 16 neurotypical adults (M_{age} = 39.81 years, SD_{age} = 12.95 years, 10 males). All observers were resident in the UK. Ethical approval was granted by the local ethics committee and the study was conducted in line with the Declaration of Helsinki. All participants provided informed consent prior to testing.

Diagnostic testing

DP participants were recruited through www.troublewithfaces.org. All members of the DP sample described lifelong face recognition difficulties that affected their daily lives. None of the DPs had a history of brain injury or psychiatric disorder (e.g., Schizophrenia, Autism Spectrum Disorder). Diagnostic evidence for the presence of DP was collected using the Cambridge Face Memory Test (CFMT; Duchaine & Nakayama, 2006a) the Twenty-Item Prosopagnosia Index (PI20; Gray, Bird, & Cook, 2017; Shah, Gaule, Sowden, Bird, & Cook, 2015), and a Famous Face Test suitable for use with UK residents (FFT_{UK}). Scores on the CFMT were compared against data from 50 typical observers reported by Duchaine & Nakayama (2006a). Participants also completed the Cambridge Face Perception Test (CFPT; Duchaine, Germine, & Nakayama, 2007) to determine whether face recognition deficits had an apperceptive origin (De Renzi, Faglioni, Grossi, & Nichelli, 1991). While participants were not selected on the basis of these scores, the DP sample was impaired at the group level [$t(22) = 2.34$, $p = .029$]. Scores on the CFPT and PI20 were compared with a group of 56 controls (M_{age} = 40.25 years, SD_{age} = 13.71 years, 24 males). Comparison data for the FFT_{UK} was collected from a sample of 20 controls (M_{age} = 30.4 years, SD_{age} = 10.27 years, 9 males). When tested on the CFMT, all DPs scored at least 1.53 standard deviations below the mean performance of the comparison sample. All DPs tested[2] also scored at least 2 standard deviations below the mean of the comparison samples on the $\mathrm{FFT}_{\mathrm{UK}}$ and the PI20. Diagnostic information is presented in Table 1.

Table-1

The composite task

Face composites were constructed from images of emotionally neutral faces taken from the Karolinska Directed Emotional Faces database (Lundqvist, Flykt, & Öhman, 1998). Faces were cropped to exclude external facial features (e.g. ears, hairline). Face halves containing the eyes were used as target regions. Face composites subtended 8° of visual angle, vertically. The to-be-judged regions subtended 4°. In the misaligned conditions, the horizontal offset corresponded to approximately 25% the width of a face.

In total, 40 face composites were employed. Each composite was allocated a partner arrangement of the same type with which it would be presented simultaneously. For half the composite pairs, the target regions were identical, for half the pairs the target regions differed. Following the standard composite design (also referred to as the original design; Murphy et al., 2017; Rossion, 2013), the distractor regions within each pair were always different. The two target regions appeared at the same vertical position in the display (the lower edge of each target region was aligned to the vertical midpoint of the display). Two dashed guidelines were imposed over the arrangements to clearly delineate the stimulus regions to be judged. Example displays are presented in Figure 1a.

Figure-1

Testing took place at City, University of London. Participants judged whether the regions shown within the guidelines were identical or not. Composite displays were presented until a response was registered. Participants were asked to respond with both speed and accuracy. Each pair was presented twice in each alignment condition with side (left or right) counterbalanced, yielding 120 ‘same’ trials and 120 ‘different’ trials (10 pairs × 2 presentations × 2 levels of alignment × 3 composite types). Composite type (upright faces, inverted faces, pseudo-words) was interleaved randomly within blocks of 60 trials. Six practice trials were provided. The experiment was programmed in MATLAB (The MathWorks, Natick, MA) using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997).

Prior to testing the DPs and age-matched controls, we piloted our novel procedure on a group of 25 young neurotypical adults (M_{age} = 18.92 years, SD_{age} = 1.42 years, 3 males) to ensure the tasks yielded the expected results. These data are provided in the supplementary material. The sample exhibited a clear composite effect for upright faces that accords closely with the existing literature. Reassuringly, we found disproportionate effects of Alignment on 'same' trials, where the presence of the illusion makes it harder to detect that target regions are identical, consistent with previous reports (e.g., Le Grand, Mondloch, Maurer, & Brent, 2004). As expected, composite effects were greatly diminished when arrangements were constructed from inverted faces.

Results

Where stimulus displays are visible until participants respond, there is a trade-off between response speed and response accuracy; slower responding allows observers to collect more perceptual evidence, and thereby reduce errors. Under these conditions, many observers approach ceiling on accuracy measures (e.g., Calder, Young, Keane, & Dean, 2000; Palermo et al., 2011). To facilitate clear interpretation we therefore present both the response speed and accuracy data (Table 2).

Table-2

Accuracy

First, we compared the composite face effects exhibited by the groups in their accuracy data. Our analyses revealed evidence of clear composite effects for upright faces. As expected, we observed a significant main effect of Alignment [$F(1,30) = 19.04$, $p < .001$, $\eta^2 = .388$], a main effect of Trial Type [$F(1,30) = 5.91$, $p = .021$, $\eta^2 = .165$], and an Alignment × Trial Type interaction [$F(1,30) = 36.72$, $p < .001$, $\eta^2 = .550$]. The analysis indicated that the composite effects exhibited by the controls and DPs did not differ. We observed no main effect of Group [$F(1,30) = .145$, $p = .706$, $\eta^2 = .005$], and the effects of Alignment [$F(1,30) = .1.35$, $p = .254$, $\eta^2 = .043$], Trial Type [$F(1,30) = 1.41$, $p = .245$, $\eta^2 = .045$], and the Alignment × Trial Type interaction [$F(1,30) = 2.99$, $p = .094$, $\eta^2 = .091$], did not interact with Group. We also note that the Alignment × Group interaction failed to reach significance when the analysis was restricted to 'same' trials [$F(1,30) = 2.61$, $p = .117$]. When considered separately, the neurotypical controls showed effects of Alignment [$F(1,15) = 12.187$, $p = .003$, $\eta^2 = .448$] and an Alignment × Trial Type interaction [$F(1,15) = 35.161$, $p < .001$, $\eta^2 = .701$]. Clear effects of Alignment [$F(1,15) = 6.855$, $p = .019$, $\eta^2 = .314$] and an Alignment × Trial Type interaction [$F(1,15) = 8.238$, $p = .012$, $\eta^2 = .355$] were also seen in the DP group.

Neither group showed evidence of composite effects for inverted faces. The analysis revealed a significant effect of Trial Type [$F(1,30) = 23.43$, $p < .001$, $\eta^2 = .439$], but the effects of Alignment [$F(1,30) = 1.29$, $p = .264$, $\eta^2 = .041$], and the Alignment × Trial Type interaction [$F(1,30) = .41$, $p = .527$, $\eta^2 = .013$] failed to reach significance. As expected, the main effects of Trial Type [$F(1,30) = 60.96$, $p = .000$, $\eta^2 = .670$] and Alignment [$F(1,30) = 16.71$, $p = .000$, $\eta^2 = .358$] both varied significantly as a function of Composite Type (upright face, inverted face). We observed no main effect of Group [$F(1,30) = .09$, $p = .763$, $\eta^2 = .003$], and none of the other main effects or interactions varied as a function of group [all F's < 0.9, p's > .35].

Response times

Next, we compared the composite face effects exhibited by the groups in their response time data. Analysis of response latencies for the upright faces revealed main effects of Alignment [$F(1,30) = 56.339$, $p < .001$, $\eta^2 = .653$], and Trial Type [$F(1,30) = 28.80$, $p < .001$, $\eta^2 = .490$], and an Alignment × Trial Type interaction [$F(1,30) = 32.219$, $p < .001$, $\eta^2 = .518$]. The analysis indicated that similar composite face effects were seen for controls and DPs. No effect of Group was observed [$F(1,30) = 1.496$, $p = .231$, $\eta^2 = .048$], and the effects of Alignment [$F(1,30) = .101$, $p = .753$, $\eta^2 = .003$], Trial Type [$F(1,30) = .101$, $p = .753$, $\eta^2 = .003$], and the Alignment × Trial Type interaction [$F(1,30) = .424$, $p = .520$, $\eta^2 = .014$], did not vary as a function of Group. Once again, the Alignment × Group interaction failed to reach significance when the analysis was restricted to 'same' trials [$F(1,30) = .043$, $p = .838$]. The neurotypical controls showed effects of Alignment [$F(1,15) = 25.108$, $p < .001$, $\eta^2 = .626$] and an Alignment × Trial Type interaction [$F(1,15) = 14.720$, $p = .002$, $\eta^2 = .495$]. Highly significant effects of Alignment [$F(1,15) = 31.517$,

$p < .001$, $\eta^2 = .678$] and an Alignment × Trial Type interaction [$F(1,15) = 19.722$, $p < .001$, $\eta^2 = .568$] were also seen in the DP group.

Neither group showed evidence of a composite face effect for inverted faces in their response time data. The main effects of Trial Type [$F(1,30) = 3.421$, $p = .075$, $\eta^2 = .102$] and Alignment [$F(1,30) = 2.831$, $p = .103$, $\eta^2 = .086$], and the Alignment × Trial Type interaction [$F(1,30) = 2.808$, $p = .104$, $\eta^2 = .086$], all failed to reach significance. The main effect of Alignment [$F(1,30) = 20.646$, $p < .001$, $\eta^2 = .408$] and the Alignment × Trial Type interaction [$F(1,30) = 10.638$, $p = .003$, $\eta^2 = .262$] varied significantly as a function of Composite Type (upright faces, inverted faces). No main effect of Group was observed [$F(1,30) = 1.459$, $p = .236$, $\eta^2 = .046$] and none of the effects or interactions varied as a function of Group [all F's < 0.8, p's $> .38$].

Figure-2

Individual differences

Next we sought to determine how susceptibility to the composite face effect related to individual differences in face processing ability in our sample of 16 DPs. Scores on the CFMT ($r = -.186$, $p = .491$) and the upright CFPT ($r = .219$, $p = .416$) failed to correlate with a measure of the composite effect based on accuracy (Δaccuracy = %Correct$_{\text{aligned}}$ - %Correct$_{\text{misaligned}}$). Similarly, composite effects based on response time (Δlatency = RT$_{\text{aligned}}$ - RT$_{\text{misaligned}}$), failed to correlate with performance on the CFMT ($r = .194$, $p = .471$) or the upright CFPT ($r = -.072$, $p = .792$). Finally, we sought to derive a single measure of performance that combined response times and accuracy. We therefore computed Inverse Efficiency Scores (IES; Figure 3) by adjusting participants' response times (RTs) upwards in proportion to their error rate [IES = RT / % correct] (Townsend & Ashby, 1978). No correlation was observed between composite face effects (ΔIES = IES$_{\text{aligned}}$ - IES$_{\text{misaligned}}$) and their performance on the CFMT ($r = .216$, $p = .422$) or their CFPT scores ($r = -.176$, $p = .514$).

Figure-3

Experiment 2

In our first experiment, we examined whether 16 individuals with DP exhibited diminished composite face effects using a simultaneous matching paradigm. Contrary to previous reports (Avidan et al., 2011; Liu & Behrmann, 2014; Palermo et al., 2011), we found that the DPs and controls exhibited comparable composite face effects. However, DP is known to be a heterogeneous condition (Eimer, Gosling, & Duchaine, 2012; Stollhoff, Jost, Elze, & Kennerknecht, 2011; Susilo & Duchaine, 2013). For example, some individuals appear to perceive facial expressions normally, whereas others exhibit impaired expression recognition (Biotti & Cook, 2016; Duchaine, Parker, & Nakayama, 2003; Duchaine, Yovel, Butterworth, & Nakayama, 2006; Humphreys, Avidan, & Behrmann, 2007). Similarly, some individuals with DP recognize objects normally, while others exhibit broader object recognition deficits (Behrmann, Avidan, Marotta, & Kimchi, 2005; Biotti, Gray, & Cook, 2017; Dalrymple, Elison, & Duchaine, 2017; Duchaine, Germine et al., 2007). In light of this heterogeneity, it is possible that a subgroup of the DP population exhibits diminished composite effects, but is under-represented in our first sample. Moreover, the use of simultaneous matching in Experiment 1 differs from the sequential matching tasks employed in the previous studies that have reported group differences (Avidan et al., 2011; Liu & Behrmann, 2014; Palermo et al., 2011). In our second experiment, we therefore tested a different group of DPs with a sequential matching composite task.

Methods

Participants

Twenty-four individuals with DP (M_{age} = 40.1 years, SD_{age} = 13.2 years, 6 males) participated in the study. The performance of the DPs was compared to a control group comprising 22 neurotypical adults (M_{age} = 45.8 years, SD_{age} = 13.9 years, 5 males). All observers were US residents. Ethical approval was granted by the local ethics committee and the study was conducted in line with the Declaration of Helsinki. All participants provided informed consent prior to testing.

Diagnostic testing

DP participants were recruited through the Dartmouth/Harvard/UCL Prosopagnosia Research Center website (www.faceblind.org). All complained of lifelong face recognition difficulties that affected their daily lives. Convergent diagnostic evidence for the presence of DP was collected using the CFMT, the Old-New Face Recognition Test (ONFRT; Duchaine & Nakayama, 2005), and a Famous Faces Test suitable for use with US residents (FFT_{US}; Duchaine & Nakayama, 2005). When tested on the CFMT, all DPs scored at least 1.7 standard deviations below the mean performance of the comparison sample described by Duchaine and Nakayama (2006a). All DPs tested[2] also scored at least 2 standard deviations below the mean of the controls on the FFT_{US} and the ONFRT (comparison data taken from Duchaine, Yovel, & Nakayama, 2007; Susilo, Wright, Tree, & Duchaine, 2015). DPs also completed the CFPT and the Leuven Perceptual Organization Screening Test (L-POST; Torfs, Vancleef, Lafosse, Wagemans, & de-Wit, 2014). All DPs scored within the normal range on the L-POST, suggesting typical mid-level vision. Detailed diagnostic results are provided in Table 3.

Table-3

Composite task

The stimuli and procedure were adapted from the composite task employed by Susilo et al. (2013; Experiment 3). Face composites were constructed from greyscale photographs of Caucasian male children posing neutral expressions (Figure 1b). The children were photographed wearing a black ski-cap to occlude their hairline. When viewed from 40 cm, aligned faces subtended 10° vertically and 6.5° horizontally, and misaligned faces 10° × 9°. All subjects were tested remotely via www.testable.org, a platform that enables precise control of experiments conducted online[3]. Participants were asked to do the task in an environment in which they would not be disturbed and to employ a viewing distance of around 40 cm.

Experimental trials presented two face composites sequentially for 200 ms each, with an inter-stimulus interval of 400 ms during which a black display was presented. Composites were either both aligned or both misaligned, both upright or both inverted (Figure 1b). Participants were asked to indicate with a keypress whether the target regions (the face halves containing the eyes) were the "same" (identical) or "different" (not identical) while ignoring the distractor regions, which were always different. There were 90 trials per orientation; 60 in which the target regions were the same (30 aligned, 30 misaligned) and

30 where the target regions were different (15 aligned, 15 misaligned), making 180 trials in total. Orientation (upright, inverted), Alignment (aligned, misaligned), and Trial Type (same, different) were randomly interleaved. Six practice trials were provided.

Results

Matching procedures that present composites sequentially for pre-determined intervals (in this case 200 ms) afford less opportunity for a trade-off between speed and accuracy, because participants cannot accumulate more perceptual evidence by responding slowly. In Experiment 2, our primary analyses focus on accuracy (% correct). Descriptive statistics for accuracy scores and RTs achieved by the two groups are presented in Table 4.

Table-4

Accuracy

The combined dataset was subjected to ANOVA with Alignment (misaligned, aligned) and Orientation (upright, inverted) as within-subjects factors, and Group (DP, NT) as a between-subjects factor (Figure 4). The analysis revealed main effects of Orientation [$F(1,44) = 30.96$, $p < .001$, $\eta^2 = .413$] and Alignment [$F(1,44) = 84.33$, $p < .001$, $\eta^2 = .65$], as well as a highly significant Alignment × Orientation interaction [$F(1,44) = 75.21$, $p < .001$, $\eta^2 = .63$], reflecting a larger difference between aligned and misaligned trials when composites were shown upright. The main effect of Group was not significant [$F(1,44) = 0.20$, $p = .65$], and neither the Group × Orientation interaction [$F(1,44) = 0.07$, $p = 0.79$], nor the Group × Alignment interaction [$F(1,44) = 0.61$, $p = .44$] reached significance. Most critically, however, the Orientation × Alignment interaction did not vary as a function of Group [$F(1,44) = 0.75$, $p = .39$]. As expected, controls' ability to discriminate the misaligned target regions exceeded their discrimination of the aligned targets when the faces were upright [$t(21) = 6.95$, $p < .001$, Cohen's $d = 1.48$], but not when arrangements were inverted [$t(21) = .33$, $p = .75$]. The DPs exhibited a similar pattern, but their ability to discriminate the misaligned target regions exceeded their discrimination of the aligned targets in both the upright [$t(23) = 7.78$, $p < .001$, Cohen's $d = 1.59$] and inverted [$t(23) = 2.70$, $p = .013$, Cohen's $d = .55$] conditions.

Unlike controls, DPs showed an effect of alignment for inverted trials. Nevertheless, we do not believe this difference is indicative of qualitatively differently face processing. First, the Alignment × Orientation interaction did not vary as a function of Group; both the DP and NT controls showed much larger alignment effects for upright faces than for inverted faces. Second, it is not uncommon for typical observers to show small but significant composite effects for inverted faces[4]. For example, Susilo and colleagues (2013) used the same inverted composite task used here and found a significant alignment effect in a large sample of typical observers (N = 242) with a magnitude similar to that exhibited by the DPs in this experiment (Typical observers: 4.0%, DPs: 5.0% respectively).

Figure-4

Response times

The response latency data was analysed using a mixed-model ANOVA with Orientation (upright, inverted) and Alignment (aligned, misaligned) as within-subjects factors, and Group (DP, NT) as a between-subjects factor. Main effects of Orientation [$F(1,44) = 12.71$, $p = .001$, $\eta^2 = .22$] and Alignment [$F(1,44) = 22.04$, $p < .001$, $\eta^2 = .32$] were observed, as well as a significant Orientation × Alignment interaction [$F(1,44) = 21.80$, $p < .001$, $\eta^2 = .32$]. However, no main effect of Group was observed [$F(1,44) = .46$ $p = .50$]. The effects of Orientation [$F(1,44) = .60$, $p = .44$], Alignment [$F(1,44) = 2.58$, $p = .12$], and the Orientation × Alignment interaction failed to interact with Group [$F(1,44) = .88$, $p = .35$].

Individual differences

Once again, no correlation was observed between the DPs' composite face effects (Δaccuracy = %Correct$_{\text{aligned}}$ - %Correct$_{\text{misaligned}}$) seen in the upright condition and their scores on the CFMT ($r = -.05$, $p = .81$) or CFPT ($r = -.07$, $p = .77$). We present the individual effects seen for the DPs and age-matched controls (Figure 4) to illustrate that the failure to find a group difference is not due to the presence of outliers.

Some cases of developmental prosopagnosia appear to have an apperceptive profile – whereby individuals have problems forming perceptual descriptions of faces – while other cases may have selective problems with face learning or face memory (De Renzi et al., 1991). Insofar as the whole-face binding revealed by composite face effect has been characterised as a face encoding process (Murphy et al., 2017; Rossion, 2013), it is possible that susceptibility to the composite face effect is reduced only in apperceptive cases of DP. We took advantage of the large sample size employed in Experiment 2 to examine this possibility in more detail. The DPs were split into apperceptive (N = 12) and non-apperceptive (N = 12) subgroups. Members of the apperceptive subgroup performed at least 2 SDs below the mean of the comparison sample on the CFPT. Contrary to the foregoing speculation, however, we found no difference in the size of the composite effects (Δaccuracy) exhibited by the subgroups in the upright [$t(22) = .324$, $p = .749$] or inverted [$t(22) = .273$, $p = .787$] conditions. The lack of relationship between scores on the CFPT and composite effect sizes accords with previous findings with typical observers (Rezlescu et al., 2017) and DPs (Palermo et al., 2011).

Discussion

The present study assessed whether individuals with DP exhibit diminished composite face effects at the group level. Across two experiments conducted on separate samples and using different paradigms, we find no evidence for diminished composite-face effects in this population. In our first experiment, a group of 16 DPs showed typical composite face effects when tested on a simultaneous matching procedure. In our second experiment, a separate group of 24 DPs also showed typical composite face effects when tested on a sequential matching procedure. Contrary to previous reports (Avidan et al., 2011; Liu & Behrmann, 2014; Palermo et al., 2011), these findings indicate that diminished composite face effects are not a characteristic feature of DP. These results have important implications, both for our understanding of DP and for our interpretation of the composite face effect.

Composite face effects in developmental prosopagnosia

Our results accord with findings from previous case studies that have described typical composite face effects in individual DPs (Le Grand et al., 2006; Schmalzl et al., 2008; Susilo et al., 2010). In particular, Le Grand and colleagues (2006) described typical composite effects in seven out of eight DPs tested. Similarly, having tested seven family members with DP, Schmalzl et al. (2008) found typical composite effects in the four youngest cases (aged 4-40 years) and atypical composite effects only in the three oldest cases (aged 66-87 years). Interestingly, we note recent findings from typical observers suggesting that composite face effects may behave differently in samples of older adults; for example, the composite processing of older observers may be less efficient (Wiese, Kachel, & Schweinberger, 2013) and be more susceptible to general factors (Meinhardt, Persike, & Meinhardt-Injac, 2016). In contrast, our results are inconsistent with previous reports of reduced composite face effects in DP at the group level (Avidan et al., 2011; Liu & Behrmann, 2014; Palermo et al., 2011). Having examined the processing of upright and inverted face composites in 40 individuals with DP (aged 21-63 years), our results suggest most members of this population exhibit normal composite face effects. On the other hand, close examination of the previous group studies calls their conclusions into doubt.

In their first experiment, Palermo and colleagues (2011) found that a sample of 12 DPs were slower to name the emotion of a target region when aligned with a distractor region expressing an incongruous emotion. However, inspection of the distribution suggests this difference was strongly influenced by the results from a single DP whose aligned RTs were considerably faster than their misaligned RTs - a reversed composite effect (see Palermo et al., 2011, Figure 5). Further complicating interpretation, neither the DPs nor the controls showed composite effects in their error rates. In their second experiment, controls and nine DPs were required to match the top halves of face composites presented sequentially for 200 ms each. Given the short presentations, accuracy is the most critical measure of composite effects, and the DPs and controls showed clear and nearly identical composite effects in their accuracy data. The evidence for atypical composite effects cited by the authors is derived from RTs. However, the Alignment × Group interaction seen in the RT data failed to reach significance when analysed in the standard manner ($p > .3$). The group difference was only significant when adjusted for performance in the baseline misaligned condition, a point we discuss further below.

Avidan and colleagues (2011) reported that a sample of 14 individuals with DP showed diminished effects of alignment both in their RTs and error rates, when matching upright composites presented sequentially. The age of the DP sample is older than is typical in this literature; half the DP participants were aged 60 years or older (mean age = 52.5 years; range 31-79 years). Inspection of the single-case data is further complicated by the fact that aligned and misaligned trials were blocked, and completed in a different order by different DPs. Whilst this treatment may have little effect on the performance of typical observers (e.g., Le Grand et al., 2004), DPs may be prone to order effects resulting from practice, fatigue, or test anxiety. Within their DP sample, those individuals who showed weaker composite face effects showed greater local bias (*r* = .52) on a compound letter task (Navon, 1977). Where observed, weaker composite face effects therefore seem to be related to wider global processing difficulties. It is possible that a subgroup exists within the DP population characterized by a global processing deficit affecting performance on composite face and compound letter tasks. However, the present results together with previous reports, suggest that this profile is relatively uncommon. For example, many DPs exhibit typical perception of global motion and Glass patterns (Le Grand et al., 2006), typical Gestalt completion (Duchaine, 2000; Duchaine et al., 2006), and process compound 'Navon' stimuli typically (Duchaine, Germine et al., 2007; Duchaine, Yovel et al., 2007; Schmalzl et al., 2008).

Lastly, Liu & Behrmann (2014) reported that eight DPs showed reduced composite effects for left and right face halves when tested using the complete design. However, several factors undermine our confidence in these findings. First, the three DPs with the lowest holistic processing index, exhibited surprisingly normal performance on the diagnostic tests (e.g. MN and SH had CFMT scores of 73.6% and 79.2%, and WA exhibited above average famous face recognition). Second, inspection of the composite results indicates that the DPs performed much worse in the baseline misaligned condition than the matched controls. This feature of the data suggests that the reduced composite effects described reflect problems encoding local regions rather than aberrant integration processes. Distractor halves perceived as homogenous or nondescript by prosopagnosics may afford weaker perceptual prediction, and thereby exert less illusory bias in the aligned condition, than distractor halves perceived as distinctive. In an attempt to factor in baseline differences, the authors computed a holistic processing index, where modulation in the aligned condition is expressed relative to misaligned performance. Crucially, this measure and similar indices (see Avidan et al., 2011; Palermo et al., 2011) make unfounded assumptions about the relationship between performance in misaligned conditions and susceptibility to the composite effect; it is not clear what constitutes a "typical" composite effect where observers exhibit atypical misaligned performance.

Traditionally, it has been assumed that the face inversion (Yin, 1969), composite face (Young et al., 1987), and part-whole effects (Tanaka & Farah, 1993), reflect the operation of a single process or mechanism (Farah et al., 1998; Maurer et al., 2002; McKone & Yovel, 2009; Piepers & Robbins, 2013). However, mounting evidence suggests that individuals' susceptibility to the composite face effect not only fails to correlate with their face recognition ability, but also appears weakly related to other putative measures of holistic face processing (Rezlescu et al., 2017; Wang et al., 2012; but see DeGutis, Wilmer et al., 2013). As a result, we do not wish to claim that every facet of holistic face processing is typical in DP. Given that different measures of holistic processing are unrelated or weakly correlated in the typical population, neuropsychological dissociations might also be seen in the DP population. While DPs may show typical susceptibility to the composite face effect, other effects attributed to holistic face processing may be aberrant; for example, many DPs may show diminished face inversion effects (Duchaine et al., 2006; Shah, Gaule, Gaigg, Bird, & Cook, 2015; Tree & Wilkie, 2010), absent part-whole effects for the eye region (DeGutis et al., 2012), and commonly report excessive reliance on local features for identity recognition (DeGutis et al., 2012; Shah, Gaule, Sowden et al., 2015).

It is worth noting an interesting inconsistency in the DP literature highlighted by our findings. In both experiments, our DPs showed large composite effects with upright faces yet little or no composite effects with inverted faces (see also Susilo et al., 2010). Most DPs also show better performance with upright faces than inverted faces when tasks are sensitive and performance is not affected by restrictions of range (Duchaine, Germine et al., 2007; Duchaine, Yovel et al., 2007; Garrido, Duchaine, & Nakayama, 2008). Similarly, a study comparing event-related potentials (ERPs) indicated upright and inverted Mooney faces were processed differently by DPs (Towler, Gosling, Duchaine, & Eimer, 2016). These results indicate that DPs process upright and inverted faces differently, however they are inconsistent with findings from an ERP study of face processing in DP (Towler, Gosling, Duchaine, & Eimer, 2012). In typical observers, inverted faces reliably elicit larger N170 potentials than upright faces (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer, 2000; Rossion et al., 1999). A group of 16 DPs, however, showed no difference in their N170s to upright and inverted faces at the group level (Towler, Fisher, & Eimer, 2017; Towler et al., 2012). While the reason for the discrepancy between these findings is unclear, it appears that behavioural inversion effects and the N170 inversion effect are measuring different aspects of face processing.

Composite face effect and face recognition ability

The view that individual differences in holistic face processing, inferred from susceptibility to the composite face effect, predict face recognition ability is widespread (DeGutis et al., 2013; Farah et al., 1998; Maurer et al., 2002; Piepers & Robbins, 2013; Richler et al., 2011). This interpretation owes much to the correlated observations that orientation inversion renders faces harder to recognise (Yin, 1969) and greatly reduces the composite face effect (Young et al., 1987). Consistent with this view, composite studies employing the congruency design have found a positive correlation between composite effects and face recognition ability (DeGutis et al., 2013; Richler et al., 2011). However, the functional significance of the composite face effect has been called into question by other studies that have found little or no correlation between typical observers' composite face effects – measured using the standard design – and their face recognition ability (Konar et al., 2010; Rezlescu et al., 2017; Wang et al., 2012). Reports of diminished composite face effects in DP (Avidan et al., 2011; Liu & Behrmann, 2014; Palermo et al., 2011) have been cited as evidence that the process responsible for the composite face effect makes a necessary contribution to face recognition ability (Murphy et al., 2017). Our findings suggest this inference is potentially misleading.

Typical composite effects in the DPs tested here, and in other cases described previously (Le Grand et al., 2006; Schmalzl et al., 2008; Susilo et al., 2010), as well as evidence that some acquired prosopagnosics exhibit normal face composite effects (Finzi et al., 2016), suggest a complex relationship between susceptibility to the composite face effect and face recognition ability. Face recognition is thought to depend on a processing stream that can be fractionated at several stages (Bruce & Young, 1986). The whole-face binding indexed by the composite effect appears to be intact in individuals with DP suggesting that the locus of their impairment lies elsewhere in the face processing stream. However, the binding process revealed by the composite effect may still make a causal contribution to face recognition ability; i.e., the composite process may be necessary, but not sufficient, for typical face perception. Cases of acquired prosopagnosia have been described where face recognition deficits are associated with aberrant composite effects (e.g., Busigny et al., 2010; Busigny et al., 2014; Ramon et al., 2009), and no neuropsychological cases have been described who show no evidence of a composite effect but normal performance on tests of face perception and face recognition.

Typical composite face effects in DP and in some cases of acquired prosopagnosia (Finzi et al., 2016; Rezlescu et al., 2012), accord with other evidence that the processes underlying the composite effect are difficult to disrupt. Photographic negation disrupts observers' ability to encode 3D face shape (Kemp, Pike, White, & Musselman, 1996), but has little effect on the strength of the composite face effect (Hole, George, & Dunsmore, 1999; Taubert & Alais, 2011). Similarly, composite effects can be seen with abstract cartoon faces that contain only schematic facial features, but bear little resemblance to naturalistic faces (Murphy et al., 2017). Moreover, several markers of face processing, notably the ability to use the internal features (Ellis, Shepherd, & Davies, 1979; Osborne & Stevenage, 2008; Young, Hay, McWeeny, Flude, & Ellis, 1985) and achieve view-point invariance (Longmore, Liu, & Young, 2008), are strongly modulated by facial familiarity. In contrast, compelling composite effects can be seen with entirely unfamiliar faces (Hole, 1994). Together with the findings from prosopagnosia, insensitivity to negation, abstraction, and familiarity, suggest that the composite face effect is resilient and disrupted only by gross changes to the faciotopy (e.g., misalignment, inversion) or catastrophic damage to the face processing stream.

Face composite designs

Like most previous studies of composite effects in DP (e.g., Avidan et al., 2011; Le Grand et al., 2006; Palermo et al., 2011; Schmalzl et al., 2008), we employed the standard design in both experiments, where the distractor regions always differ. There has been considerable debate about the merits of an alternate congruency design, employing a full factorial combination of target regions (same, different) and distractor regions (same, different) (Richler & Gauthier, 2014; Rossion, 2013). Some authors have suggested that congruency designs mitigate the effects of response bias (for discussion see Richler & Gauthier, 2014). However, congruency designs have been criticized because the predicted effect on congruent-different trials – where different distractor halves are paired with different target halves – is unclear (Robbins & McKone, 2007), and because the congruency design produces composite effects for stimuli that do not yield demonstrable composite illusions (Rossion, 2013). The additional trials may induce domain-general facilitation / interference effects that differ from the illusory interference seen for upright-aligned face composites (Murphy et al., 2017; Rossion, 2013). Crucially, because the standard design is thought to limit the domain-general effects of congruency, the present findings represent a conservative test of the hypothesis that composite face effects are diminished in DP. Where observed, domain-general congruency effects may be expected to attenuate a group difference arising from a face-specific deficit.

Conclusion

In summary, we have described two experiments that sought to compare the composite face effects seen in typical observers and those with DP. Having employed complementary procedures and independent samples we find convergent results: evidence of highly significant composite effects in typical controls and DP groups that were indistinguishable. Contrary to previous reports, these results suggest that the whole-face binding process indexed by the composite face effect is intact in DP, indicating that the locus of this condition lies elsewhere in the face processing stream.

Footnotes

[1] We use the term *developmental prosopagnosia* instead of *congenital prosopagnosia* to indicate the possibility that in some cases the disorder may not be present at birth.

[2] In Experiment 1, two DPs did not complete FFT_{UK}. In Experiment 2, two DPs did not complete the FFT_{US} and two did not complete the ONFRT.

[3] One DP had technical difficulties, but a switch to another browser resolved the issue. This individual completed approximately one third of the trials before the task crashed, at which point the individual switched browsers and did the full task on the new browser.

[4] Composite face stimuli that include a gap of a few pixels between the target and distractor regions may be less likely to produce composite effects when arrangements are inverted (Rossion & Retter, 2015). It remains unknown how the presence or absence of this feature affects composite face processing in observers with DP. Addressing this issue in future studies of the composite effect in DP may prove worthwhile.

Author note

FB and EW contributed equally to the work described.

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Figures

Figure 1

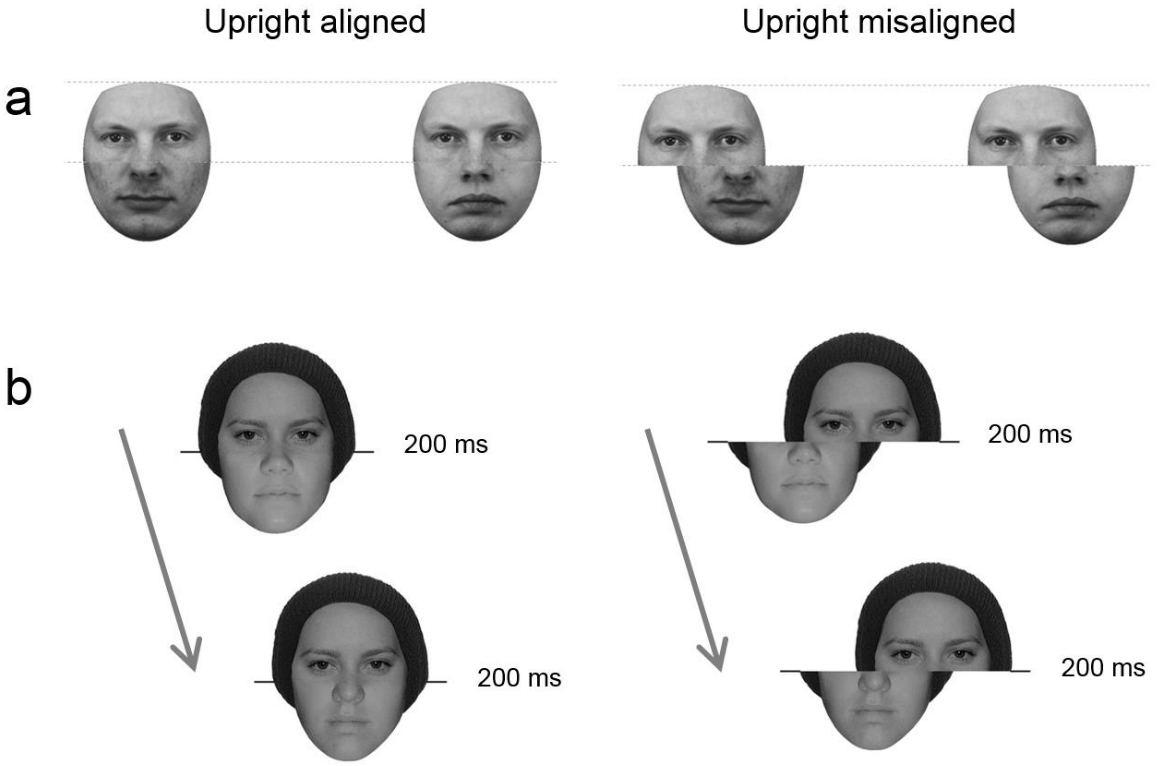

Figure 1: (a) In our first experiment, trials presented pairs of composite arrangements simultaneously. Composites were visible until a response was registered. (b) In our second experiment, trials presented pairs of face composites sequentially. Composites were presented for 200 ms each, with an inter-stimulus-interval of 400 ms during which a black display was presented.

Figure 2

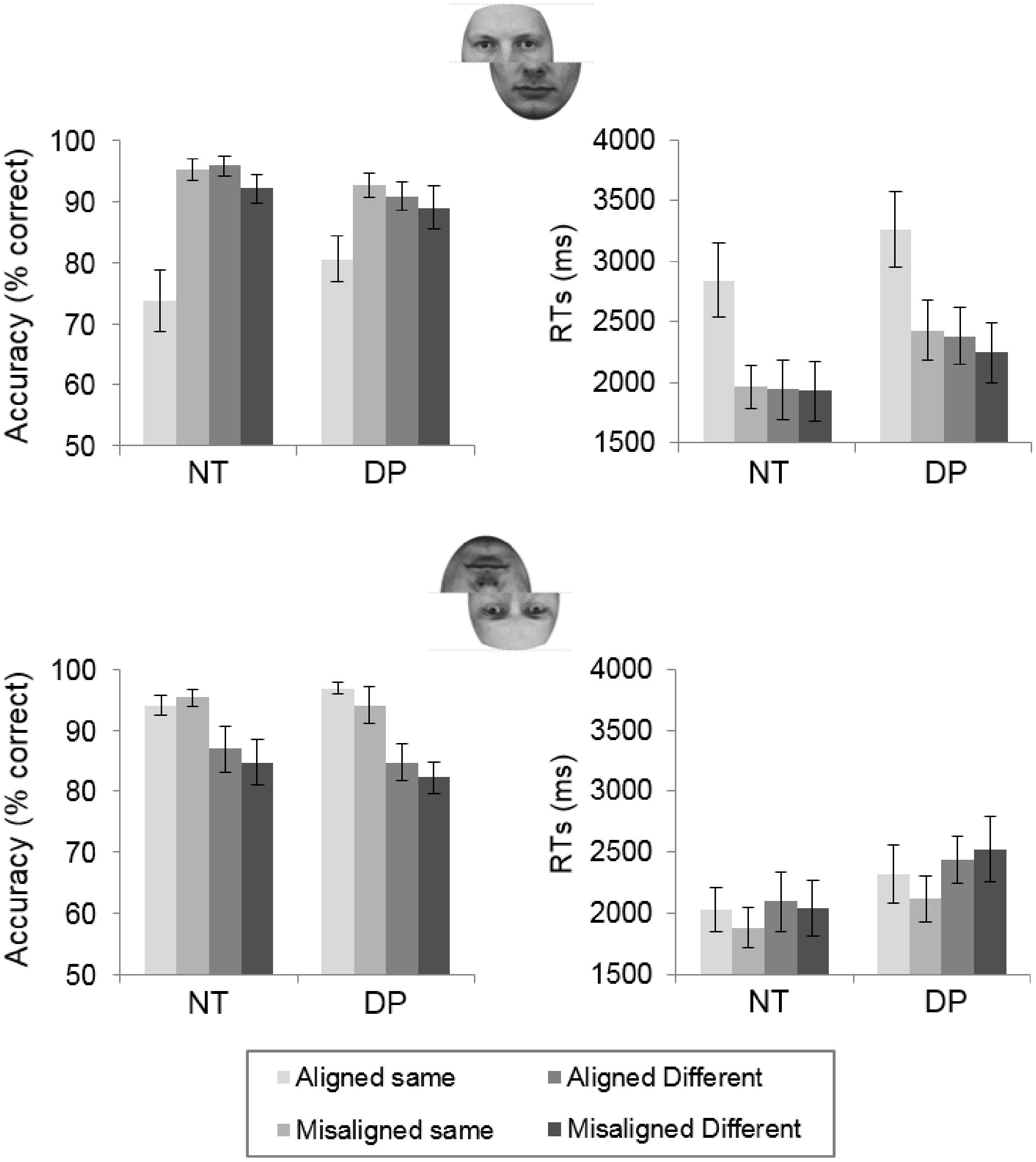

Figure 2: Results from Experiment 1 for composite arrangements constructed from upright faces (top) and inverted faces (bottom). Error bars represent ± 1 standard error of the mean.

Figure 3

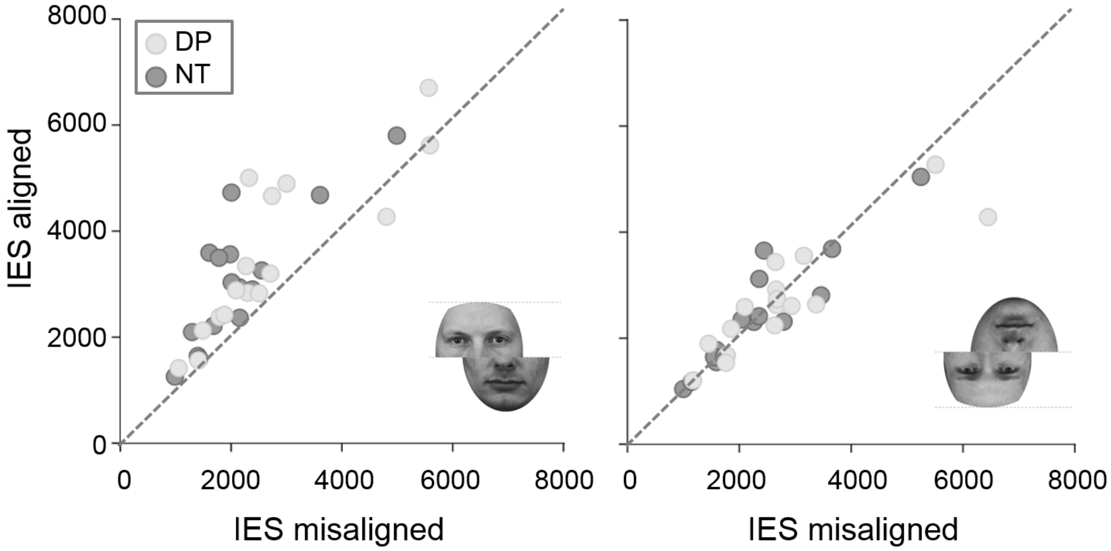

Figure 3: Inverse efficiency scores (IES) for aligned composites plotted against those seen for misaligned composites, for upright faces (left), inverted faces (middle), and pseudo-words (right). Points lying to the left of the dashed line are indicative of typical composite effects (performance misaligned > performance aligned).

Figure 4

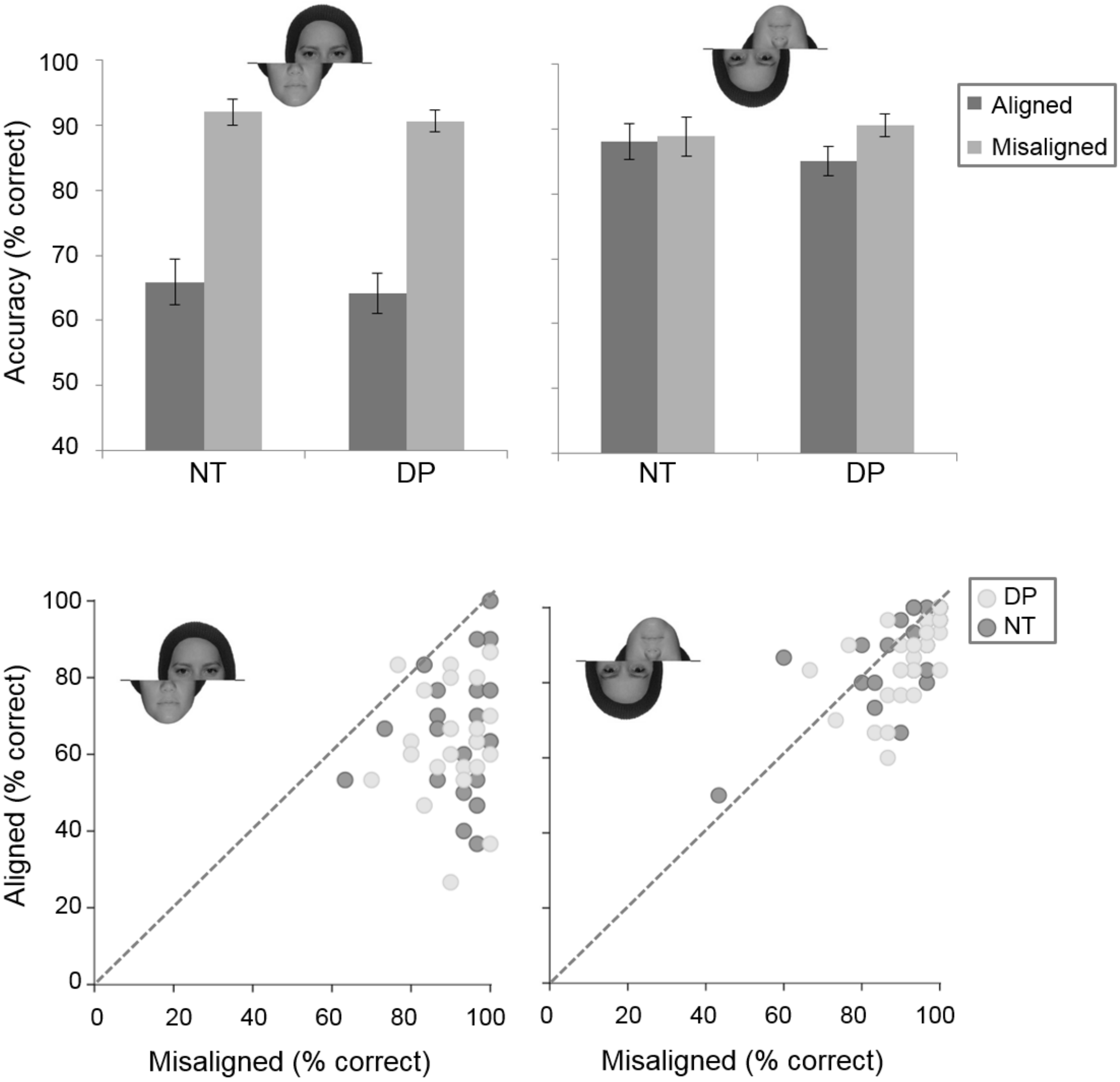

Figure 4: Results of Experiment 2. Top panels present accuracy scores for the two groups on the upright (left) and inverted composites (right). Error bars represent ± 1 standard error of the mean. Bottom panels show accuracy scores seen for aligned composites plotted against those seen for misaligned composites, for upright faces (left) and inverted faces (right). Points lying to the right of the dashed line are indicative of typical composite effects (performance misaligned > performance aligned).

Tables

Table 1: Scores of each DP in Experiment 1 on the 20-Item Prosopagnosia Index (PI20), the Cambridge Face Memory Test (CFMT), the Cambridge Face Perception Test (CFPT), and the Famous Faces Test (FFT_{UK}). Z-scores are shown in parentheses. Negative z-scores denote performance worse than the typical mean. The mean and standard deviation of the comparison samples are provided below.

Participant	Age	PI20	FFT_{UK} %	CFMT %	CFPT Upright [Errors]
F1	21	59 (-2.3)	25 (-4.2)	62.50 (-1.6)	30 (-0.0)
F2	22	89 (-5.6)	-	50.00 (-2.8)	30 (-0.0)
F3	25	87 (-5.4)	41 (-2.9)	63.89 (-1.5)	44 (-1.6)
F4	28	68 (-3.3)	48 (-2.3)	61.11 (-1.8)	32 (-0.3)
F5	35	85 (-5.2)	34 (-3.4)	43.06 (-3.4)	46 (-1.8)
F6	42	92 (-5.9)	18 (-4.8)	45.83 (-3.1)	62 (-3.5)
F7	50	78 (-4.4)	30 (-3.8)	58.33 (-2.0)	34 (-0.5)
F8	53	85 (-5.2)	42 (-2.8)	45.83 (-3.1)	74 (-4.8)
F9	55	85 (-5.2)	-	58.33 (-2.0)	36 (-0.7)
F10	65	79 (-4.5)	14 (-5.1)	61.11 (-1.8)	40 (-1.1)
F11	65	81 (-4.7)	25 (-4.2)	59.72 (-1.9)	44 (-1.6)
F12	48	78 (-4.4)	45 (-2.5)	58.33 (-2.0)	26 (+0.4)
F13	48	85 (-5.2)	37 (-3.2)	63.89 (-1.5)	60 (-3.3)
M1	28	62 (-2.6)	44 (-2.6)	62.50 (-1.6)	46 (-1.8)
M2	54	88 (-5.5)	48 (-2.3)	58.33 (-2.0)	66 (-3.9)
M3	58	92 (-5.9)	5 (-5.9)	44.44 (-3.3)	68 (-4.2)
DP mean		80.81	32.57	56.26	46.12
DP SD		9.97	13.53	7.66	15.31
Comparison mean		37.75	75.35	80.4	36.7
Comparison SD		9.16	12.00	11.0	12.2

Table 2: Mean accuracy and response time measures from Experiment 1. Standard deviations are shown in parentheses.

		Aligned Same		Misaligned same		Aligned different		Misaligned different	
Upright faces									
Accuracy (%)	NT	73.8	(20.0)	95.3	(7.2)	95.9	(6.6)	92.2	(9.3)
	DP	80.6	(15.2)	92.8	(8.0)	90.9	(9.5)	89.1	(14.3)
RT (ms)	NT	2840	(1228)	1964	(711)	1937	(992)	1925	(1006)
	DP	3257	(1241)	2430	(981)	2383	(945)	2243	(974)
Inverted faces									
Accuracy (%)	NT	94.1	(6.4)	95.3	(5.9)	86.9	(14.6)	95.3	(14.8)
	DP	96.9	(4.0)	94.1	(12.3)	84.7	(12.3)	82.2	(10.6)
RT (ms)	NT	2028	(741)	1882	(661)	2095	(990)	1882	(909)
	DP	2323	(969)	2120	(753)	2438	(787)	2522	(1068)

Table 3: Scores for each developmental prosopagnosic in Experiment 2 on the Cambridge Face Memory Test (CFMT), The Famous Faces Test (FFT_{US}), and the Old-New Faces Test (ONFT). Z-scores are shown in parentheses. Negative z-scores denote performance worse than the typical mean. The mean and standard deviation of the comparison samples are provided below.

Participant	Age	FFT_{US} %	ONFT A’	CFMT %	CFPT Upright [Errors]
F1	23	8 (-7.2)	0.87 (-4.5)	45.83 (-3.1)	54 (-1.4)
F2	26	23 (-5.9)	-	58.33 (-2.0)	-
F3	27	27 (-5.5)	0.81 (-7.5)	51.39 (-2.6)	54 (-1.4)
F4	27	-	0.83 (-6.5)	55.56 (-2.3)	66 (-2.4)
F5	29	63 (-2.2)	0.69 (-13.5)	50.00 (-2.8)	54 (-1.4)
F6	31	61 (-2.4)	0.98 (1.0)	56.94 (-2.1)	52 (-1.3)
F7	32	51 (-3.3)	0.89 (-3.5)	54.17 (-2.4)	78 (-3.4)
F8	34	-	0.77 (-9.5)	56.94 (-2.1)	48 (-0.9)
F9	38	58 (-2.7)	0.87 (-4.5)	61.11 (-1.8)	62 (-2.1)
F10	38	36 (-4.7)	0.77 (-9.5)	47.22 (-3.0)	56 (-1.6)
F11	41	28 (-5.4)	0.87 (-4.5)	38.89 (-3.8)	92 (-4.5)
F12	41	40 (-4.3)	0.91 (-2.5)	47.22 (-3.0)	42 (-0.4)
F13	44	61 (-2.4)	0.82 (-7.0)	52.78 (-2.5)	-
F14	44	40 (-4.3)	0.90 (-3.0)	51.39 (-2.6)	34 (+0.2)
F15	46	50 (-3.4)	0.81 (-7.5)	58.33 (-2.0)	62 (-2.1)
F16	51	45 (-3.9)	0.91 (-2.5)	61.11 (-1.8)	42 (-0.4)
F17	60	33 (-5.0)	0.75 (-10.5)	51.39 (-2.6)	70 (-2.7)
F18	62	48 (-3.6)	0.81 (-7.5)	50.00 (-2.8)	70 (-2.7)
M1	23	26 (-5.6)	0.90 (-3.0)	47.22 (-3.0)	92 (-4.5)
M2	28	24 (-5.8)	0.94 (-1.0)	51.39 (-2.6)	62 (-2.1)
M3	34	56 (-2.9)	-	45.83 (-3.1)	80 (-3.5)
M4	58	33 (-5.0)	0.81 (-7.5)	50.00 (-2.8)	78 (-3.4)
M5	62	43 (-4.0)	0.93 (-1.5)	56.94 (-2.1)	62 (-2.1)
M6	63	40 (-4.3)	0.87 (-4.5)	56.94 (-2.1)	50 (-1.1)
DP mean		40.64	0.85	52.37	61.82
DP SD		14.63	0.07	5.47	15.48
Comparison mean		87.5	0.96	80.4	36.7
Comparison SD		11.0	0.02	11.0	12.2

Table 4: Mean accuracy and response time measures from Experiment 2. Standard deviations are shown in parentheses.

		Aligned		Misaligned	
Upright faces					
Accuracy (%)	NT	65.9	(16.5)	92.0	(9.4)
	DP	67.6	(16.9)	91.2	(8.0)
RT (ms)	NT	1105	(362)	874	(234)
	DP	1090	(277)	978	(255)
Inverted faces					
Accuracy (%)	NT	88.0	(12.9)	88.8	(13.8)
	DP	86.7	(11.2)	91.7	(8.6)
RT (ms)	NT	928	(247)	889	(215)
	DP	991	(260)	999	(303)

Supplementary material for:

Normal composite face effects in developmental prosopagnosia

Federica Biotti, Esther Wu, Hua Yang, Jiahui Guo, Bradley Duchaine, & Richard Cook

1. Pseudo-word composite task

In addition to the upright and inverted composite face conditions employed in Experiment 1, we also examined composite effects for pseudo-words, because they resemble the effects found for upright faces (Anstis, 2005). By employing an additional comparison with a non-face composite effect we hoped to determine whether any diminished composite effects result from a face-specific deficit or from a non-specific problem affecting global processing of configurations. We elected to use pseudo-words in light of recent suggestions that the visual processing of words and faces may recruit similar neurocognitive mechanisms (Behrmann & Plaut, 2013; Hills, Pancaroglu, Duchaine, & Barton, 2015; Ipser, Ring, Murphy, Gaigg, & Cook, 2016).

Figure S1: trials presented pairs of composite arrangements simultaneously. Composites were visible until a response was registered.

Four-letter pseudo-words written in lower-case *Juice ITC* font were used to create the composites following the procedure described by Anstis (2005). Pseudo-word composites subtended 8° of visual angle, vertically. The to-be-judged regions subtended 4°. In the misaligned conditions, the horizontal offset corresponded to approximately 25% the width of pseudo-word. 40 pseudo-word composites were employed. Each composite was allocated a partner arrangement of the same type with which it would be presented simultaneously. For half the composites pairs, the target regions were identical, for half the pairs the target regions differed. The distractor regions within each pair were always different. The two target regions appeared at the same vertical position in the display (the lower edge of each target region was aligned to the vertical midpoint of the display). Two dashed guidelines were imposed over the arrangements to clearly delineate the stimulus regions to be judged. Example displays are presented in Figure S1. Participants judged whether the regions shown within the guidelines were or were not identical. Composite displays were presented until a response was registered. Participants were asked to respond with both speed and accuracy. Arrangements were shown until a response was registered. Each pair was presented twice in each alignment condition with side (left or right) counterbalanced. Composite type (upright faces, inverted faces, pseudo-words) was interleaved randomly within blocks of 80 trials.

2. Pilot testing of composite tasks for upright faces, inverted faces, and pseudo-words

Before testing the simultaneous matching task on the sample of DPs and age-matched controls, we piloted the task on a sample of 25 young neurotypical adults (M_{age} = 18.92 years, SD_{age} = 1.42 years, 3 males). We describe the results here (see Table S1 and Figure S2).

Table S1: descriptive statistics for the piloting conducted with young neurotypical controls. Standard deviations are shown in parentheses.

		Aligned same		Misaligned same		Aligned different		Misaligned different	
Accuracy (% correct)									
	Upright faces	68.2	(22.5)	94.2	(8.5)	97.8	(3.3)	95.4	(7.2)
	Inverted faces	93.2	(6.8)	95.0	(6.1)	87.8	(8.8)	86.2	(9.9)
	Pseudo-words	84.8	(21.2)	93.8	(9.2)	84.6	(14.2)	80.0	(18.7)
RT (ms)									
	Upright faces	2148	(1080)	1402	(475)	1348	(427)	1280	(356)
	Inverted faces	1555	(538)	1427	(423)	1481	(471)	1538	(508)
	Pseudo-words	3014	(1134)	2335	(999)	2574	(868)	2181	(675)

Accuracy

Analysis of the accuracy data (% correct) for the upright face composites revealed a main effect of Alignment [$F(1,24) = 29.12$, $p = .000$, $\eta^2 = .548$]. Target regions were harder to discriminate in the aligned than in the misaligned condition. We also observed a main effect of Trial Type [$F(1,24) = 28.62$, $p = .000$, $\eta^2 = .544$] and a significant Trial Type × Alignment interaction [$F(1,24) = 45.93$, $p = .000$, $\eta^2 = .657$], whereby aligned distractors were particularly detrimental when targets were the same.

No composite effect was observed for the inverted face arrangements. We did not see a main effect of Alignment [$F(1,24) = .01$, $p = .922$, $\eta^2 = .000$], nor an Alignment × Trial Type interaction [$F(1,24) = 2.36$, $p = .137$, $\eta^2 = .09$]. We observed a main effect of Trial Type [$F(1,24) = 12.12$, $p = .002$, $\eta^2 = .336$], whereby participants made more errors when the target regions differed than when they were identical.

Analyses suggested only a weak pseudo-word composite effect in the accuracy data of the young adults. While we found a main effect of Trial Type [$F(1,24) = 9.15$, $p = .006$, $\eta^2 = .276$] and an Alignment × Trial Type interaction [$F(1,24) = 5.74$, $p = .025$, $\eta^2 = .193$], the critical main effect of Alignment failed to reach significance [$F(1,24) = 1.25$, $p = .274$, $\eta^2 = .05$].

Response times

Analysis of response latencies (ms) revealed a main effect of Alignment for upright face composites [$F(1,24) = 21.41$, $p = .000$, $\eta^2 = .471$]. Participants were slower to discriminate target regions when the distractors were aligned than when distractors were misaligned. We also found a main effect of Trial Type [$F(1,24) = 31.08$, $p = .000$, $\eta^2 = .564$], which interacted significantly with Alignment [$F(1,24) = 16.04$, $p = .001$, $\eta^2 = .401$]. When distractor and target regions were aligned, we observed a disproportionate interference effect on same trials.

The response latency analysis revealed little evidence of a composite effect for inverted faces. While we observed a significant Alignment × Trial Type interaction [$F(1,24) = 5.42$, $p = .029$, $\eta^2 = .184$], we found no main effects for either Alignment [$F(1,24) = .83$, $p = .371$, $\eta^2 = .034$], nor Trial Type [$F(1,24) = .14$, $p = .707$, $\eta^2 = .006$].

The response latency analysis revealed a strong composite effect for pseudo-words. We observed a significant main effect of Alignment [$F(1,24) = 71.30$, $p = .000$, $\eta^2 = .748$], whereby participants took longer to discriminate target regions in the aligned condition. We also observed a significant main effect of Trial Type [$F(1,24) = 8.97$, $p = .006$, $\eta^2 = .272$] and a significant Alignment × Trial Type interaction [$F(1,24) = 15.68$, $p = .001$, $\eta^2 =$

.395]. Overall participants responded slower on same trials, but this effect was particularly pronounced in the aligned condition.

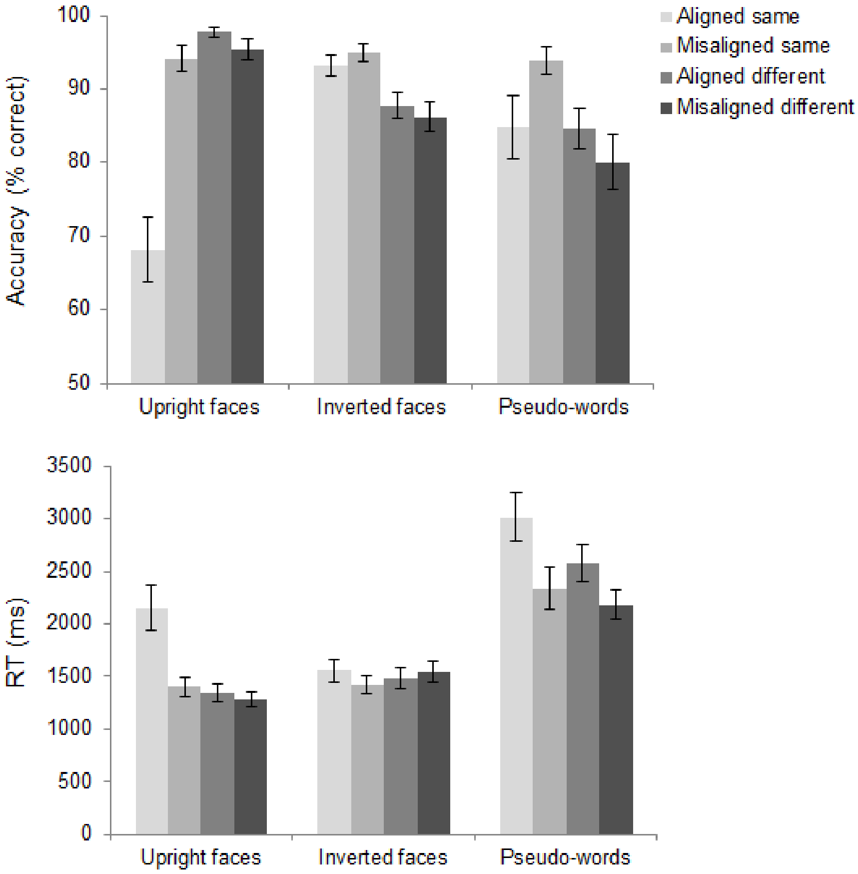

Figure S2: Mean accuracy and RTs exhibited by the young NT controls during the piloting procedure.

3. Group comparison: pseudo-words

Group analyses for the upright and inverted face composites are reported in the main text of the paper. Here we describe additional comparison of the pseudo-word composite effects exhibited by the two groups (see Table S2 and Figure S3).

Table S2: Mean accuracy and RTs exhibited by the NT and DP groups in the pseudo-word condition.

		Aligned Same		Misaligned same		Aligned different		Misaligned different	
Accuracy (%)	NT	93.1	(10.6)	95.3	(8.7)	85.0	(15.1)	88.4	(12.2)
	DP	94.7	(5.3)	95.9	(6.6)	90.3	(14.0)	95.6	(4.4)
RT (ms)	NT	3954	(1314)	2891	(962)	3107	(971)	2684	(777)
	DP	4136	(1369)	3342	(1109)	3511	(1217)	2739	(808)

Accuracy

We observed a significant effect of Alignment [$F(1,30) = 8.33$, $p = .007$, $\eta^2 = .217$], whereby participants made more errors in the aligned condition. The main effect of Trial Type was also significant [$F(1,30) = 4.446$, $p = .043$, $\eta^2 = .129$], but the Alignment × Trial Type interaction did not reach significance [$F(1,30) = 1.078$, $p = .308$, $\eta^2 = .035$]. The pseudo-word composite effects were comparable for the two groups: No main effect of Group was observed [$F(1,30) = 2.651$, $p = .114$, $\eta^2 = .081$], and neither the main effect of Alignment [$F(1,30) = .049$, $p = .826$, $\eta^2 = .002$], the main effect of Trial Type [$F(1,30) = 1.220$, $p = .278$, $\eta^2 = .039$], nor Alignment × Trial Type interaction [$F(1,30) = .302$, $p = .587$, $\eta^2 = .010$] varied as a function of Group.

Response latencies

Both groups showed evidence of pseudo-word composite effects in their response latency data. Main effects of Trial Type [$F(1,30) = 51.765$, $p = .000$, $\eta^2 = .633$] and Alignment [$F(1,30) = 95.193$, $p = .000$, $\eta^2 = .760$] were observed, as well as a significant Alignment × Trial Type interaction [$F(1,30) = 15.495$, $p = .000$, $\eta^2 = .341$]. No main effect of Group was observed [$F(1,30) = .560$, $p = .460$, $\eta^2 = .018$]. Neither the effects of Alignment [$F(1,30) = .065$, $p = .801$, $\eta^2 = .002$], Trial Type [$F(1,30) = .297$, $p = .590$, $\eta^2 = .010$], nor Alignment × Trial Type interaction [$F(1,30) = 1.220$, $p = .001$, $\eta^2 = .310$], varied as a function of Group.

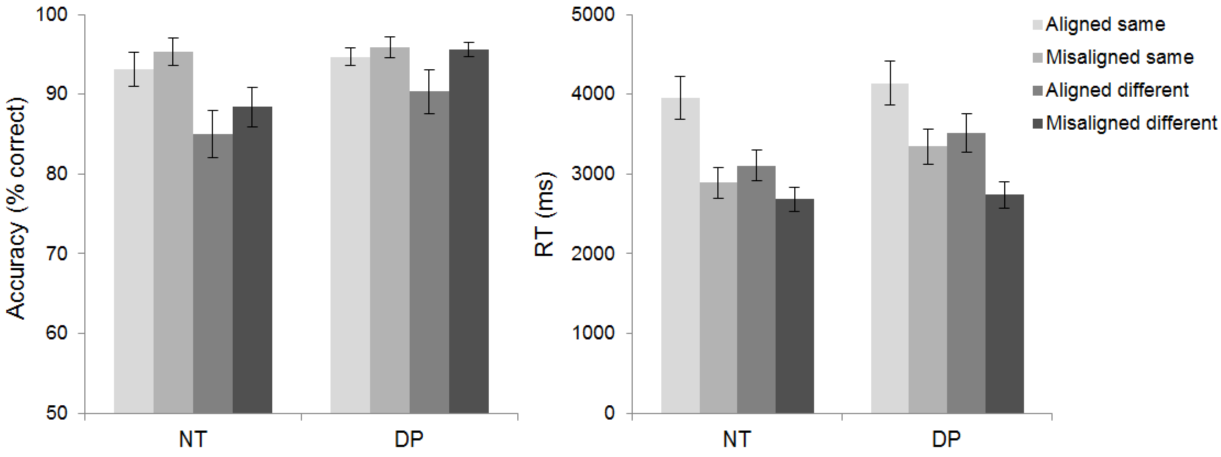

Figure S3: Mean accuracy and RTs exhibited by the DPs and aged-matched NT controls during the piloting procedure.

4. Supplementary references

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