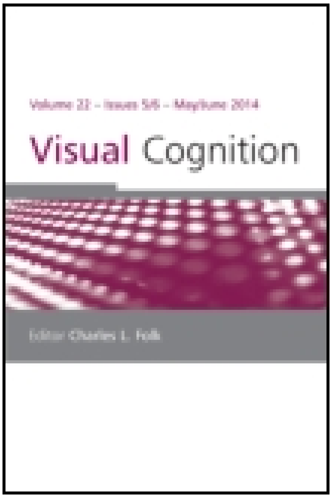

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Holistic processing for left–right composite faces in Chinese and Caucasian observers

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In Caucasian individuals, holistic processing and face recognition is lateralized to the right hemisphere, whereas part-based processing and word recognition is lateralized to the left hemisphere. Whether this hemispheric complementarity holds more generally is unclear. We compare the hemispheric basis of holistic processing of faces in Caucasian and Chinese observers (who, as readers of logographic script, may have different hemispheric organization). Participants made same/different judgements about the left/right halves of two sequentially presented composite faces (comprised of the left half of one face and the right half of another face) when the halves were aligned or were misaligned. There was a larger congruency effect for aligned than misaligned faces, reflecting significant holistic processing, and this was equivalent for face halves judged in the right and left visual fields and for Caucasian and Chinese observers. This same result was replicated in a second study with Caucasian observers, in which we presented the cue simultaneous with the study face, rather than simultaneous with the test face. These findings reflect equal participation of both hemispheres in holistic face perception and suggest that orthographic experience does not necessarily affect the hemispheric basis of holistic processing.

Keywords: Holistic processing; Composite face effect; Face lateralization; Lateralization of language processing; Other race effect.

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Research on hemispheric asymmetry in humans has consistently documented greater activation of the left over right hemisphere for visual word recognition and greater activation of the right over the left hemisphere for face recognition (for examples, see Cohen & Dehaene, 2004; Kanwisher, McDermott, & Chun, 1997). Evidence for this division of labour comes from investigations using a multitude of techniques. For example, behavioural studies report that performance in English word recognition is better when words are presented to the right visual field (RVF) than the left visual field (LVF; for example, Bradshaw & Gates, 1978; Dundas, Plaut, & Behrmann, 2013) and ERP studies show that the N170 waveform generated in response to orthographic input is left-lateralized (for example, Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Maurer, Brandeis, & McCandliss, 2005). Consistently, fMRI studies show that a region located in the left fusiform gyrus, the "visual word form area" (VWFA), is selectively activated during orthographic processing of alphabetic words (for example, Cohen et al., 2000; McCandliss, Cohen, & Dehaene, 2003).

The complement of these findings exists for face recognition. For example, a chimeric face made from two left halves of a stimulus face is usually judged more similar to the original face than a chimeric face made from two right halves, suggesting a right hemisphere (RH) involvement of face processing (Gilbert & Bakan, 1973; Wolff, 1933). Human ERP studies indicate that the N170 has a larger amplitude for faces than nonface objects over the right than the left hemisphere (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Rossion, Joyce, Cottrell, & Tarr, 2003) and fMRI studies reveal that an area located in the right inferior temporal cortex, the "fusiform face area" (FFA), responds more strongly to faces than to nonface objects (Kanwisher et al., 1997).

One explanation offered for these hemispheric differences concerns the underlying computations mediated by the two hemispheres. The critical distinction offered is that the RH computes in a more holistic or Gestalt fashion, whereas the LH processes visual images in a more part-based or featural fashion (for example, see Farah, 1990, 1991). Evidence to support this distinction comes from studies reporting that the RH advantage (left visual field stimulus presentation) is reduced or eliminated when faces are inverted, a condition in which holistic processing is minimized (Hillger & Koenig, 1991; Leehey, Carey, Diamond, & Cahn, 1978). Consistently, in a study using PET imaging, greater RH activation was observed when participants matched two whole faces compared with when they matched just the eyes or mouths across two faces, whereas greater LH activation was observed for the reverse comparison (Rossion et al., 2000). Similarly, in an fMRI study using a composite face task, there was recovery from adaptation only in the fusiform gyrus of the RH when participants evinced the composite effect, one of the strong signatures of holistic face processing (e.g., misjudgement of the identical top parts as being different when the bottom parts differ in the aligned but not misaligned condition) (Schiltz, Dricot, Goebel, & Rossion, 2010).

HEMISPHERIC SPECIALIZATION IN NONALPHABETIC SCRIPTS

The ascription of holistic (face) processing to the RH (and feature-based/word processing to the LH) results almost entirely from investigations conducted with individuals who read scripts that are alphabetic (for example, English). There is reason to predict, however, that this hemispheric arrangement might not be true universally. For example, some (but not all) studies have shown that the recognition of Chinese characters involves more bilateral activation (Liu, Dunlap, Fiez, & Perfetti, 2007), or perhaps even greater engagement of visual areas in the right than left hemisphere (Tan et al., 2000, 2001). This latter result is consistent with behavioural reports of a RH advantage in tachistoscopic recognition of Chinese characters (Tzeng, Hung, Cotton, & Wang, 1979; for conflicting results, see Bolger, Perfetti, & Schneider, 2005; Liu et al., 2008, Uchida et al., 1999). Thus, experience with alphabetic versus logographic scripts may be accompanied by differential cortical organization of word and face processing in Caucasian and Chinese readers.[1] The question to be addressed, then, is whether the holistic processing of faces differs as a function of hemisphere in readers who have experience with alphabetic versus more logographic orthographies.

Possible differences in holistic processing as a function of hemispheric organization in Caucasian versus Chinese readers derives from a series of studies we have conducted in which the specialization for word representations competes with that for face representations. As the left hemisphere (LH) comes to be tuned for word recognition over the course of development (to keep connectivity between visual areas and top-down language areas close), so face recognition becomes increasingly mediated by the right hemisphere (RH) (Behrmann & Plaut, 2013; Dundas et al., 2013). The prediction then is that experience with alphabetic scripts (i.e., Caucasian participants) may not result in the same hemispheric organization as for logographic scripts (Chinese participants) and, whereas the RH might be engaged in HP in Caucasian individuals, this may be so to a lesser extent in Chinese individuals. After we describe the

[1] We refer to the observers (and the stimuli) in this paper as being “Chinese” or “Caucasian”. We realize there is some inconsistency in our use of these terms. The term “Chinese” can be taken as an ethnic description of the dominant ethnic group in greater China, overseas Chinese, or as umbrella term of ethnic groups in China (Zhonghua minzu), whereas the term “Caucasian” only refers to the Caucasian race. To name the two groups of observers and stimuli at the same level, one ought to call them by the race: Caucasian and Asian. We have elected to use the term “Chinese” for the observers and the displays because “Asian” captures a large group of different observers and faces and there is even a near-race effect within the class of Asian faces: Taiwanese adults show a near-race effect for Philippine faces (Wang, Chien, Hsu, & Chiu, 2011). We realize our terms are not equated but wished to convey the particular subgroup of observers and faces adopted in this study, i.e., Chinese and Caucasian.

paradigm, we offer a specific prediction for how these potential hemispheric tuning differences across race may play out for face perception.

THE CURRENT STUDY

In the current study, we explore the extent to which holistic processing is modulated by hemispheric lateralization, and whether this differs as a function of the race of the observer. Here, we combine the "chimeric face" technique (for example, see Indersmitten & Gur, 2003) in which two face halves are paired (along the vertical midline here) with the established composite face paradigm to explore the hemispheric basis of holistic face processing in the Caucasian and Chinese observers. Because of the well-known "other race effect" phenomenon, in which observers perceive faces from their own race better than from other races (for a review, see Hancock & Rhodes, 2008; Meissner & Brigham, 2001), we include face images of both races to control for this factor.

In the standard top/bottom composite design, subjects are instructed to make same/different judgements of one half of two faces (say the top half) and the two halves of a face are either misaligned or aligned. The signature of holistic processing, known as the composite face effect, is the pattern in which performance is adversely affected when the two relevant halves are the same and the two irrelevant halves are different to a greater degree in the aligned than misaligned condition. That is, when face halves are aligned, the interference from the irrelevant bottom halves convincingly demonstrates that face processing is "holistic": Observers cannot help but process information about the face, even if it is task-irrelevant. Our task borrows that logic and we examine whether there is any effect on performance from the uncued half-face when participants are cued to the left (right visual field) or right (left visual field) of the chimeric face stimulus. To this end, we created left–right composite (or chimeric) faces by pairing one left half with the right half of another face of the same gender and race. Figure 1 shows a schematic depiction of the paradigm illustrating the rationale of the paradigm.

We adopt the complete version of the composite task here (for a review, see Gauthier & Bukach, 2007; for a recent exchange of opinions, see Rossion, 2013, and Richler & Gauthier, 2013), which includes both congruent trials where the relevant and irrelevant halves lead to the same response (i.e., both are same or both are different), and incongruent trials where the relevant and irrelevant halves elicit different responses. In the example of Figure 1 where the cued part is on the left (with a green/shaded background), the format of the study and test faces can be either both aligned or both misaligned. In addition, the study and test face halves can be either both the same/different (congruent condition, e.g., study face AB is followed by test face DC), or one half is different between study and test (incongruent condition, e.g., study face AB is followed by test face AC). Although we expect performance differences between congruent and incongruent conditions

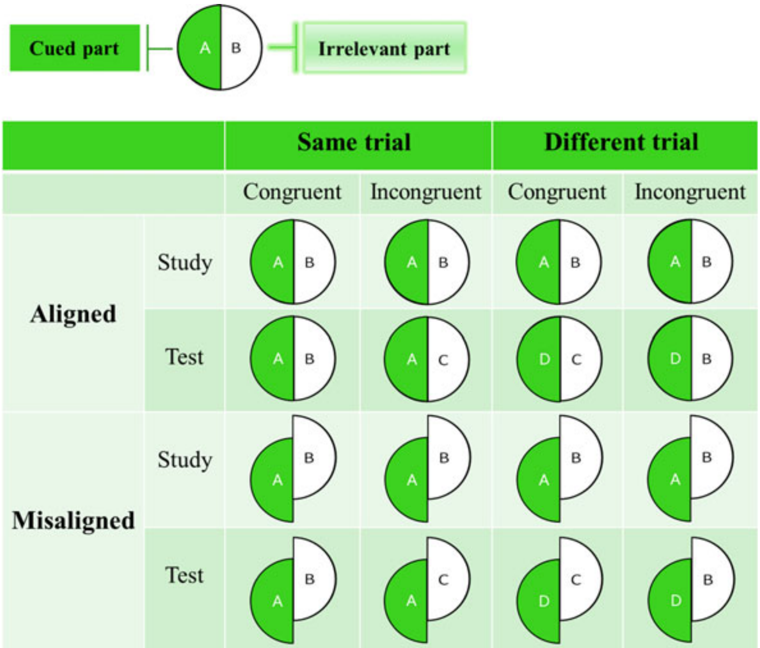

Figure 1. Schematic diagram depicting the left–right composite paradigm. In this example, the cued part is on the left (with a green/shaded background) and the irrelevant part is on the right (with a white background). The format of the study and test faces can be either both aligned or both misaligned. Participants are instructed to make a same/different judgement based on the cued part in the study face and the test face, and to ignore the other irrelevant part. In congruent trials, the study and test face halves can both be the same (AB→AB) or different (AB→DC). In incongruent trials, a change can occur either in the irrelevant part (AB→AC) or in the cued part (AB→DB). To view this figure in colour, please see the online issue of the journal.

(i.e., the "congruency effect"), the critical result, generally taken as an indicator of holistic processing, is the interaction between alignment and congruency. That is, holistic processing is defined as aligned (congruent–incongruent)–misaligned (congruent–incongruent). Based on our predictions, we expect to find evidence of greater holistic face processing (i.e., interaction between alignment and congruency) in the RH than LH of Caucasian participants but an equal magnitude of holistic processing in both hemispheres in Chinese participants. As will be seen later, the data are not consistent with these predictions and we examine why this is the case.

EXPERIMENT 1

Methods

Participants

Two groups of 32 Caucasian participants each (one group performed the Caucasian face task, mean age = 22.6 years, 12 male and 20 female, and the other group performed the Chinese face task, mean age = 22.1 years, 17 male and 15 female) from Carnegie Mellon University (CMU) and two groups of 32 Chinese participants each (one group performed the Caucasian face task, mean age = 24.2 years, 12 male and 20 female, and the other group performed the Chinese face task, mean age = 21.3 years, 10 male and 22 female) from the University of Hong Kong (HKU) participated in the study for course credit or payment. All participants reported normal or corrected-to-normal vision and all were right-handed according to their responses to the Edinburgh Handedness Inventory (Oldfield, 1971). Informed consent was obtained prior to the start of the experiment and the protocol was approved by the Institutional Review Board at CMU and HKU.

Materials and apparatus

The composite stimuli were created from 40 front-view male faces with neutral expressions and without hair or glasses. All faces were converted to greyscale images. Half of the faces were Caucasian (stimuli from Tanaka Lab), and the other half were Chinese (stimuli from Hayward Lab). All faces were approximately 170 pixels in width and 240 pixels in height and were fitted onto a 320 × 420 pixel black background. To ensure that the task could not be performed based on the facial symmetry (e.g., one eye is higher than the other, larger proportion of mouth on the right side), within each race, the 20 faces were subdivided into five groups of four similar faces based on prior ratings.[2] Each composite face was then created by pairing the left half of one face with the right half of another face from the same group. A 3-pixel-thick vertical white line was inserted at the centre of the face to form a gap between the left- and right-half face. Within each group, the positions of the eight face halves (left and right halves of the four faces) were rotated through a partial Latin-square design such that one composite face was never studied again throughout the experiment. Two misaligned versions were included to counterbalance the up/down position of the left and right sides of the composite face: Each misaligned composite face was created by moving the left half up or down approximately 80 pixels (around one third of the face). Stimuli were displayed on a 20-inch monitor with a resolution of 1680 × 1050 pixels and 60 Hz frame rate. Participants viewed the display from a distance of approximately 50 cm, and the face on the screen was 4.4 cm wide and 6.2 cm high; thus, each face subtended about 5° of visual angle horizontally and 7° of visual angle vertically.

[2] We printed all the 46 Chinese male faces in our database on paper and asked three naïve observers to group them in a way that maximizes face similarity within each group. Each group contained up to five faces (mostly four) and each face was used only once. The Caucasian faces were rated in a similar fashion by a naïve observer at CMU.

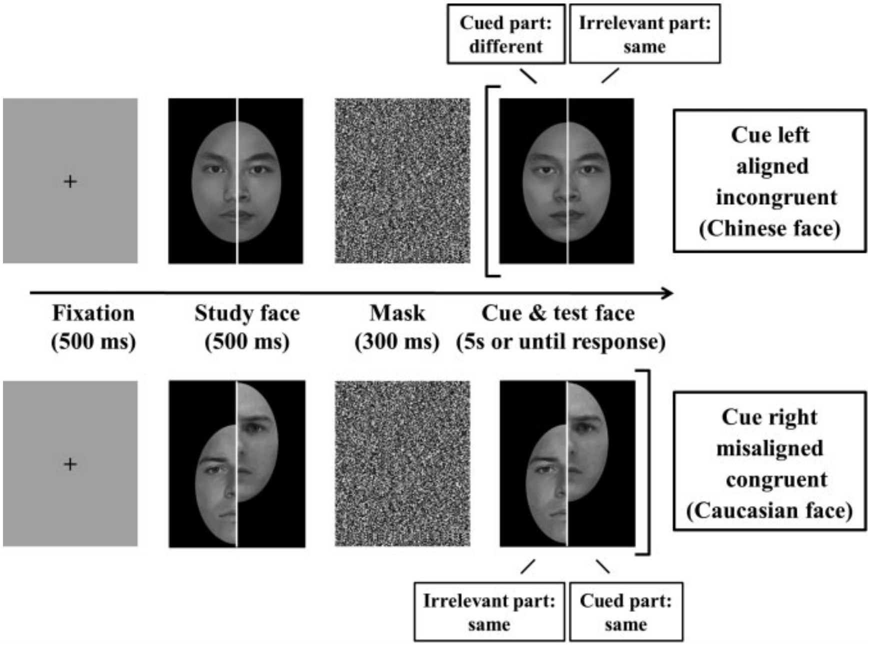

Figure 2. Two sample trials of the vertical composite task. As depicted here, a trial proceeds from fixation (left of image) to response (right of image). Participants were shown a composite face (study), which was masked, and were required to indicate whether the cued[3] part in the subsequent test face was the same or different as the same half (left or right) in the study face. Top: a cue-left aligned incongruent trial (example of a Chinese face). Bottom: a cue-right misaligned congruent trial (example of a Caucasian face).

Design

This study had two between-subject variables: image face race (Caucasian vs. Chinese) and participant race (Caucasian vs. Chinese), and three within-subject variables: alignment (aligned vs. misaligned), congruency (congruent, incongruent), and visual field (left vs. right of test face). The dependent variable was recognition performance (d'). Thirty-two Caucasian participants and 32 Chinese participants performed the Caucasian face version and a different 32 Caucasian participants and 32 Chinese participants performed the Chinese face version (2 × 2 design of Observer race × Face race). See Figure 2 for examples of a cue-left aligned incongruent trial (Chinese face) and a cue-right misaligned congruent trial (Caucasian face).

[3] The black brackets in the figure are for illustration purposes only. In both Experiments 1 and 2, the cue was a yellow frame overlaid on top of the black outline of either the left or the right face half.

Procedure

The sequence of displays in a single trial is illustrated in Figure 2. Each trial began with a black fixation cross presented at the centre of the grey screen for 500 ms. After that, a study composite face was shown for 500 ms, followed by a 300 ms mask. A test composite face, together with a bracket cueing which half of the face (left or right half) was to be judged, was then displayed for 5s or until a response was made (whichever came first). Participants were asked to judge whether the cued half in the test composite was identical or not to that in the study composite. Participants were instructed to respond as quickly and as accurately as possible by pressing "F" and "J" on the keyboard. The mapping of the key response was counterbalanced across participants. The aligned and misaligned trials were blocked and the experiment consisted of eight blocks of 80 trials each, so there were 640 trials in total and the experiment took around 35 min to complete. Each participant completed a practice session of 24 trials (consisting of both aligned and misaligned conditions) prior to the experiment. Practice data were checked and, in very rare cases, when accuracy fell below 60% correct, the participant was asked to complete one more practice session before proceeding to the experiment.

Results and discussion

A mixed ANOVA was conducted on discrimination performance (d'), with alignment (aligned, misaligned), congruency (congruent, incongruent), and visual field (cueing left, right of the test face) varying within subjects, and participant race (Caucasian, Chinese) and face race (Caucasian, Chinese) varying between subjects. Because the main focus of the study was on holistic processing (i.e., alignment by congruency interaction), we examined this interaction first and thereafter we assessed its modulation by the other within- and between-subject factors.

Performance (d') on congruent and incongruent trials for aligned versus misaligned faces as a function of visual field is plotted in Figure 3. There was a significant alignment by congruency interaction, $F(1, 124) = 117.611$, $p < .001$, $\eta_p^2 = .487$, indicating that the performance difference between congruent and incongruent trials was reduced in the misaligned relative to the aligned condition; in other words, judgement of the cued half was strongly influenced by the uncued (irrelevant) half, and this influence was greater when the face halves were aligned than when misaligned. Holistic processing was further corroborated by a significant main effect of congruency, $F(1, 124) = 473.498$, $p < .001$, $\eta_p^2 = .792$. Better performance was found in congruent trials than incongruent trials, in both aligned and misaligned conditions. Although here holistic processing was defined in terms of the alignment by congruency interaction, it is argued that the congruency effect alone can be interpreted as evidence of holistic processing (Bukach, Bub, Gauthier, & Tarr, 2006; Curby, Goldstein, & Blacker, 2013; Richler, Gauthier, Wenger, & Palmeri, 2008; but see

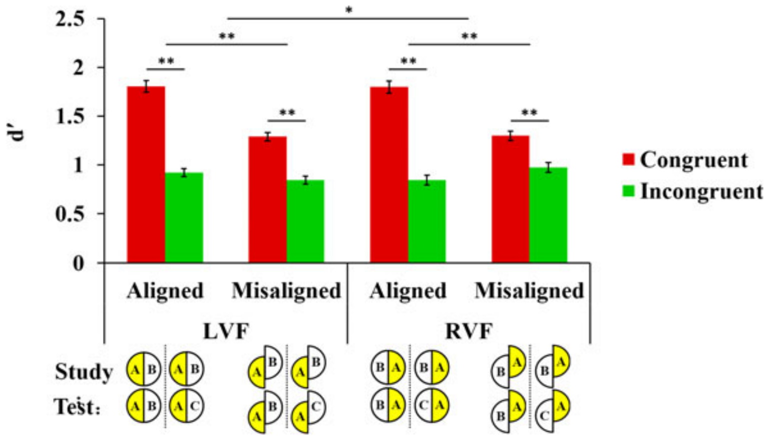

Figure 3. Results from Experiment 1. Mean performance (d') for all participants on congruent and incongruent trials for aligned versus misaligned faces where the cued half was in the left visual field (LVF) or right visual field (RVF). Error bars show ±1 standard error of the mean, *$p < .05$ and **$p < .01$. To view this figure in colour, please see the online issue of the journal.

Rossion, 2013, for a counterargument). Taken together, both the alignment by congruency interaction and the congruency effect itself suggest that the left–right composite faces are processed holistically. Having established the signature effect of holistic processing, we now go on to examine the other factors.

There was a significant main effect of alignment, $F(1, 124) = 64.632$, $p < .001$, $\eta_p^2 = .343$, with better overall performance in the aligned than misaligned condition. Note that this pattern is the reverse of that obtained from the standard top/bottom composite task in which holistic processing is attenuated in the misaligned condition because face halves are no longer presented in a meaningful configuration. Our findings also show this pattern: enhanced performance in the aligned than misaligned condition for the congruent trials—the unattended face half contributes positively when the status of the unattended half is shared with that of the attended part (both halves are either the same or both halves are different). When the two halves are misaligned, the irrelevant part can still influence performance in the congruent trials albeit to a lesser extent than when aligned. Finally, in incongruent trials, performance is equivalent for the aligned and misaligned conditions. Taken together, this suggests that congruency facilitates (especially when aligned), whereas incongruency neither facilitates nor inhibits.

Next, we examined whether the observed holistic processing (i.e., alignment by congruency interaction) was modulated by the visual field in which the face half was cued (processed in the contralateral hemisphere). A significant three-way interaction between alignment, congruency, and hemisphere was found, $F(1, 124) = 4.977$, $p = .027$, $\eta_p^2 = .039$. However, a post hoc Tukey's HSD test revealed no substantial difference in the magnitude of holistic processing when the cued face half fell in the left or in the right visual field, at the .05 level of significance. In other words, the magnitude of holistic processing was equivalent when the stimulus was cued in the right and left visual field. But, because of this three-way interaction, we were prompted to undertake closer examination of the findings, and a pairwise *t*-test revealed that the likely source of this interaction was in the difference in the misaligned incongruent condition across visual field, $t(127) = 2.162$, $p = .033$. This better performance in the incongruent condition when the cued part is on the right (LH) seems to imply a small amount of interference reduction as a result of better processing of the irrelevant face half in the LVF (RH). This finding is difficult to interpret as there is no theoretically relevant reason that the unattended (incongruent) LVF information should be helpful when misaligned but not when aligned. We take this up again for further discussion. The main effect of visual field was not significant, $F(1, 124) = 0.120$, $p = .729$, $\eta_p^2 = .001$, also reflecting equal participation of both hemispheres in processing left-right composite faces.

When the between-subject factors were taken into account, participant race did not interact with the above visual field by holistic processing interaction, $F(1, 124) = 0.602$, $p = .439$, $\eta_p^2 = .005$. Further, participant race did not interact with any of the factors alone, or in any combination, also suggesting that holistic performance was comparable for own versus other race faces. The absence of any effect of the observer's race both disconfirmed our expectation of the other race effect and also ruled out the differential hemispheric involvement as a function of race. Although there is no statistical interaction with race of the observer, we plot the Alignment × Congruency × Hemisphere interaction separately for the two groups to make apparent the null finding of observer race. These results are summarized in Figure 4.

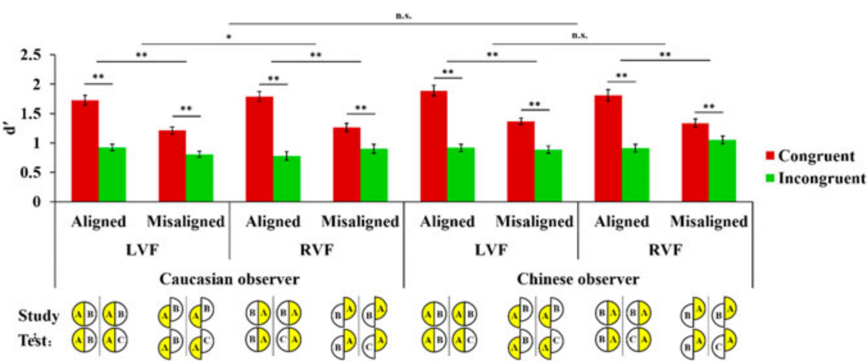

Figure 4. Results from Experiment 1. Mean performance (*d′*) for Caucasian observers (left) and Chinese observers (right) on congruent and incongruent trials for aligned versus misaligned faces where the cued half was in the left visual field (LVF) or right visual field (RVF). Error bars show ±1 standard error of the mean, $*p < .05$, and $**p < .01$. To view this figure in colour, please see the online issue of the journal.

However, when the face race (image of Caucasian or image of Chinese face) was considered, there was a marginally significant four-way interaction between face race, hemisphere, alignment, and congruency, $F(1, 124) = 4.017$, $p = .047$, $\eta_p^2 = .031$ (but not participant race). There was a significant Hemisphere × Alignment × Congruency interaction for Chinese faces, $F(1, 63) = 10.078$, $p = .002$, $\eta_p^2 = .138$, but not for Caucasian faces, $F(1, 63) = 0.024$, $p = .878$, $\eta_p^2 < .001$. This interaction arose from the larger difference in d' for congruent versus incongruent Caucasian than Chinese faces in the LH than RH. Unsurprisingly, in light of this interaction, face race interacted with each of three within-subject variables: Face race × Hemisphere interaction, $F(1, 124) = 5.636$, $p = .019$, $\eta_p^2 = .043$, Face race × Alignment interaction, $F(1, 124) = 6.096$, $p = .015$, $\eta_p^2 = .047$, and Face race × Congruency interaction, $F(1, 124) = 7.844$, $p = .006$, $\eta_p^2 = .059$. There was also a significant main effect of face race, $F(1, 124) = 47.509$, $p < .001$, $\eta_p^2 = .277$, with better performance for both groups of observers with Caucasian than Chinese face images (see Supplementary Figure 1), even though we had attempted a priori to equate the difficulty of the two sets. As pointed out by Hole (1994), even a small amount of asymmetry between the left and the right side of the face (i.e., misaligned eyes and mouth) may greatly reduce the percept of a new face. It is likely that misalignment of facial features is slightly larger in the Caucasian than the Chinese face images although the overall similarity among faces in each set is roughly equal. Because our interest was in differences between Chinese and Caucasian observers and group does not interact with the race of the displayed face, we do not go into further detail.

EXPERIMENT 2

The results of Experiment 1 provide evidence of holistic processing of left–right composite faces but show that this is not obviously modulated by hemisphere, race of the images used, or race of the observer. One possible explanation for the absence of these interactions is that the paradigm first entails viewing an intact face presented at fixation for a somewhat lengthy duration (500 ms). The cue to attend to one or the other half of the face only appears later. The relatively long exposure duration (in which face information may be relayed to both hemispheres) and/or the possibility of eye movements, together with the later cueing, when both hemispheres may have computed a precise representation of the input, might have precluded our ability to observe a modulation of the Alignment × Congruency interaction by hemisphere.

In this second experiment, then, to evaluate the holistic effects in further detail, we alter the composite paradigm such that the cue appears earlier (together with the study face) to minimize the interference from the unattended half visual field. In addition, we restrict the duration of the cue (200 ms). Finally, the half field in which the cue appears is random and because of the lack of predictability, this likely minimizes anticipatory eye movements prior to the cue presentation. We also take this opportunity to explore the somewhat better d' for the misaligned incongruent trials when the cue is on the right versus left side. Finally, in light of the fact that there was no evidence of the other-race effect nor of differential hemispheric involvement as a function of race in Experiment 1, here, we only examine performance with Caucasian participants viewing Caucasian faces.

Methods

Participants

Twenty-four Caucasian observers from CMU (mean age = 19.6 years, 11 male and 13 female) participated in the experiment for course credit. All participants reported normal or corrected-to-normal vision and all were right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). Informed consent was obtained prior to the start of the experiment and the protocol was approved by the Institutional Review Board at CMU.

Materials and apparatus

The materials and apparatus were identical to those used in the Caucasian face version of Experiment 1 conducted at CMU.

Design

This study had three within-subject variables: alignment (aligned vs. misaligned), congruency (congruent, incongruent), and visual field (left vs. right of test face). The dependent variable was recognition performance (d').

Procedure

The procedure was identical to Experiment 1 except that the cue appeared around the left or right half of the face together with the study face. The sequence of a trial was as follows: A black fixation cross was first presented at the centre of the grey screen for 500 ms. Then, a study composite face, together with a yellow bracket cueing which half of the face (left or right half) to attend to, were shown for 200 ms. This was followed by a 500 ms mask. After that, a test composite face, together with the cue, was shown for 5 s or until a response was made (whichever came first).

Results and discussion

A 2 × 2 × 2 (Alignment × Congruency × Visual field) repeated measures ANOVA revealed a significant alignment by congruency interaction, $F(1, 23) = 9.182$, $p = .006$, $\eta_p^2 = .285$. Mirroring the results from Experiment 1, a larger congruency effect was observed when face halves were aligned than when they were misaligned. This finding reveals that the composite face effect was sufficiently robust that even when the observers were told explicitly to attend to only the cued half, the unattended face half could not be ignored and still enhanced processing in the congruent aligned case. In other words, the left–right composite faces were still processed holistically.

In addition, there was a significant main effect of congruency, $F(1, 23) = 20.024$, $p < .001$, $\eta_p^2 = .465$, with better performance for congruent trials than incongruent trials. Unsurprisingly, there was also a significant main effect of alignment, $F(1, 23) = 20.798$, $p < .001$, $\eta_p^2 = .475$, with better performance for aligned compared with misaligned trials.

Importantly, the composite face effect was not modulated by the visual field in which the face half was cued (processed in the contralateral hemisphere). The three-way interaction between hemisphere, alignment, and congruency was not significant, $F(1, 23) = 0.013$, $p = .909$, $\eta_p^2 = .001$. There was also no main effect of visual field, $F(1, 23) = 0.006$, $p = .940$, $\eta_p^2 < .001$. These results are summarized in Figure 5.

To compare holistic processing across the two experiments and explore the impact of the cue later versus cue earlier design, we conducted a final ANOVA with experiment (Experiment 1, Experiment 2) as a between-subject variable, with the same three within-subject variables (alignment, congruency, and visual field). To make the two experiments comparable, we only included those Caucasian participants who performed the Caucasian face version in Experiment

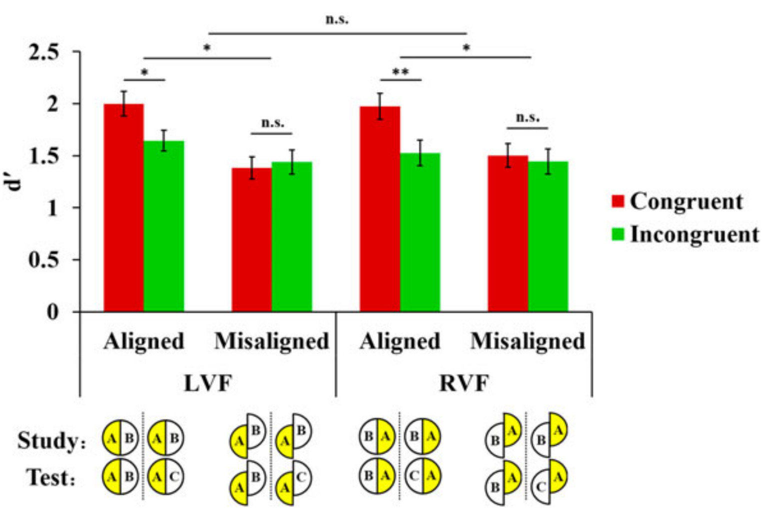

Figure 5. Results from Experiment 2. Mean performance (d') in congruent and incongruent trials for aligned versus misaligned faces was plotted as a function of the cued position (LVF vs. RVF). Error bars show ±1 standard error of the mean, *$p < .05$, and **$p < .01$. To view this figure in colour, please see the online issue of the journal.

1. This between-subject variable did not interact with holistic processing, $F(1, 54) = 1.393$, $p = .243$, $\eta_p^2 = .025$, alignment, $F(1, 54) = 3.942$, $p = .052$, $\eta_p^2 = .068$, or visual field, $F(1, 54) = 0.191$, $p = .664$, $\eta_p^2 = .004$. However, there was a significant experiment by congruency interaction, $F(1, 54) = 30.502$, $p < .001$, $\eta_p^2 = .361$, such that the performance difference between congruent and incongruent trials in Experiment 2 was smaller than that in Experiment 1. In particular, the congruency effect was present in the aligned condition but was absent in the misaligned condition in Experiment 2. That is, when the two halves are misaligned, the irrelevant part did not influence performance in the composite face task when the to-be-attended side is known.

Taken together, these results largely replicate and extend Experiment 1. In this second experiment, even with more constrained timing and with the cue appearing earlier, the composite effect was still observed. The major implication of these findings is that, as is standard with the holistic effect, it is difficult for an observer to attend to only half a face. Also, the difficulty in ignoring the task-irrelevant face half is even greater when the face halves are aligned than when misaligned. In other words, there appears to be mandatory processing of the whole face with both halves being encoded and this holistic effect was equally strong for face halves presented in the right and in the left visual field (processed in the corresponding hemisphere). As noted, one difference between Experiments 1 and 2 is that there is no congruency effect in the misaligned trials in Experiment 2. We suspect this congruency effect in the misaligned condition in Experiment 1 results from mentally combining the left and right face halves or simultaneously splitting attention between the left and right face halves of the study face. This congruency effect is not found in Experiment 2 where the cue appears earlier and participants are instructed to attend to the cued half while ignoring the irrelevant half. What is more critical for the current investigation is that there is no effect of visual field/hemisphere on the composite effect in Experiment 2 suggesting that the modulation by visual field in Experiment 1 may be more spurious than real.

GENERAL DISCUSSION

The purpose of the present investigation was to examine the hemispheric basis of holistic face processing in two groups of observers: Caucasian readers with experience with alphabetic script and Chinese readers with experience with logographic script. The hypothesis derived from the cognitive architecture argument (Coltheart, Curtis, Atkins, & Haller, 1993; Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; Frost, 2005; Perfetti, Liu, & Tan, 2005) is that because of their differential reading experience, with Chinese readers showing more bilateral or right hemisphere engagement in reading than Caucasian readers (Liu et al., 2007; Tan et al., 2000, 2001), the Chinese observers may show a more distributed or graded pattern of holistic processing (across both hemispheres) compared with the Caucasian participants (generally assumed to be right-hemisphere based). To test this hypothesis, we developed a paradigm, the vertical left–right composite in which two half (chimeric) faces are adjacent and are overlaid over fixation with each half falling in a different visual field. Participants make same/different judgements on one half of the face shown at study and at test, and the uncued face is task irrelevant.

The first major result is that the vertical composite paradigm we developed is sufficiently robust to yield clear evidence of holistic processing, defined as the alignment by congruency interaction. This was true under two different experimental conditions: In one scenario, when both halves of the study face were relevant at study and the cue appeared at test and in a second scenario when the cue appeared at study. Arguably the latter design is the more powerful as the participants are cued to attend to only one half of the face at study and can essentially ignore the other half entirely; that notwithstanding, we see an influence of the unattended half on the observer's same/different judgement of only the attended half (although this manifests primarily when the two face halves are aligned rather than misaligned, perhaps an even stronger indicator of holistic processing). The second major result was that the magnitude of the composite effect was equivalent when the cued half face appeared in the left or right visual field in the Chinese observers (independent of the race of the viewed face). Finally, and perhaps counterintuitively, we see no difference in the magnitude of the composite effect when the cued half (either earlier or later cue) appears in the left versus the right visual field in the Caucasian observers (again, independent of race of viewed face). Taken together, these last two findings combine to indicate that the race of the observer does not modulate the composite effect and that, in both groups of participants, we see essentially robust holistic processing in both hemispheres.

Holistic processing and the absence of hemispheric modulation

Before turning to the hemispheric effects, we briefly consider the difference between the two experiments. As discussed, we observed holistic processing in both experiments reported here. The design of these two paradigms closely resemble the sequential response task (although only one response is required here) and the selective attention task in Richler et al. (2008), respectively, and although we see a composite effect in both cases, there was one difference between the experiments that is worthy of consideration. While both experiments yield the holistic effect (Congruency × Alignment), this manifests slightly differently under the two experimental conditions: Specifically, the congruency effect was observed in both aligned and misaligned conditions in Experiment 1, but only in the aligned condition in Experiment 2. According to the rationale of the complete composite face paradigm design with a full factorial crossing of same/different face halves (Richler et al., 2008), the congruency effect is commonly obtained but reduced in the misaligned condition where the meaningful configurations are disrupted. It is perhaps surprising then that we see the congruency effect in the misaligned condition in Experiment 1 at all. The reason for this, we suspect, was due to a natural tendency to mentally reconstruct the left and right halves into a whole face even if misaligned. This congruency effect is abolished in the selective attention manipulation adopted in Experiment 2 where it is no longer strategically beneficial to combine the two misaligned halves into a whole face when the to-be-attended side is known in advance. The more important take-home message is that there is a difference in performance for aligned and misaligned faces in both experiments indicating that left–right composite faces can be processed holistically.

Having demonstrated the presence of holistic processing, we can then proceed to explore the hemispheric effects. Based on the idea that holistic processing is primarily a property of the right hemisphere and featural processing is primarily a property of the left hemisphere (Cattaneo et al., 2014; Ramon & Rossion, 2012; Rossion et al., 2000), we predicted a differential extent of holistic processing as a function of visual field. Surprisingly, the magnitude of holistic processing was equivalent for face halves presented in either visual field, suggesting equal participation of both hemispheres in face perception, and this was true in both Experiments 1 and 2. The modulation of the composite effect by hemisphere (misaligned incongruent has higher *d′* in RVF than LVF) was not replicated in the second experiment and there were no other hemispheric effects.

One possible explanation for the absence of substantive hemispheric modulation (especially in Caucasian observers, as we had predicted) is that both hemispheres do mediate face perception, even if weighted to a greater degree by the right hemisphere (Behrmann & Plaut, 2013; Moscovitch, Scullion, & Christie, 1976). Two possible factors, which play off against each other, might account for this. The first factor is that face information in the LVF (which projects to the RH) should be dominant; for example, there is a well-known preference to select chimeric faces made from two left sides of the original face (with the left side usually projected to the RH) (Brady, Campbett, & Flaherty, 2005; Gilbert & Bakan, 1973). This relative RH advantage for faces is so robust that it is even observed in nonhuman primates (Dahl, Rasch, Tomonaga, & Adachi, 2013). In contrast, there is a scanning preference to look at the left side of a person's face (where left is defined from the interlocutor's perspective) and this enhances information from the RVF, which would project more facial information to the LH (Hsiao & Cottrell, 2008; Leonards & Scott-Samuel, 2005). As an example, if an observer fixates the left eye of the image, more information of the displayed face is in the RVF and processed by the LH. The scanning preference might result from an underlying bias to orient to the left of a face (from the viewer's perspective; Gilbert & Bakan, 1973) as it may contain more salient information along some dimensions, especially emotion and lip reading

(Christman & Hackworth, 1993; but see Coronel & Federmeier, 2014, and Ocklenburg, Ness, Güntürkün, Suchan & Beste, 2013, for arguments on hemispheric asymmetries in information processing). These two pressures may both be at play in which case both hemispheres are engaged and this overrides the RH advantage for holistic processing. These effects are not relevant in the case of the top–bottom composite effect and thus the RH advantage may be easier to elicit under those conditions (Ramon & Rossion, 2012).

A further possible explanation for the absence of hemispheric effects involves differences in central versus peripheral vision and that is that faces presented closer to fovea typically give rise to weaker lateralization effects (Hsiao & Liu, 2012). In the experiments we present, each face subtended 5° of visual angle horizontally (so each face half spanned about 2.5° of visual angle) and 7° of visual angle vertically. The absence of hemispheric differences here replicates Hsiao and Liu (2012), who also reported minimal effects of hemispheric asymmetry when faces were presented in central vision. If it is indeed the case that faces presented close to central vision do not give rise to effects of hemispheric lateralization, one might wonder about the use of the centrally presented chimeric faces task as traditional behavioural estimates of lateralization. In both of our experiments, the size of our stimuli was highly comparable to that used as in a typical chimeric face task (Bourne, 2010) where each chimeric face subtended approximately 4.5° of visual angle horizontally and 7° vertically. It remains a possibility, however, that presenting the entire composite face in one or the other half field might serve as a stronger test of hemispheric modulation of HP and might reveal differences as a function of the race (and hemispheric organization) of the observer.

Finally, we note that the asymmetric holistic effects in the two fields may depend on the exact details of the task. Even when the standard top–bottom composite faces were displayed in the half-field (all in the left or all in the right field), no difference in the magnitude of holistic processing was observed when participants were to verbalize their response, and a difference only emerged when the top halves of the stimuli were to be matched (Ramon & Rossion, 2012). Whether our participants incidentally engaged in verbal recoding is unknown but this task difference suggests that hemispheric differences may be somewhat fragile and that future investigations might want to take this into consideration.

No modulation of holistic face processing by race of observer or stimulus

We laid out three hypotheses regarding the performance of Caucasian and Chinese participants in this vertical composite task. The first was related to the phenomenon of the other race effect and we manipulated this factor in our design by including face stimuli from both races. Results from our Caucasian participants suggest indistinguishable performance in perceiving Caucasian faces and Chinese faces, and the same equivalence was evident in the results from the Chinese participants. The absence of the other race effect, that is, the advantage in perceiving faces of the race with which one has the most experience (Brigham & Malpass, 1985; Chance & Goldstein, 1996), may be explained by the fact that, although the large majority of residents in Hong Kong are ethnically Chinese, the growing diversity in the population exposes participants to faces of all races (see Hayward, Crookes, & Rhodes, 2013, for a discussion). It is also the case that the Caucasian participants were students from Carnegie Mellon University, which also has a large percentage of Asian students on campus. Our samples might simply have had too much exposure to other races to yield the advantage for their own race faces. Last, we need to consider that, just like the observers have experience with different races, they also have experience with different orthographies and although the Chinese were all native and fluent speakers and readers of Chinese, they also had been exposed to English, an alphabetic script. This multiscript exposure may offset the differential hemispheric tuning in the Chinese participants, precluding our ability to see a difference amongst our groups of observers. Note that similar to Harrison, Gauthier, Hayward and Richler (2014), we also do not find an interaction of holistic processing for self race versus other race faces. Although this could also be a direct result of the exposure to many races, the absence of a Race × Holistic interaction is corroborated by Mondloch et al. (2010), who also showed that the extent of holistic processing of own versus other race faces did not differ in degree, using both composite face task and the part/whole task.

CONCLUSIONS

Contrary to our hypothesis that we might find both a hemispheric modulation of holistic processing of faces, and that this might manifest differently in Caucasian versus Chinese individuals, neither of these patterns was upheld statistically. We have offered a myriad of reasons why this might be the case and, indeed, many different and even conflicting explanations might hold. Although it remains a possibility that our paradigm itself was insufficiently sensitive, this does not seem obviously true: We were able to uncover a robust Alignment × Congruency interaction (i.e., holistic processing) and we did so under two different experimental conditions (i.e., cue-later and cue-first). We also replicated the expected pattern of reduced congruency for misaligned than aligned faces, and so confirm the standard pattern. Notwithstanding the fact that the findings challenge the predictions, there are several informative conclusions that can be reached. For the first time, we demonstrate the presence of holistic processing of left–right composite faces and we map out these results under carefully controlled stimulus and presentation conditions. It is clear, though, that further research is needed to iron out some of the disparities and we offer several cautionary notes for future investigations of holistic processing and its hemispheric underpinnings.

Supplementary material

Supplemental material for this article is available via the supplemental tab on the article's online page at (http://dx.doi.org/10.1080/13506285.2014.944613).

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