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The composite-face effect survives asymmetric face distortions

Adélaïde de Heering§, Jessica Wallis, Daphne Maurer
Visual Development Lab, Department of Psychology, Neuroscience & Behaviour, McMaster University, 1280 Main Street West, Hamilton, ON L8S 4L8, Canada;
e-mail: adelaide.deheering@uclouvain.be
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Abstract. In two experiments, we investigated whether adults use holistic processing even for faces that are grossly distorted because their eyes have been moved asymmetrically to violate the common layout of a face (distorting its first-order relations). To this end we used a compelling demonstration that faces are processed as wholes, the composite-face effect. Specifically, adults judged the similarity of sequentially presented top halves of normal (original condition) and distorted faces with one eye (one-eye condition) or two eyes (two-eyes condition) shifted up by an abnormal amount. Trials were either blocked by type of distortion (experiment 1) or intermixed within the experiment (experiment 2). In both experiments, participants demonstrated a composite-face effect of the same magnitude in the three conditions, a pattern suggesting that they processed holistically even faces whose first-order relations were violated.

Keywords: faces, composite-face effect, holistic processing, distorted features

1 Introduction

Adults are experts at processing faces. They are able to remember hundreds of faces, recognise a familiar face within half a second, and accurately extract information from faces about gender, age, emotional expression, and direction of gaze (eg Bruce and Young 2000; Carey 1992). Underlying this expertise is the ability to extract the first-order and second-order relations of faces. First-order relations typically refer to the facial arrangement of two aligned eyes above a nose, which is in turn above a mouth, that allows individuals to categorise a face rapidly as a face and not an object (Biederman and Kalocsai 1997; Diamond and Carey 1986; Maurer et al 2002). Detecting face-like first-order relations is facilitated by the fact that all faces share the same basic configuration. As a result, normalised facial representations can be superimposed and the resulting stimulus remains recognisably face-like (Diamond and Carey 1986; Maurer et al 2002). Conversely, second-order relations refer to the metric distances between these features that allow individuals to differentiate among faces of different individuals (Maurer et al 2002; Rossion 2008, 2009).

Adults' expertise with faces also involves their ability to process faces holistically, as wholes, rather than as sums of independent features (Sergent 1986; Tanaka and Farah 1993; Young et al 1987). Evidence that faces are processed holistically comes from the composite-face effect (CFE). This perceptual illusion was originally described as individuals' greater difficulty in naming the top half of a familiar face when it is aligned with, rather than laterally offset from, the distracting bottom half of another face (Young et al 1987). The illusion was also found for same/different judgments about the top halves of unfamiliar faces (for a review see Rossion 2008). When faces are upright, performance on same trials is typically poorer in the aligned condition than in the misaligned condition, as revealed by worse accuracy and/or longer response times (eg de Heering et al 2008; Goffaux and Rossion 2006; Le Grand et al 2004; Michel et al 2006b; Rossion and Boremanse 2008). Interestingly, it was recently

§ Current address: Université Catholique de Louvain, Faculté de Psychologie, Louvain-la-Neuve, Belgium.

demonstrated that bands of spatial frequencies that are oriented horizontally contribute more than vertically oriented bands to a number of phenomena illustrating adults' expertise for upright faces, including the composite-face effect. Specifically adults were more sensitive to the composite illusion when they were exposed to face stimuli preserving horizontally oriented bands rather than stimuli preserving vertically oriented bands (Goffaux and Dakin 2010; see also Dakin and Watt 2009).

Holistic processing emerges early in development. Three-month-old infants already show evidence of holistic face processing: after familiarisation with the top half of one face, they respond randomly to the choice of a completely novel face or a composite face with the familiar top half aligned with the bottom half of a novel face—unless the top halves are misaligned to break holistic processing (Turati et al 2010). 3- to 4-year-old preschool children also show a classic CFE for faces (de Heering et al 2007; Macchi Cassia et al 2009). At least in adults, the CFE extends to upright chimpanzee faces (Taubert 2009), which have first-order relations similar to those of humans, but not to the faces of other animals (eg, gorillas, roosters, lizards) or to objects with more dissimilar first-order relations (Taubert 2009). Nevertheless, the strength of holistic processing also appears to be tuned by experience so that it is stronger for the most experienced types of faces, namely upright and own-race faces (Michel et al 2006a, 2006b).

In a review, Tsao and Livingstone (2008) suggested that adults' holistic face processing follows automatically from face detection (for similar observations based on the face inversion effect, see Taubert et al 2011). It follows that a stimulus that is distorted so that it is not detected as a face will not be processed holistically. Taubert and Alais (2009) supported this hypothesis by demonstrating that the CFE disappears when the top and bottom halves of a face are presented stereoscopically in different depth planes but re-emerges when stereo pairs are slanted so as to create the impression that faces are coherently leaning towards or away from the observer. In another experiment the same authors explored how much misalignment is needed to allow adults to make judgments about the top halves of faces without interference from discrepant bottom halves; that is, how much misalignment is necessary to offset holistic processing. When the shift was horizontal (sliding the top half to the side), an offset as small as a quarter face width was sufficient, but when the shift was vertical (moving the top half away from the bottom half, leaving blank space in between), a larger shift, of a half face width was necessary. The authors attributed the difference to the fact that long faces are sometimes encountered in real life unlike faces with their parts laterally offset. They concluded from these two experiments that preserved first-order relations (two aligned eyes above a nose, which is in turn above a mouth) and biological plausibility are prerequisites for holistic face processing, as measured by the CFE. Collectively, these studies suggest that adults process upright human faces holistically so long as they can be detected as a face (rather than an object or scrambled image) because they grossly preserve the correct first-order relations. The strongest argument against this conclusion comes from the observation that adults show a CFE of the same magnitude for positive and negative faces (Hole et al 1999; Taubert and Alais 2011), even though negative faces do not look biologically plausible and are difficult to differentiate (Galper 1970; Gaspar et al 2008). We note, however, that they do preserve the correct first-order relations.

Here we tested the limits to holistic processing with faces in which we grossly distorted the first-order relations by moving one eye up well beyond natural limits. For comparison, we used faces with preserved first-order relations but with the second-order relations altered by the same extent so that both eyes appeared outside natural limits. In a third condition, we used faces in which we had not manipulated the position of the eyes. Thus, we compared the CFE for three sets of faces: normal faces (original condition), faces with one eye moved up by an abnormal amount that disrupted their first-order relations (one-eye condition), and faces with two eyes moved up by the same amount that preserved the first-order relations while being outside the normal range of variation (two-eyes condition). The trials of the three conditions were either blocked by type of distortion (experiment 1) or intermixed so as to prevent adaptation to the distortion during the course of a block (experiment 2).

If preserved first-order relations are a requirement for holistic face processing, we expected no evidence of holistic face processing for the unnatural faces of the one-eye condition since they violate the superposition rule (Diamond and Carey 1986; Maurer et al 2002) while also disrupting the horizontal bands of information that are critical for face recognition, including holistic processing (Goffaux and Dakin 2010). They are also more difficult to recognise as a face than faces with distortions involving both eyes that keep them aligned (Cooper and Wojan 2000). We expected a typical CFE for the original faces (eg Hole 1994) and perhaps even for the two-eyes conditions because this manipulation, like the minimally disruptive manipulation of inserting a gap between the top and bottom halves (eg Taubert and Alais 2009), preserved the basic structure of a face of two aligned eyes above a nose above a mouth, even though both eyes were outside natural limits.

We used the original version of the composite task (Hole 1994) rather than the so-called full design of Richler and colleagues (eg Richler et al 2011) because it taps the perceptual level of processing more directly since participants are instructed to pay attention only to the top halves of the faces from the start rather than having to hold the first stimulus of each trial in memory until being told at the time of the second stimulus to respond on the basis of the similarity of the top halves or of the bottom halves. Another reason for choosing the traditional design is the recent evidence that the CFE is revealed in event-related potentials at an early stage of perception rather than a later decisional stage (Kuefner et al 2010).

2 Experiment 1: Distortion type blocked

In experiment 1, the three types of faces were blocked so that participants could adopt an optimal strategy for each type of distortion by, for example, looking at the appropriate part of the screen to make the judgment. We expected this experiment to maximise participants' ability to ignore the bottom halves of unnaturally distorted faces.

2.1 *Methods*

2.1.1 *Participants.* Twenty undergraduate students (four males; mean age: 19.8 years; age range: 17–35 years; 1 left-handed) from McMaster University participated in the study for course credit. All had normal or corrected-to-normal vision. Informed written consent was obtained before participation and participants were debriefed upon experimental completion.

2.1.2 *Stimuli.* Stimuli were coloured digitised full-front photographs of 24 unfamiliar Caucasian adults whose hair had been cropped (12 males, neutral expression, free of jewelry, makeup, glasses) centred on a uniform white background. Each face was used twice in each of the three conditions, once as a target face and once as a probe face. These images were considered as the undistorted faces and were further manipulated with Adobe Photoshop 8.0 to create the faces we used in the one-eye condition and the two-eyes condition. The undistorted faces were 250 pixels wide and their height varied from 280 pixels to 360 pixels according to their natural proportions.

In the undistorted condition, an aligned trial was composed of an undistorted face paired with the same undistorted face with either the bottom half replaced by that of another undistorted face (aligned same [AS)] condition) or both the top half and the bottom half replaced by that of another undistorted face (aligned different [AD] condition). The face halves of each stimulus were laterally offset by half a face width using Adobe Photoshop 8.0 to create the stimuli used in the misaligned-same condition (MS) and misaligned-different condition (MD) (figure 1). The faces in the aligned condition subtended approximately 4.9×4.4 deg of visual angle when viewed from 100 cm.

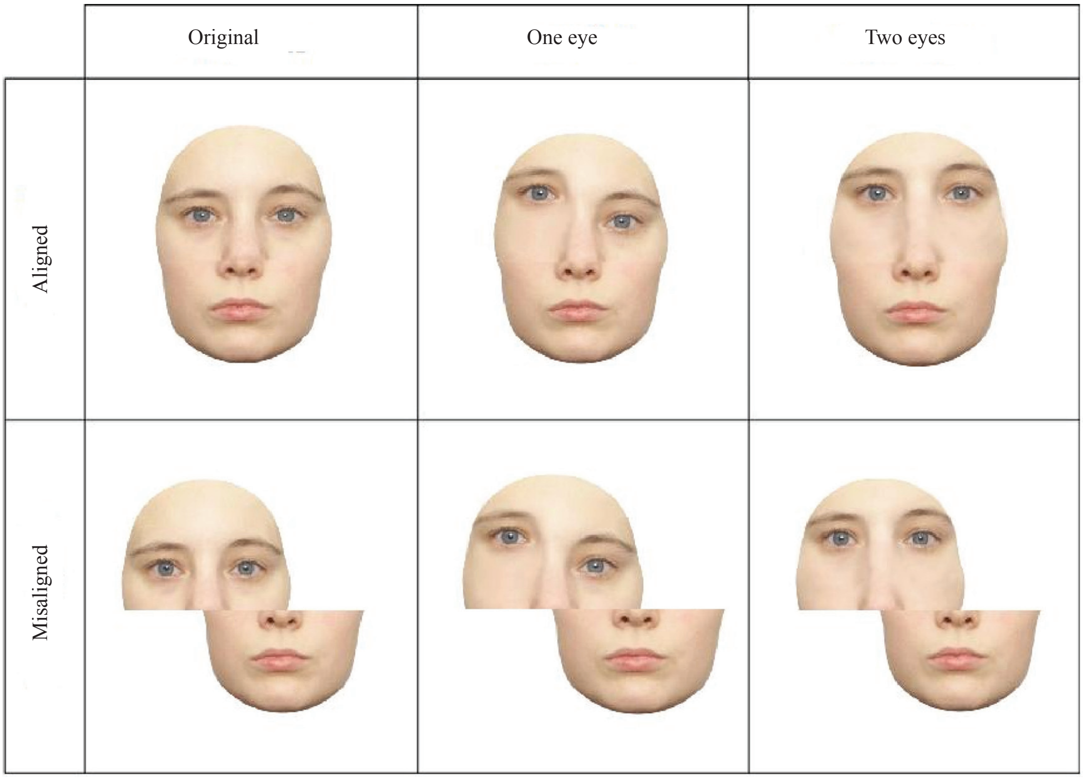

Figure 1. [In colour online, see http://dx.doi.org/10.1068/p7212] Examples of a face stimulus in its undistorted form (original condition), with one eye moved up by 40 pixels (one-eye condition) or with two eyes moved up by 40 pixels (two-eyes condition), and with the top and bottom halves either aligned with each other or misaligned by a horizontal offset.

To create the faces for the other conditions, we shifted one eye (½ left; ½ right) of each of the original undistorted faces up by 40 pixels or both eyes up by 40 pixels (figure 1). This level of distortion puts the eyes in positions well outside the range found in adult Caucasian faces (Farkas et al 1994).

2.1.3 *Procedure.* All participants were tested in a dark room and seated 100 cm from a Dell Trinitron P1140 computer screen measuring 51 cm diagonally. Stimuli were generated by a Mac mini (Apple) and controlled by Superlab 4.0.7b. Accuracy (% of correct) and reaction times (ms) were recorded. Participants were instructed that there would be three consecutive blocks in which they would have to compare the top halves of two sequentially presented faces in order to decide if they were of the same identity or of a different identity. They were asked to press the spacebar to launch the trial as well as to press the 1 key of the keyboard if the top halves were the same and the 2 key if they were different. They were also told that some of the faces would be distorted, but that their task remained the same.

Participants began the experiment with 15 practice trials which included 5 trials from the original condition, 5 trials from the one-eye condition, and 5 trials from the two-eyes condition. They were then given three blocks of 192 trials each (original—one eye—two eyes), the order of which was randomised across participants. They were provided with short breaks every 96 trials and were given no feedback. Each block was composed of 48 AS, 48 AD, 48 MS, and 48 MD intermixed trials. Each trial started with the presentation of a fixation cross at the centre of the computer screen and was followed by the consecutive presentation of two composite faces, both being either aligned or misaligned. The first composite face was presented in the middle of the screen for 200 ms, then after a 300 ms inter-stimulus interval, the second composite stimulus was shown until participants made a response. In order to discourage participants from basing their responses on luminance differences, the position of the second face was shifted from the original location by 10 pixels up and 10 pixels right so that the two sequentially presented faces appeared at slightly different screen locations.

2.1.4 *Analyses.* We based the analyses on same trials (AS trials vs MS trials) during which the different bottom halves make it more difficult to perceive that the top halves are the same in the aligned condition than in the misaligned condition (Young et al 1987). Specifically, we tested whether participants' CFE differed in the three conditions of interest by performing repeated-measures analyses of variance (ANOVAs) on both accuracy (% correct) and the means of median correct reaction times (ms), with the alignment of the face parts (aligned vs misaligned) and the condition (original vs one eye vs two eyes) as within-subject factors. We also performed two-tailed paired *t*-tests between the AS condition and the MS condition to test the significance of the CFE in each condition. We concentrated on the analyses of reaction times because many participants' accuracy was near ceiling for the MS condition, making it difficult to estimate the magnitude of their CFE.

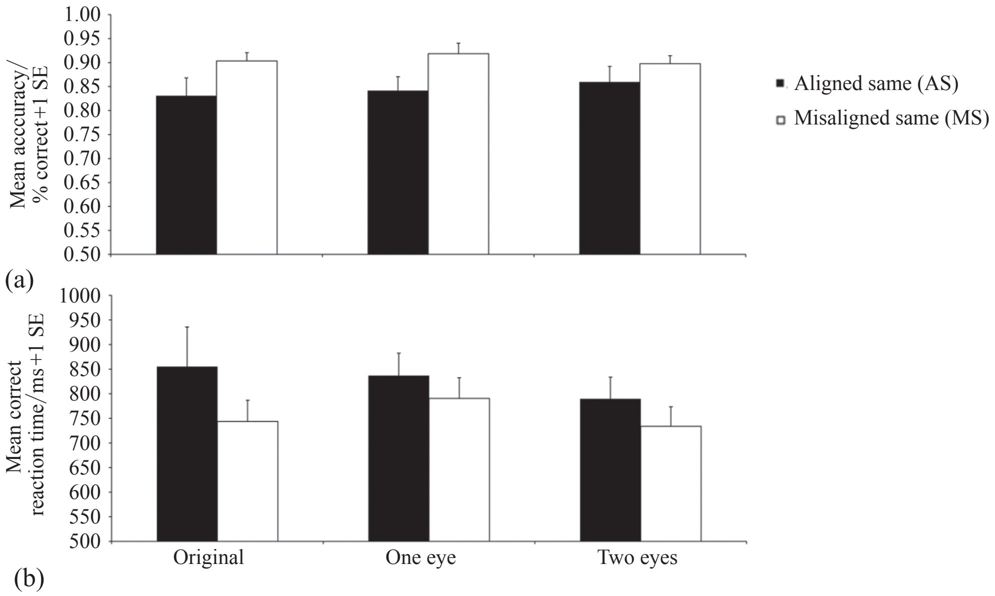

Figure 2. Participants' proportion of correct responses (a) and mean correct reaction times (b) for aligned same (AS) and misaligned same (MS) trials for the three blocked conditions of experiment 1. Shown are the means across participants and the between-subjects standard errors.

2.2 *Results*

For trials of interest (AS vs MS trials), there was a main effect of the alignment of the face halves ($F_{1,19} = 6.933$, $p = 0.02$) on participants' accuracy because they were more accurate on misaligned trials (MS) than on aligned trials (AS). There was no difference between the three conditions of interest ($F_{2,38} = 0.562$, $p = 0.58$) and the effect of alignment did not differ among the conditions, as shown by the absence of interaction between the condition and the alignment of the face halves ($F_{2,38} = 1.805$, $p = 0.18$) (figure 2a). For different trials, there was a significant effect of condition ($F_{2,38} = 4.585$, $p = 0.02$) because participants performed slightly better in the two-eyes condition ($M = 93\%$; SE = 2%) than in the original condition ($M = 91\%$; SE = 2%) and the one-eye condition ($M = 89\%$; SE = 2%). There was also no effect of alignment (AD vs MD: $F_{1,19} = 2.436$, $p = 0.14$) and no interaction between the alignment and the testing conditions ($F_{2,38} = 0.844$, $p = 0.44$).

For reaction times, there was a main effect of the alignment of the face halves (AS vs MS trials: $F_{1,38} = 14.038$, $p < 0.01$), participants being much faster in the misaligned condition (MS) than in the aligned condition (AS). However, there was no effect of condition ($F_{2,38} = 1.171$, $p = 0.32$) or interaction between the condition and the alignment of the face ($F_{2,38} = 2.025$, $p = 0.16$) (figure 2b). Subsequent analyses for each condition separately (two-tailed paired *t*-tests) indicated a significant CFE in the original condition (AS: $M = 855$ ms; SE = 81 ms; MS: $M = 744$ ms; SE = 43 ms; $t_{19} = 2.651$, $p = 0.02$), the one-eye condition (AS: $M = 837$ ms; SE = 46 ms; MS: $M = 791$ ms; SE = 42 ms; $t_{19} = 2.637$, $p = 0.02$), and the two-eyes condition (AS: $M = 790$ ms; SE = 44 ms; MS: $M = 734$ ms; SE = 40 ms; $t_{19} = 3.747$, $p = 0.01$). For different trials there was no effect of condition ($F_{2,38} = 1.957$, $p = 0.16$), no effect of alignment (AD vs MD: $F_{1,38} = 0.706$, $p = 0.41$) and no interaction between the alignment and the testing conditions ($F_{2,38} = 0.876$, $p = 0.43$).

3 Experiment 2: Distortion type intermixed

We ran a second experiment that was identical to experiment 1, except that the trials with one-eye and two-eyes distortions were intermixed with the original trials because it was possible that the results of experiment 1 were influenced by adaptation during each block that caused participants to see the distorted faces as more normal as the distorted block progressed. This hypothesis is unlikely to explain the results for the one-eye condition of experiment 1 because the distortion involved the right eye half the time and the left eye the other half. Nevertheless, we ran experiment 2 to minimise adaptation in every condition and to determine whether we could replicate the pattern in experiment 1 with intermixed distortions.

3.1 *Methods*

3.1.1 *Participants.* The final sample consisted of twenty participants. They were students from McMaster University participating for course credit. An additional subject was tested but her data were excluded because her results were close to chance for the different conditions with undistorted images (AD = 58%; MD = 54%), that is, the condition where performance is expected to be good because holistic processing does not interfere with correct different responses. Therefore, the final sample consisted of twenty participants (three males; mean age: 18.9 years, age range: 18–21 years; one left-handed). As for experiment 1, all of them had normal or corrected-to-normal vision, they signed an informed consent form before participation, and they were debriefed upon experimental completion.

3.1.2 *Stimuli.* The stimuli were identical to those used in experiment 1.

3.1.3 *Procedure.* The procedure was the same as that used in experiment 1 with the exception that the trials of the original condition, the one-eye condition and the two-eyes condition were intermixed. In total, there were 576 trials (192 per condition, as in experiment 1) with 144 AS trials, 144 AD trials, 144 MS trials, and 144 MD trials. As in experiment 1, participants were provided with short breaks every 96 trials and were given no feedback.

3.1.4 *Analyses.* The analyses were the same as those used for experiment 1.

3.2 *Results*

There was a main effect of the alignment of the face halves for trials of interest on participants' accuracy (AS vs MS trials; $F_{1,19} = 6.457$, $p = 0.02$). There was also a difference in accuracy between the three conditions ($F_{1.476,28.047}$[1] $= 5.002$, $p = 0.02$) because participants performed on average better in the one-eye condition ($M = 93\%$; SE = 2%) than in the original condition ($M = 91\%$; SE = 3%) and the two-eyes condition ($M = 90\%$; SE = 3%). The effect of alignment

[1] We used a Greenhouse–Geisser's correction when the data were not normally distributed according to the Mauchly's test of sphericity.

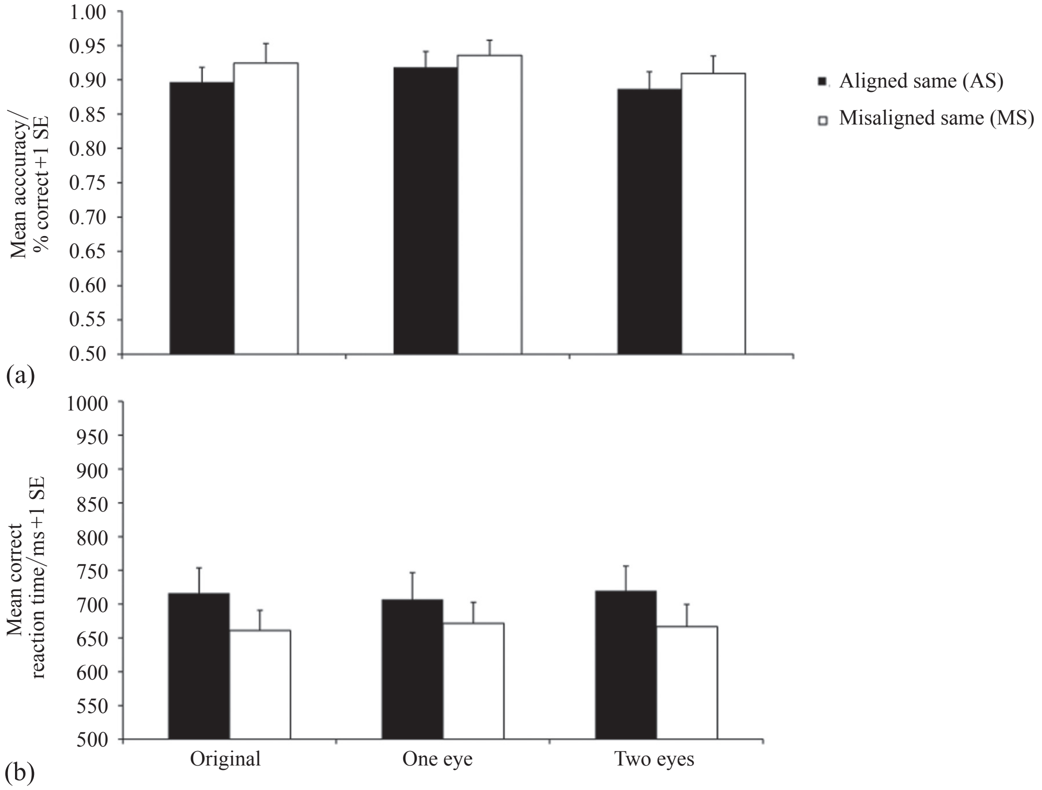

Figure 3. Participants' proportion of correct responses (a) and mean correct reaction times (b) for the aligned same (AS) and the misaligned same (MS) trials in experiment 2 when the three conditions of interest were intermixed. Shown are the means across participants and the within-subject standard errors.

did not differ between conditions, as shown by the absence of interaction between alignment and condition ($F_{2,38} = 0.218$, $p = 0.81$) (figure 3a). For different trials, there was no effect of condition ($F_{2,38} = 1.934$, $p = 0.16$), no effect of alignment (AD vs MD: $F_{1,19} = 0.374$, $p = 0.55$) or interaction between the alignment and the testing condition ($F_{2,38} = 0.286$, $p = 0.75$).

For trials of interest (AS vs MS trials), there was a main effect of the alignment of the face halves on participants' median correct reaction times ($F_{1,19} = 21.214$, $p < 0.01$) because they were much faster when matching the top halves in the MS condition than in the AS condition. There was no difference between the three conditions ($F_{1.504,28.575} = 0.286$, $p = 0.69$) and the effect of alignment did not differ between these conditions (absence of interaction condition × alignment: $F_{2,38} = 1.389$, $p = 0.26$) (figure 3b). Subsequent analyses (two-tailed paired *t*-tests) for each condition separately indicated a significant CFE in the original condition (AS: $M = 716$ ms; SE = 38 ms; MS: $M = 661$ ms; SE = 30 ms; $t_{19} = 3.771$, $p = 0.01$), the one-eye condition (AS: $M = 707$ ms; SE = 40 ms; MS: $M = 671$ ms; SE = 31 ms; $t_{19} = 2.532$, $p = 0.02$), and the two-eyes condition (AS: $M = 720$ ms; SE = 37 ms; MS: $M = 667$ ms; SE = 33; $t_{19} = 5.627$, $p < 0.01$). For different trials, there was a main effect of condition ($F(_{1.516,28.806}) = 6.508$, $p = 0.01$) because participants were equally fast in the two-eyes condition ($M = 679$ ms; SE = 29 ms) and in the original condition ($M = 681$ ms; SE = 31 ms) while being generally slower in one-eye condition ($M = 693$ ms; SE = 30 ms). There was also no effect of alignment for different trials (AD vs MD: $F_{1,19} = 3.887$, $p = 0.06$) and no interaction between alignment and the testing condition ($F_{2,38} = 0.348$, $p = 0.71$).

4 General discussion

In this study we tested whether adults' composite-face effect (CFE) persists despite distortions to the face that moved the eyes outside natural limits. Surprisingly, the magnitude of participants' CFE did not differ for undistorted faces and faces made biologically implausible because one eye (one-eye condition) or two eyes (two-eyes condition) were shifted up by an abnormal amount. The same pattern of faster reaction times for misaligned same trials than for aligned same trials was found in all three conditions whether the face manipulation was blocked (experiment 1) or intermixed (experiment 2) within the experiment.

The results for the two-eyes condition fit with the observation that holistic face processing extends to some types of faces that are not natural human faces but that grossly preserve the correct first-order relations (two aligned eyes above a nose, which is above a mouth), such as faces with a gap between the top and bottom halves (Taubert and Alais 2009), negative faces (Hole et al 1999; Taubert and Alais 2011), and chimpanzee faces (Taubert 2009). However, we also found that adults process holistically faces that distort the first-order relations of faces because their eyes were moved asymmetrically, again with a CFE as large as for undistorted faces. These results are surprising in light of hierarchical models of face processing (eg Tsao and Livingstone 2008) according to which stimuli that violate the first-order relations of faces will not be processed holistically since they cannot be detected, in the first place, as faces (see Cooper and Wojan 2000 for empirical verification that they are recognised less easily as a face than faces in which the eye distortions keep them aligned). They are also surprising because the manipulation in the one-eye condition breaks up the horizontally orientated bands of information across the eye region that has shown to be important for the processing of facial identity (Cooper and Wojan 2000) and in light of evidence that the magnitude of the CFE is related to experience, being larger for the types of faces individuals experience most often (upright, own race) (eg Hole 1994; Michel et al 2006a, 2006b). As a result of prior experience, one would have expected to observe a stronger CFE for the undistorted own-race upright faces we used than for faces with one eye or both eyes moved up beyond natural limits.

Overall, our results suggest that preserved first-order relations are not a requirement for holistic face processing. We speculate that what may be necessary and sufficient to elicit a CFE is a number of recognisable facial features bounded by a human-like facial contour. Indeed newborns are already sensitive to the congruency of these elements (Turati 2004), and adults judge facial identity using both the internal features and the external contour of a face (Haig 1986; Sinha and Poggio 1996). More specifically, we speculate that a CFE would fail to emerge if the contour or features are not detected to be those of a human face. If this is the case, the absence of a CFE for faces of gorillas, spider monkeys, sheep, chickens, and Jacky lizards (Taubert 2009) can be explained by the fact that the face contour of these species, unlike chimpanzee faces, is very different from that of human faces while their feature shapes may also be sufficiently different not to be recognised readily as human face parts. Similarly the progressive tuning of the CFE, and by implication of holistic face processing, for the most experienced face category could arise from the finer processing of the facial features and of the contour of members of that category. This view is consistent with evidence that adults discriminate and recognise more accurately and more quickly the facial features of own-race faces than other-race faces (eg Rhodes et al 2006) and that the ability to process feature shapes improves with age (Mondloch et al 2010). However it is difficult to reconcile with the absence of a difference in the size of the CFE for humans (Cohen's d statistic = 0.66) and chimpanzees (Cohen's d statistic = 0.68) (Taubert 2009), although it is possible that participants' attentional and emotional reactions modulate the effect for other-race faces (Ackerman et al 2006), but not for chimpanzee faces, which most adults describe as cute.

In sum, we found that adults showed a CFE of the same magnitude for undistorted faces (original condition), faces with one eye moved up by an abnormal amount that disrupted their first-order relations (one-eye condition) and faces with two eyes moved up by the same amount that preserved the first-order relations (two-eyes condition), a pattern suggesting that they processed holistically even faces that were not biologically possible and whose first-order relations were violated. Future studies might investigate more specifically the extent to which impoverished faces can induce holistic face processing. For example, it would be interesting to test whether adults show a CFE for stimuli with only human-like contours. Neuroimaging data suggest that this feature alone is probably not sufficient to induce a CFE since all three face-selective regions (FFA, OFA, STS) respond actively to it (Liu et al 2010), whereas only the FFA responds with a pattern mimicking the CFE (Schiltz and Rossion 2006).

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