**A Composite Face Effect for Vertically Divided Faces**

Bartholomew P. A. Quinn1, A. Mike Burton1,2, and Timothy J. Andrews1

1Department of Psychology, University of York, UK

2Faculty of Society and Design, Bond University, Australia

\* Corresponding authors: bpaq500@york.ac.uk & timothy.andrews@york.ac.uk

**Author ORCID identifiers:**

Bartholomew Quinn: [https://orcid.org/0000-0001-8595-4433](https://orcid.org/????????)

Mike Burton: https://orcid.org/0000-0002-2035-2084

Tim Andrews: <https://orcid.org/0000-0001-8255-9120>

# Abstract

The composite face effect (CFE) provides evidence for holistic face processing by demonstrating that when halves of different faces are aligned to resemble a single face, recognition of the component identities is disrupted. However, if the face halves are misaligned, the component identities become easier to recognise. While the horizontal CFE – wherein the top and bottom halves of the face are aligned – has been extensively studied, the existence of a vertical CFE – involving the combination of left-right face halves – remains unclear. This study investigated the vertical CFE using composite stimuli created by pairing familiar and unfamiliar faces. Participants made familiarity judgments for aligned and misaligned vertical and horizontal composites. Familiarity judgements were made more accurately and with faster response times with misaligned compared to aligned composites. The magnitude of the vertical CFE was comparable to the horizontal CFE and was unaffected by identity priming or which half of the face was attended. However, the size of the CFE was reduced when attention was not directed to a specific face half. These findings suggest that both the vertical and horizontal CFE reflect a common mechanism for integrating facial information across the visual field, underscoring holistic processing as a fundamental process in face recognition.

# Introduction

Humans can rapidly and accurately distinguish identities based on subtle differences in facial structure (Bruce & Young, 2012). The effectiveness of human face recognition has, in part, been attributed to holistic processing, in which facial information is integrated into a simultaneously processed, unified perceptual representation, rather than being analysed as isolated features (Tanaka & Farah, 1993; Tanaka & Gordon, 2011; Rossion & Boremanse, 2008). Support for this holistic integration is evident in the part-whole task, in which participants more accurately recognise facial features when viewed in the context of the whole face compared to when viewed in isolation (Tanaka & Farah, 1993).

Holistic processing is also shown by the composite face effect (CFE), in which the top half of one face is combined with the bottom half of another. In their seminal study, Young and colleagues (1987) found that when the top and bottom halves of different familiar faces were aligned to resemble a single face, participants struggled to recognise the identity of either half. In contrast, when the halves were misaligned, participants more easily recognised the halves’ identity. These findings suggest that when the horizontally divided halves of a composite are aligned, facial features are not processed in isolation but are instead automatically integrated into a holistic representation, leading to a unified percept that can interfere with the recognition of individual components. In contrast, when the halves of a composite are misaligned, holistic integration is no longer initiated, and it, therefore, becomes easier to recognise the identity of either component half without interference from the other (Rossion, 2013; Murphy *et al.*, 2017).

The CFE has also been observed with unfamiliar faces. For example, participants have difficulty perceiving whether two identical top halves are the same, if the bottom halves are different (Hole, 1994). As with familiar faces, this task becomes easier if the composites are misaligned. Additionally, the CFE is also evident for facial judgements other than identity, such as expression (Calder *et al.,* 2000; Palermo *et al.,* 2011; Tanaka *et al.,* 2012), race (Michel *et al.*, 2007), and gender (Baudouin & Humphreys, 2006). This evidence indicates that holistic integration is a fundamental mechanism across various aspects of face perception.

The anatomical structure of the human visual system suggests that this integration of information in the CFE is more likely to occur at later rather than early stages of visual processing. In natural viewing, we typically fixate upon the horizontal mid-point of faces, just below the eyes (Peterson & Eckstein, 2012; Walker-Smith *et al.*, 2013; Hsiao & Cottrell, 2008). While individual differences in attentive fixation have been shown to exist, these are rarely distant from the horizontal centre of the face, allowing diagnostic facial features to be processed with high visual acuity on the fovea (Peterson & Eckstein, 2013). These typical patterns of fixation result in the left and right halves of the face being vertically divided across separate visual hemifields, with each projecting to early visual regions in the contralateral hemisphere (Hsiao *et al.*, 2008). This suggests that the holistic processing of faces emerges as visual information advances to higher visual regions that support a unified facial percept. Neuroimaging evidence for integration of facial information at later stages of processing is shown by greater neural responses to whole faces compared to isolated facial features, or scrambled faces in the fusiform face area (Zhang *et al.*, 2012; Tong *et al.*, 2000; Kamps *et al.*, 2019; Liu *et al.*, 2010).

Despite strong evidence for the holistic integration of the upper and lower halves of the face, surprisingly few behavioural studies have examined the holistic integration of left and right face halves (Hole, 1994; Young *et al.*, 1990; Strathie *et al.*, 2012). Of these, only two studies have directly investigated the effects of alignment on vertically divided ‘vertical’ composites (Liu & Behrmann, 2014; Liu *et al.*, 2014). These have demonstrated that congruency between relevant and irrelevant vertically divided face halves facilitates same/different judgments in a matching task. For example, a face half that remains the same through study and test phases is more accurately identified as such when the irrelevant half also remains the same, compared to when it differs. This effect is only evident when face halves are aligned. This is taken to indicate that, when perceiving a whole face, the ability to match a relevant half is affected by the irrelevant half, regardless of its congruency. This ‘complete’ CFE paradigm characterises holistic processing as a failure of selective attention to face parts (Richler *et al.*, 2008a; 2008b). In contrast, the interference effect demonstrated by Young *et al.* (1987) in their original ‘partial’ CFE study is taken to reflect perceptual integration. While the merits of these respective designs and the interpretation of their results are debated (e.g., Rossion, 2013; Richler & Gauthier, 2013; 2014), it has been suggested that theoretical conclusions regarding holistic integration must rely upon converging evidence across different paradigms (Jin *et al.*, 2024; Li *et al.*, 2017; 2019; Boutet *et al.*, 2021).

To firmly establish if left and right halves of the face are holistically integrated, a number of questions need to be addressed. First, it is important to show the CFE for vertically divided faces using the original ‘partial’ design (Young *et al.*, 1987). Second, it must be shown to be relevant to ecologically valid face recognition and not to rely on low-level visual mechanisms such as image matching or priming (Ellis *et al.*, 1987; Bruce & Valentine, 1985). Finally, if instigated by the same holistic mechanism, a vertical CFE should have a similar magnitude to the horizontal CFE. While anecdotal evidence has suggested that the CFE produced by aligned vertical composites is ‘not as strong as in the case of the horizontally split faces’ (Hole, 1994, p. 72), this has yet to be systematically examined.

The aim of this study was therefore to explore whether there is a vertical CFE indicative of perceptual integration of the left and right halves of the face. We used familiar face composites in a comparable partial paradigm to that used by Young *et al.* (1987). To address the issues of effective alignment (see Experiment 1), we created composites in which we combined a face half from a famous face with a face half from an unfamiliar foil. This allowed us to make localised manipulations to the configuration of the unfamiliar face so that it effectively aligned with the familiar face, while leaving the familiar face unchanged. The combination of familiar and unfamiliar face halves also allowed us to use a naturalistic familiar/unfamiliar judgment on each half of the composite, rather than relying on an unfamiliar image matching task. The same approach was used to measure the CFE with horizontal composites, providing a direct point of comparison for CFE magnitude. Our pre-registered hypotheses (tested across 4 experiments) were that an interference effect suggestive of holistic integration of left and right halves would be evident for judgements of familiarity in both vertical and horizontal composites.

# Experiment 1

The aim of this experiment was to establish whether there is a CFE for vertically divided faces, and if so, to compare its magnitude to the CFE for horizontally divided faces. Evidence for the CFE, including its vertical counterpart (Liu & Behrmann, 2014; Liu *et al.*, 2014), has predominantly used unfamiliar faces to create composites. While indubitably informative due to high levels of control, unfamiliar face recognition represents a task with low ecological validity – we rarely need to recognise unfamiliar individuals from a single image in real-world situations. Accordingly, recognition of unfamiliar faces relies upon qualitatively different mechanisms than their ecologically relevant familiar counterparts, which are used regularly, and encoded based upon their multidimensional variability experienced in natural viewing (Johnston & Edmonds, 2009; Young & Burton, 2017). While studies such as that of Young *et al.* (1987) have shown that the horizontal CFE is sufficiently robust to affect naturalistic familiar face recognition, this has yet to be demonstrated for vertically divided composites.

The lack of evidence for a vertical CFE derived from familiar face recognition may result from the difficulty of effectively aligning left and right face halves. Although the construction of horizontal composites relies on the alignment of a few consistently positioned facial features (nose and cheekbones), vertical composites require the alignment of many features (chin, mouth, nose, eyes, brows, hairline). Effective manipulation of these into a plausible composite is extremely difficult using only linear manipulations of the image (see Young *et al.*, 1990; Fig. 2), given that a misalignment by only 8% of image width is sufficient to break the CFE (Laguesse & Rossion, 2013). Furthermore, the effective production of a CFE also relies on the biological plausibility of the image (Taubert & Alais, 2009). Evidence suggests that facial processing is disproportionately attuned to the horizontal orientation structure within faces, particularly naturalistic predictable sequences of luminance contrast (Dakin & Watt, 2009; Goffaux & Dakin, 2010). The plausibility of a vertical composite may therefore be more disrupted by inconsistencies in the predicted sequence of horizontal information across the left and right halves, than upper and lower halves to which processing is less sensitive. As such, it is not clear whether there has yet been an adequate test of the vertical CFE for ecologically valid face recognition.

To address these concerns and create a task suitable to ascertain if vertically divided composites would demonstrate the interference effect first demonstrated by Young *et al.* (1987), we developed a novel form of composite face comprised one half from a ‘familiar’ famous face and the other half from an unfamiliar face whose features had been manipulated to align with the familiar half. This had the advantage of allowing single presentations of faces for a more ecologically valid familiar face judgment, while at the same time letting us manipulate and align composites without removing pre-existing identity information.

The task for this experiment was to indicate which face half appeared familiar, and, in doing so, determining whether the familiar/unfamiliar composite images would demonstrate the well-established horizontal CFE. Additionally, whether a similar CFE would be evident for vertical composites. Given the assumption that the holistic integration of features is a fundamental element of facial processing (Murphy *et al.*, 2017), and should cause an interference effect of the irrelevant face half, we predicted that both vertical and horizontal composites should have lower identification accuracy rates and increased reaction times when aligned compared to when they were misaligned. If the integrative process was comparable across horizontal and vertical composite divisions, we should expect no significant difference in the magnitude of the CFE.

## Materials and Methods

### Participants

Prior to data collection, sample size was calculated using G\*Power (Faul *et al.*, 2007). Based on indications of a small effect size for a similar button-press task for familiar face composites (Garcia-Marques *et al.*, 2015; Isolate condition) and unfamiliar composites (Harrison & Strother, 2020, Exp. 1a) in a comparable participant demographic, power analysis (Cohen’s *d* = 0.40, power = .95, α=.05) revealed a minimum sample size of 57 participants. To maintain even counterbalancing groups, we aimed to recruit 64 participants. Although 67 participants took part in the experiment, 3 were excluded due to insufficient familiarity with the celebrity faces used (<50%). The remaining 64 participants (58 female; mean age = 19.0, *SD* = 0.8, range = 18 - 22; all right-handed by self-report) were divided into eight counterbalanced groups (counterbalanced by: block ordering (vertically divided first, horizontally divided first); input hand use (left, right); and familiarity keypresses (G familiar & H unfamiliar, H familiar & G familiar)). All participants in this and the following experiments were predominantly white, middle-class university students, and reported normal or corrected-to-normal vision and no known neurological disorders. They provided written informed consent and were compensated with course credit. All experiments were approved by the ethics committee of the University of York Psychology department.

### Stimuli

Composite faces were generated by combining images of familiar and unfamiliar faces from different individuals. Front-facing, high-resolution images of famous people (i.e., actors, politicians, musicians; detailed in Suppl. Table 1) were collected using Google Image search (familiar faces). Faces were selected without consideration towards even counterbalancing of race or gender, but were predominantly chosen based on an assumed high level of familiarity to the participant demographic (see Suppl. Table 2 for overall participant recognition accuracy statistics for each experiment). Front-facing, high-resolution face images of non-famous individuals (unfamiliar faces) were collected from different face database repositories (SiblingsDB, Vieira *et al.*, 2014; Chicago Face Database, Ma *et al.*, 2020; The London Set, Debruine & Jones, 2017) and stock photo repositories (www.flickr.com, www.unsplash.com, and www.gettyimages.co.uk). Unfamiliar face images were individually selected based on comparability to one of the familiar face identities (similar hair colour/style, skin tone, & face shape). All Faces were standardised by cropping them from backgrounds, converting them to greyscale, pasting them onto a uniform grey background, and scaling them to a height of 480px. One standardised face was created for each identity, totalling 55 standardised familiar faces, and 55 standardised comparable unfamiliar faces. All experiments used these same faces to create composites. In each instance, the same 50 familiar and 50 unfamiliar faces were used in the main blocks, while five familiar and five unfamiliar images were kept separate for use in practice blocks only.

Vertical composites were created by splitting a familiar face and its matched unfamiliar face into left and right halves at the mid-point of the nose. Unfamiliar and familiar halves were combined into an aligned composite. The unfamiliar half was edited to align salient facial features with the familiar face along the midline (e.g. eyes, nose, lips, hairline, chin), and adjust contrast and luminance values to match the familiar half as closely as possible. The familiar half was not manipulated. Misaligned horizontal composites were created by moving the left half of an aligned composite downward by 30px, and the right half upward by 30px (Laguesse & Rossion, 2013; Taubert & Alais, 2009). Horizontal composites were created in the same manner, but using upper and lower halves of faces, split at the mid-point of the nose. Misaligned horizontal composites adjusted the upper half of an aligned composite rightward by 30px, and the lower half leftward by 30px. Images were standardised and edited using Adobe Photoshop CS6 (Version 13.0.1; www.adobe.com). Examples of all stimulus conditions for a single identity are provided in Figure 3.1.



Figure 1. Example stimuli used in experiments 1-4. (a) a familiar (left; former U.K. Prime Minister Boris Johnson) and unfamiliar face (right) used to construct a composite. (b) Aligned composites using these faces were divided vertically or horizontally. (c) Misaligned composites using these faces were also divided vertically and horizontally. Directions listed on the x-axis indicate the familiar half of each composite. Across four experiments, participants had to indicate whether a portion of the face was familiar or unfamiliar. Images of Boris Johnson is reproduced here under creative commons licence, Source: https://commons.wikimedia.org/w/index.php?curid=73747417, Attribution: Foreign and Commonwealth Office, CC BY 2.0. Unfamiliar face is reproduced here under creative commons licence, Source: https://www.flickr.com/photos/139820784@N07/26237907116, Attribution: M. SegnestamDSC\_0068, Public Domain Mark.

### Procedure

The experiment was presented online via Pavlovia (www.pavlovia.org). Participants were requested to sit in an evenly lit room at an approximate distance of 80cm from their screen. While participant screen size and resolution could not be precisely controlled, to ensure stimulus viewing angle was generally consistent across participant screens (height = 9.72°), the experiment began with a screen scaling task adapted from the Pavlovia database (https://gitlab.pavlovia.org/Wake/screenscale), and stimulus scaling was adjusted automatically. The experiment was built using PsychoPy (Version 2021.2.3; www.psychopy.org), and consisted of three blocks. This and subsequent experiments each featured a within-subjects design, with participants completing all blocks.

In the first block, we determined whether participants were familiar with the identities of the famous faces used to generate the composites by presenting them with the same face images used in the construction of the composites. This is consistent with previous experiments using familiar face composites, which have measured familiarity with the identities used prior to presenting the composite faces (e.g., Young *et al.*, 1987). Participants indicated whether they recognised a face by inputting a name, or relevant identity-specific information into a textbox (e.g., a specific role they had played in a film). If participants did not recognise the individual, they could respond with a button press and move to the next trial. Composites constructed from any faces which were not recognised in the first block were excluded from the analysis of the following two blocks. Any participants who were unable to identify over 50% of the familiar identities used were completely removed from the analysed sample. Range and median number of exclusions per participant for each experiment are reported in Suppl. Table 2.

In the second and third block, participants viewed either vertical or horizontal composites, the order of which was counterbalanced across participants. Each of these two blocks began with practice trials, in which five composite faces in the aligned and misaligned conditions were presented. The identities of these faces were not used elsewhere in the experiment and were provided to familiarise participants with the task. In each block, after the practice trials, participants viewed 100 composite trials, composed of 50 familiar and 50 unfamiliar faces. Each of the 50 familiar and 50 unfamiliar faces appeared in two composites within each block, once with the familiar face as the left/upper half, and once with the familiar face as the right/lower half. Within each block, one of these composites was presented aligned, and one misaligned, with these alignment and familiar half combinations counterbalanced evenly across participants. The order in which the composite faces were presented was randomised across participants.

Trials began with a white fixation cross in the centre of the screen, which participants were instructed to fixate on for the duration of each trial, 500ms later, they were presented with a composite face centred on the location of the fixation cross. Based on indications of more reliable and substantial CFEs for judgements focused on the upper half of the face (Wang *et al.*, 2023; 2019; Young *et al.*, 1987), and an advantage for holistic processing in the left visual field (Bradshaw & Nettleton, 1981; Bombari, Preuss, & Mast, 2014), in this initial experiment, participants were asked to judge the familiarity of the upper half of the face in the horizontal composite condition, or the left half of the face in the vertical composite condition.

Participants were instructed to respond using the ‘G’ and ‘H’ keys on a keypad to provide familiar and unfamiliar responses as rapidly and accurately as possible. Response hand (left or right hand) and response input key (the ‘G’ key representing familiar, and the ‘H’ key representing unfamiliar, or the reverse) were counterbalanced. Composites remained on the screen until a response was made. Accuracy and reaction time for correct responses were recorded. Only results from faces that had been correctly recognised by each participant in the recognition block of the experiment were used in the subsequent analysis.

The study design, hypotheses, and analysis plan for the experiment were preregistered (https://osf.io/tpgbj). All data for this and subsequent experiments is publicly available on the Open Science Framework (https://osf.io/3y2kp). Our pre-registered hypotheses test the following predictions: H1) For horizontal composites, i) lower accuracy of familiarity judgments in the aligned compared to misaligned condition; ii) slower reaction times for correct familiarity judgements in the aligned compared to the misaligned condition; H2) For vertical composites, i) lower accuracy of familiarity judgments in the aligned compared to misaligned condition; ii) slower reaction times for correct familiarity judgements in the aligned compared to the misaligned condition. In all experiments within-subjects comparisons were used to compare the effects of alignment. The results of paired sample *t*-tests used to examine these hypotheses directly were corrected using the Holm-Bonferroni method for multiple comparisons (for the 4 tests within each experiment: Vertical accuracy, Vertical RT, Horizontal accuracy, & Horizontal RT). To compare the magnitude of the CFE between vertically and horizontally divided composites, we integrated our dependent variables into balanced integration scores (BIS; Liesefeld *et al.*, 2015, Liesefeld & Janczyk, 2019), comparing these within-subjects using paired sample *t*-tests, incorporating Bayesian statistics. Familiar and unfamiliar faces are not made publicly available for copyright reasons, but licensed examples are provided in this paper.

## Results

To identify a CFE for vertical composites and compare it with that of horizontal composites, a repeated-measures ANOVA was used to assess the effect of Composite (vertical, horizontal), and Alignment (aligned, misaligned) on accuracy and reaction time. The results of this analysis are shown in Figure 3.2.



Figure 2. Experiment 1 - (a) Lower accuracy and (b) slower reaction times were evident for aligned compared to misaligned composites. This effect was evident for both vertical and horizontal composites. Error bars represent Cousineau’s Y within-subject error values.

For accuracy (Figure 3.2a), there was a significant effect of alignment [*F*(1, 63) = 50.43, *p* < .001, *ηp2* = 0.44], and composite [*F*(1, 63) = 5.18, *p* = .026, *ηp2* = 0.08], but no interaction between alignment and composite [*F*(1, 63) = 2.71, *p* = .105]. To assess our pre-registered hypotheses, planned comparisons (paired sample *t*-tests) were conducted on the effect of alignment for each composite condition (Table 3.1). For vertical composites (Aligned *M* = 93.5%, *SD* = 4.8; Misaligned *M* = 95.5%, *SD* = 4.8) and horizontal composites (Aligned *M* = 90.8%, *SD* = 7.0; Misaligned *M* = 94.3%, *SD* = 5.6), aligned images were less accurately recognised than misaligned images.

For reaction time (Figure 3.2b), the ANOVA showed only a significant effect for alignment [*F*(1, 63) = 15.26, *p* <.001, *ηp2*  = 0.20]. However, there was no effect of composite [*F*(1, 63) = 0.05, *p* = .820], nor any interaction between alignment and composite [*F*(1, 63) = 0.24, *p* = .623]. To assess our pre-registered hypotheses, planned comparisons (paired sample *t*-tests) were conducted on the effect of alignment for each composite condition (Table 3.1). For vertical composites (Aligned *M* = 0.85s, *SD* = 0.16; Misaligned *M* = 0.82s, *SD* = 0.15) and horizontal composites (Aligned *M* = 0.85s, *SD* = 0.21; Misaligned *M* = 0.83s, *SD* = 0.18), there was a slower reaction time for aligned images compared to misaligned images.

Table 1. *Statistical differences in accuracy and reaction time for aligned > misaligned conditions of the vertical and horizontal composite faces in Experiment 1.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | df | t | p | davg | BF10 |
| Accuracy  |  |  |  |  |  |
|  | Vertical composite | 63 | 3.37 | .001 | 0.43 | 41.21 |
|  | Horizontal composite | 63 | 6.11 | <.001 | 0.56 | >100 |
| Reaction Time  |  |  |  |  |  |
|  | Vertical composite | 63 | 3.90 | <.001 | 0.16 | >100 |
|  | Horizontal composite | 63 | 2.11 | .019 | 0.10 | 2.18 |

To provide an integrated measure that combines accuracy and reaction time, we also calculated BIS. Accuracy and reaction time measures were converted to standardised z-scores, before subtracting standardised accuracy from standardised reaction time to generate the BIS. Paired sample *t*-tests were also calculated for alignment effects on BIS, these showed the same pattern as shown for the non-integrated measures (*p* < .001), and descriptive statistics and results for these comparisons are reported in Suppl. Tables 3 & 4. CFE size was calculated using aligned – misaligned BIS for horizontal and vertically divided composites independently, and these were compared using standard and Bayesian statistics. The CFE for horizontal (*M* = 0.72, *SD* = 0.94) and vertical (*M* = 0.50, *SD* = 0.86) composites were not significantly different [*t*(63) = 1.33, *p* = .188]. There was moderate evidence in favour of a lack of difference between vertical and horizontal composites (BF01 = 3.17). Comparison of CFE size was also calculated for accuracy and reaction time measures independently, which also showed no significant difference between composite division directions (*p* > .105). Descriptive statistics and results from these comparisons are reported in Suppl. Tables 5 & 6.

# Experiment 2

The results of Experiment 1 showed a comparably sized CFE for vertical and horizontal composites. This suggests that the left and right face halves also appear to be holistically bound together during face perception and require cognitive effort to disentangle their component identities. An important feature of the design for Experiment 1 was that participants viewed the famous faces used to make the composites in a familiarity block before the composites were presented. This was consistent with the approach used in previous studies examining the CFE using familiar faces (e.g., Young *et al.*, 1987; Chen *et al.*, 2018; Fitousi, 2020; Robbins & McKone, 2003). Image and identity priming of faces is known to facilitate subsequent familiarity decision tasks (Ellis *et al.*, 1987; Bruce & Valentine, 1985). Our paradigm which avoids the sequential presentation of matching images, necessary in an unfamiliar composite paradigm, removes any immediate repetition priming effects from familiarity judgements. However, our composites included previously seen (familiar) and previously unseen (unfamiliar) components. Given that priming effects on face recognition are known to persist over periods of time longer than our experiment (e.g. Roberts & Bruce, 1989), it is unclear if prior exposure or priming is relevant to CFE production. To determine whether prior exposure to these images was important, we repeated the experiment without exposing participants to the full familiar faces before composite testing. Based on the results of Experiment 1, we predicted lower identification accuracy and increased reaction times for aligned, compared to misaligned vertical and horizontal composites. If face priming is important for the CFE, we would also expect smaller CFE sizes when compared with Experiment 1.

## Materials and Methods

### Participants

69 participants were recruited for this experiment, although 5 were excluded due to insufficient familiarity with the celebrity faces used (<50%), or failure to meet the laterality quotient to indicate dominant right-handedness (<+40). The remaining 64 right-handed (mean laterality quotient = 89.5, *SD* = 16.1) participants (59 female, mean age = 19.7, *SD* = 3.6, range = 18 - 31) were randomly divided into the eight counterbalancing groups described in Experiment 1. Participants who had completed any experiment in the series were excluded from participation in any other experiment to avoid previous exposure to the stimuli.

### Stimuli

The same stimuli used in Experiment 1 were reused in Experiment 2.

### Procedure

Experiment 2 was conducted in-person. Participants were seated in an evenly lit laboratory 80cm from a computer screen with the dimensions 544mm x 306mm (1920px x 1080px). Images of aligned faces subtended a height of 9.72° of visual angle. Stimuli were presented using PsychoPy (Version 2021.2.3; www.psychopy.org). Participants were asked to judge the familiarity of the left half of the face in the vertical composite condition, or the upper half of the face in the horizontal composite condition. The experiment used the same trial-within-block structure and counterbalancing as described in Experiment 1. However, to mitigate any potential effects of face priming on CFE production, in Experiment 2, the recognition block, in which participants had to indicate whether they were familiar with the faces used to construct the composites, was always presented after the vertical and horizontal composite blocks had been completed. Despite the differences in block ordering, as in Experiment 1, only results from faces reported to have been correctly recognised by each participant in the recognition block of the experiment were retained in the subsequent analysis.

The study design, hypotheses, and analysis plan for the experiment were preregistered (https://osf.io/54vcf). Our pre-registered hypotheses test the following predictions: H1) For horizontal composites, i) lower accuracy of familiarity judgments in the aligned compared to misaligned condition; ii) slower reaction times for correct familiarity judgements in the aligned compared to the misaligned condition; H2) For vertical composites, i) lower accuracy of familiarity judgments in the aligned compared to misaligned condition; ii) slower reaction times for correct familiarity judgements in the aligned compared to the misaligned condition. In addition to the within-subjects comparisons described in Experiment 1, to examine the effects of priming we also compared BIS between-subjects of Experiments 1 and 2 using independent *t*-tests, incorporating Bayesian statistics.

### Results

To assess the effects of absent familiar face priming in the production of the CFE, a repeated-measures ANOVA was used to assess the effect of Composite (vertical, horizontal), and Alignment (aligned, misaligned) on accuracy and reaction time. The results of this analysis are shown in Figure 3.3.



Figure 3. Experiment 2 - (a) Lower accuracy and (b) slower reaction times were evident for aligned compared to misaligned composites. This effect was evident for both vertical and horizontal composites. Error bars represent Cousineau’s Y within-subject error values.

For accuracy (Figure 3.3a), there was a significant effect of Alignment [*F*(1, 63) = 36.28, *p* < .001, *ηp2* = 0.36], and Composite [*F*(1, 63) = 4.26, *p* = .043, *ηp2* = 0.06], but no interaction between Alignment and Composite [*F*(1, 63) = 3.79, *p* = .056]. To assess our pre-registered hypotheses, planned comparisons (paired sample *t*-tests) were conducted on the effect of alignment for each composite condition (Table 3.2). For vertical composites (Aligned *M* = 89.3%, *SD* = 7.5; Misaligned *M* = 91.5%, *SD* = 6.3) and horizontal composites (Aligned *M* = 86.4%, *SD* = 7.8; Misaligned *M* = 91.3%, *SD* = 5.9), aligned images were less accurately recognised than misaligned images.

For reaction time (Figure 3.3b), the ANOVA only showed a significant effect for alignment [*F*(1, 63) = 16.44, *p* < .001, *ηp2* = 0.21]. There was no effect of composite [*F*(1, 63) = 0.11, *p* = .741], nor any interaction between alignment and composite [*F*(1, 63) = 0.34, *p* = .565]. To assess our pre-registered hypotheses, planned comparisons (paired sample *t*-tests) were conducted on the effect of alignment for each composite condition (Table 3.2). For vertical composites (Aligned *M* = 0.97s, *SD* = 0.27; Misaligned *M* = 0.93s, *SD* = 0.23) and horizontal composites (Aligned *M* = 0.95s, *SD* = 0.27; Misaligned *M* = 0.92s, *SD* = 0.26), there was a slower reaction time for aligned images compared to misaligned images.

Table 2. *Statistical differences in accuracy and reaction time for aligned > misaligned conditions of the vertical and horizontal composite faces in Experiment 2.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | df | t | p | davg | BF10 |
| Accuracy  |  |  |  |  |  |
|  | Vertical composite | 63 | 2.63 | .011 | 0.33 | 6.37 |
|  | Horizontal composite | 63 | 5.29 | <.001 | 0.70 | >100 |
| Reaction Time  |  |  |  |  |  |
|  | Vertical composite | 63 | 3.59 | <.001 | 0.15 | 77.97 |
|  | Horizontal composite | 63 | 2.37 | .011 | 0.10 | 3.64 |

As described in Experiment 1, accuracy and reaction time measures were also integrated into BIS. These showed the same effects of alignment as reported for non-integrated measures (*p* <.001). Descriptive statistics and results for this comparison are reported in Suppl. Tables 3 & 4. BIS were again used to provide a comparison of CFE size between vertical and horizontal composites with standard and Bayesian statistics. This comparison showed that the size of the CFE for BIS was not significantly different between vertical (*M* = 0.47, *SD* = 0.99) and horizontal (*M* = 0.78, *SD* = 1.15) composites [*t*(63) = 1.56, *p* = .124]. There was moderate evidence in favour of a lack of difference between vertical and horizontal composites (BF01 = 4.31). Comparison of CFE size was also calculated for accuracy and reaction time measures independently, showing no significant differences between composite division directions (*p* > .056). Descriptive statistics and results from these comparisons are reported in Suppl. Tables 5 & 6.

While both Experiments 1 and 2 produced evidence of a CFE, to examine if face priming had any effect on its magnitude, we compared BIS CFE sizes between experiments using standard and Bayesian statistics. We additionally compared the integrated accuracy and reaction time BIS score CFE sizes between Experiments 1 and 2, examining differences between these alongside Bayesian statistics. For vertical composites (Expt 1 *M* = 0.50, *SD* = 0.86; Expt 2 *M* = 0.47, *SD* = 0.99), there were no significant differences in BIS CFE size between experiments [*t*(126) = 0.17, *p* = .863], with weak evidence in favour of a lack of CFE size difference between experiments (BF01 = 1.91). Horizontal composites (Expt 1 *M* = 0.72, *SD* = 0.94; Expt 2 *M* = 0.78, *SD* = 1.15), also showed a lack of significant difference between experiments [*t*(126) = -0.36, *p* = .721], again, with weak evidence in favour of a lack of CFE size difference between experiments (BF01 = 2.00). We also performed this comparison with accuracy and reaction time measures independently, which showed no significant differences between experiments (*p* > .213). The descriptive statistics and results of these comparisons are reported in Suppl Tables 7 & 8.

# Experiment 3

Experiments 1 & 2 showed evidence of a reliable CFE for vertical composites, which was similar in size to the CFE of horizontal composites. Comparable CFE sizes across both experiments suggested that the size of this effect was not dependent on prior exposure (priming) of the familiar faces. Given that prior exposure was not necessary to elicit a CFE, subsequent experiments used the same structure used in Experiment 2, in which the face recognition block occurred at the end of the task.

In Experiments 1 & 2 judgements of familiarity were focused on face halves that we assumed would elicit the most reliable CFEs. For horizontal composites, judgements of the upper half of the face produce more substantial and reliable CFEs than of the lower half of the face (Wang *et al.*, 2023; 2019). For vertical composites, the left half of the face typically projects to the right hemisphere, which has been suggested to be dominant for facial processing (Rossion, 2014; Prete & Tommasi, 2018). Indeed, it has been suggested that the right hemisphere advantage may be due to greater specialisation for holistic processing (Bradshaw & Nettleton, 1981; Bombari *et al.,* 2014). Evidence for this is shown by greater neural responses in face-selective areas in the right hemisphere when presented with whole, faces compared to parts of faces (Rossion *et al.,* 2000), and the selective responses of right (but not left) hemisphere areas to aligned, but not misaligned composite faces (Schiltz *et al.*, 2010; Schiltz & Rossion, 2006).

In Experiment 3, we focused judgements on either the lower half of the face (horizontal composites) or the right half of the face (vertical composites). Again, we predicted that both vertical and horizontal composites should lower identification accuracy and increase reaction times for aligned, compared to misaligned composites. However, it remains unclear if a right hemisphere bias in face processing would produce a less substantial CFE for judgements of right face halves projecting to the left hemisphere. We also predicted smaller CFE sizes for horizontal composites in Experiment 3 than Experiment 2.

## Materials and Methods

### Participants

69 participants were recruited for this experiment, although 5 were excluded due to insufficient familiarity with the celebrity faces used (<50%), or failure to meet the laterality quotient to indicate dominant right-handedness (<+40). The remaining 64 right-handed (mean laterality quotient = 89.5, *SD* = 16.1) participants (59 female, mean age = 19.7, *SD* = 3.6, range = 18 - 37) were randomly divided into the eight counterbalancing groups described in Experiment 1. Participants who had completed any experiment in the series were excluded from participation in any other experiment to avoid previous exposure to the stimuli.

### Stimuli

The same stimuli used in the previous experiments were reused in Experiment 3.

### Procedure

We used the same in-person procedure and block ordering that was used in Experiment 2. However, in this experiment, participants were asked to judge the familiarity of the right half of the face in the vertical composite condition, and the lower half of the face in the horizontal composite condition. Despite the change in the relevant half, participants were still requested to retain fixation on the central fixation cross during each trial.

The study design, hypotheses, and analysis plan for the experiment were preregistered (https://osf.io/akmpv). Our pre-registered hypotheses test the following predictions: H1) For horizontal composites, i) lower accuracy of familiarity judgments in the aligned compared to misaligned condition; ii) slower reaction times for correct familiarity judgements in the aligned compared to the misaligned condition; H2) For vertical composites, i) lower accuracy of familiarity judgments in the aligned compared to misaligned condition; ii) slower reaction times for correct familiarity judgements in the aligned compared to the misaligned condition. H3) For horizontal composites, CFEs for i) accuracy, and ii) reaction time would be smaller than those elicited in Experiment 2. In addition to the within-subjects comparisons described in Experiment 1, to examine the effects of half attendance, we also compared BIS between-subjects of Experiments 2 and 3 using independent *t*-tests, incorporating Bayesian statistics.

## Results

To assess the reliability and versatility of the CFE, participants made familiarity judgements on the right half of the vertical composites and the lower half of the horizontal composites. A repeated-measures ANOVA was used to assess the effect of Composite (vertical, horizontal), and Alignment (aligned, misaligned) on accuracy and reaction time. The results of this analysis are shown in Figure 3.4.



Figure 4. Experiment 3 - (a) Lower accuracy and (b) slower reaction times were evident for aligned compared to misaligned composites. This effect was evident for both vertical and horizontal composites. Error bars represent Cousineau’s Y within-subject error values.

For accuracy (Figure 3.4a), there was a significant effect of alignment [*F*(1, 63) = 32.79, *p* <.001, *ηp2* = 0.34], and composite [*F*(1, 63) = 5.14, *p* = .027, *ηp2* = 0.08], but no interaction between alignment and composite [*F*(1, 63) = 1.84, *p* = .179]. To assess our pre-registered hypotheses, planned comparisons (paired sample *t*-tests) were conducted on the effect of alignment for each composite condition (Table 3.3). For vertical composites (Aligned *M* = 78.0%, *SD* = 23.8; Misaligned *M* = 81.5%, *SD* = 25.3) and horizontal composites (Aligned *M* = 69.4%, *SD* = 14.8; Misaligned *M* = 74.7%, *SD* = 13.3), aligned images were less accurately recognised than misaligned images.

For reaction time (Figure 3.4b), the ANOVA showed significant effects for both alignment [*F*(1, 63) = 14.81, *p* <.001, *ηp2* = 0.19], and composite [*F*(1, 63) = 47.63, *p* <.001, *ηp2* = 0.43], but no interaction between alignment and composite [*F*(1, 63) = 0.12, *p* = .733]. To assess our pre-registered hypotheses, planned comparisons (paired sample *t*-tests) were conducted on the effect of alignment for each composite condition (Table 3.3). For vertical composites (Aligned *M* = 0.98s, *SD* = 0.32; Misaligned *M* = 0.92s, *SD* = 0.34) and horizontal composites (Aligned *M* = 1.18s, *SD* = 0.32; Misaligned *M* = 1.13s, *SD* = 0.27), there was a slower reaction time for aligned images compared to misaligned images.

Table 3. *Statistical differences in accuracy and reaction time for aligned > misaligned conditions of the vertical and horizontal composite faces in Experiment 3.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | df | t | p | davg | BF10 |
| Accuracy  |  |  |  |  |  |
|  | Vertical composite | 63 | 4.03 | <.001 | 0.14 | >100 |
|  | Horizontal composite | 63 | 4.53 | <.001 | 0.38 | >100 |
| Reaction Time  |  |  |  |  |  |
|  | Vertical composite | 63 | 3.30 | .002 | 0.18 | 34.72 |
|  | Horizontal composite | 63 | 2.75 | .004 | 0.17 | 8.51 |

As described in Experiment 1, accuracy and reaction time measures were integrated into BIS. These showed the same effects of alignment as reported for non-integrated measures (*p* < .001). Descriptive statistics and results for this comparison are reported in Suppl. Tables 3 & 4. BIS were again used to provide a comparison of CFE size between vertical and horizontal composites with standard and Bayesian statistics. This comparison showed that the size of the CFE for BIS was not significantly different between vertical (*M* = 0.35, *SD* = 0.51) and horizontal (*M* = 0.42, *SD* = 0.65) composites [*t*(63) = 0.72, *p* = .474]. There was weak evidence in favour of a lack of difference between vertical and horizontal composites (BF01 = 1.76). Comparison of CFE size was also calculated for accuracy and reaction time measures independently, showing no significant differences between composite division directions (*p* > .179) Descriptive statistics and results from these comparisons are reported in Suppl. Tables 5 & 6.

To determine if there was an effect of attending to specific halves of the face, we compared BIS CFE sizes between Experiments 2 and 3 using standard and Bayesian statistics. For vertical composites (Expt 2 *M* = *M* = 0.47, *SD* = 0.99; Expt 3 *M* = 0.35, *SD* = 0.51), there were no significant differences in BIS CFE size between experiments [*t*(126) = 0.86, *p* = .394], with weak evidence in favour of a lack of CFE size difference between experiments (BF01 = 2.63). However, Horizontal composites (Expt 2 *M* = 0.78, *SD* = 1.15; Expt 3 *M* = 0.42, *SD* = 0.65) showed a greater BIS CFE size when judgments were focused on upper halves than lower halves [*t*(126) = 2.21, *p* = .029, *d* = 0.39], with weak evidence in favour of a difference in CFE size between experiments (BF10 = 1.68).

# Experiment 4

In all the previous experiments, a vertical CFE was evident when participants were instructed to attend to either the left or the right half of the composite. An indication of automatic processing is that it requires only limited attentional resources (Schneider & Shiffrin, 1977; Shiffrin 1988). In Experiment 4, we asked whether attention to a face half was necessary for the production of the vertical CFE or whether the CFE occurs automatically in the absence of attention.

Automaticity in face processing can be determined by the extent to which the attentional demands of a relevant task influence the processing of a facial image (Palermo & Rhodes, 2007; Yan, Young, & Andrews, 2017). Evidence of automaticity can be found in studies showing that an irrelevant face can influence the ability to categorise a name, based on whether it is congruent or incongruent with the correct response (Jenkins, Lavie, & Driver, 2003; Lavie, Ro, & Russell, 2003). However, other studies have shown that the ability to discriminate faces can be affected by attention (Palermo & Rhodes, 2002; Reinitz, Morrissey, & Demb, 1994), indicating that this process may not be fully automatic.

Holistic integration is commonly assumed to be automatic (Murphy *et al.*, 2017). Our final experiment tested the automaticity of the CFE as a marker of holistic integration in vertical and horizontal composites. In contrast to the previous experiments in this study, participants were not instructed to attend to a particular face half. Rather, participants had to indicate which half of the face was familiar. Here, our aim was to determine if the CFE was evident in the absence of attention directed to one half of the face. If holistic integration is automatic, we predicted that a CFE would still be evident.

## Materials and Methods

### Participants

66 participants were recruited for this experiment, although 2 were excluded due to insufficient familiarity with the celebrity faces used (<50%). The remaining 64 right-handed (mean laterality quotient = 74.9, *SD* = 16.1) participants (49 female, mean age = 19.8, *SD* = 1.4, range = 18 - 22) were randomly divided into eight counterbalancing groups (counterbalanced by: block ordering (vertically divided first, horizontally divided first); input hand use (left, right); and composite half alignment condition (set 1 – e.g., Boris Johnson: right half aligned, left half misaligned; set 2 – e.g., Boris Johnson: right half misaligned, left half aligned)).

### Stimuli

The same stimuli used in the previous experiments were re-used in Experiment 4.

### Procedure

We used the same in-person procedure and block ordering that was described in Experiments 2 & 3. However, the task for participants in this block was to indicate which half of the face was familiar using a button press. For vertical composites, the ‘left arrow’ key indicated that the left half was familiar, and the ‘right arrow’ key indicated that the right half was familiar. For horizontal composites, the ‘up arrow’ key indicated that the upper half was familiar, and the ‘down arrow’ key indicated that the lower half was familiar. As in previous experiments, participants were requested to retain fixation on a cross throughout the experiment, corresponding with the optimal fixation point of the composite stimuli (Peterson & Eckstein, 2012; Walker-Smith *et al.,* 2013; Hsiao & Cottrell, 2008). While block ordering, and response hand were counterbalanced as in previous experiments, response input keys remained consistent across all participants to avoid errors caused by counterintuitive inputs. An additional composite stimulus alignment condition was added to avoid repeated presentations of half images. As in previous experiments, only results from faces reported to have been correctly recognised by each participant in the recognition block of the experiment were used in the subsequent analysis.

The study design, hypotheses, and analysis plan for the experiment were preregistered (https://osf.io/j4mvk). Our pre-registered hypotheses test the following predictions: H1) For horizontal composites, i) lower accuracy of familiarity judgments in the aligned compared to misaligned condition; ii) slower reaction times for correct familiarity judgements in the aligned compared to the misaligned condition; H2) For vertical composites, i) lower accuracy of familiarity judgments in the aligned compared to misaligned condition; ii) slower reaction times for correct familiarity judgements in the aligned compared to the misaligned condition. In addition to the within-subjects comparisons described in Experiment 1, to examine the effects of half familiarity we also performed within-subjects comparisons of BIS between left and right halves, and upper and lower halves using paired-sample *t*-tests, incorporating Bayesian statistics.

## Results

The aim of this experiment was to determine if the vertical CFE could withstand the effects of undirected attention. A repeated-measures ANOVA was used to assess the effect of Composite (vertical, horizontal), and Alignment (aligned, misaligned) on accuracy and reaction time. The results of this analysis are shown in Figure 3.5.



Figure 5. Experiment 4 - (a) Lower accuracy and (b) slower reaction times were evident for aligned compared to misaligned composites. This effect was evident for both vertical and horizontal composites. Error bars represent Cousineau’s Y within-subject error values.

For accuracy (Figure 3.5a), there was a significant effect of composite [*F*(1, 63) = 73.86, *p* <.001, *ηp2* = 0.54]. There was no effect of alignment [*F*(1, 63) = 3.31, *p* = .074], nor an interaction between alignment and composite [*F*(1, 63) = 2.94, *p* = .092]. To assess our pre-registered hypotheses, planned comparisons (paired sample *t*-tests) were conducted on the effect of alignment for each composite condition (Table 3.4). For vertical composites (Aligned *M* = 94.8%, *SD* = 4.5; Misaligned *M* = 94.9%, *SD* = 4.2), and horizontal composites (Aligned *M* = 89.6%, *SD* = 6.2; Misaligned *M* = 87.9%, *SD* = 6.5), there was no significant difference in recognition accuracy between aligned images and misaligned images.

For reaction time (Figure 3.5b), the ANOVA showed a main effect of alignment [*F*(1, 63) = 49.39, *p* <.001, *ηp2* = 0.44], but not composite [*F*(1, 63) = 1.46, *p* = .231], with a significant interaction between alignment and composite [*F*(1, 63) = 35.16, *p* <.001, *ηp2* = 0.36]. To assess our pre-registered hypotheses, planned comparisons (paired sample *t*-tests) were conducted on the effect of alignment for each composite condition (Table 3.4). For vertical composites, there were faster reaction times for aligned images (*M* = 0.92s, *SD* = 0.21) compared to misaligned images (*M* = 0.87s, *SD* = 0.17). However, for horizontal composites, there was no significant difference between aligned images (*M* = 1.11s, *SD* = 0.35) and misaligned images (*M* = 1.16s, *SD* = 0.33).

Table 4. *Statistical differences in accuracy and reaction time for aligned and misaligned conditions of the vertical and horizontal composite faces in Experiment 4.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Df | t | p | davg | BF10 |
| Accuracy  |  |  |  |  |  |
|  | Vertical composite | 63 | 0.09 | .464 | 0.01 | 0.28 |
|  | Horizontal composite | 63 | -2.11 | >.999 | 0.28 | 0.46 |
| Reaction Time  |  |  |  |  |  |
|  | Vertical composite | 63 | 3.94 | <.001 | 0.25 | >100 |
|  | Horizontal composite | 63 | -2.97 | >.999 | 0.15 | 0.07 |

*Note.* as in previous tables, *t*-tests presented here are one-tailed, representing a-priori hypothesis predictions of aligned<misaligned for accuracy, and aligned>misaligned for reaction time. High *p*-values for horizontal composites represent results in the opposite direction from these predictions.

As described in Experiment 1, accuracy and reaction time measures were also integrated into BIS. These showed no significant differences between aligned and misaligned vertical composites (*p* = .078), but significantly greater BIS for misaligned composites in the horizontal condition (*p* = .002). Descriptive statistics and results for this comparison are reported in Suppl. Tables 3 & 4. BIS were again used to provide a comparison of CFE size between vertical (familiar left + unfamiliar right & familiar right + unfamiliar left) and horizontal (familiar upper + unfamiliar lower & familiar upper + unfamiliar lower) composites with standard and Bayesian statistics. This comparison showed that the size of the CFE for BIS was significantly different between vertical (*M* = 0.17, *SD* = 0.74) and horizontal (*M* = 0.45, *SD* = 1.12) composites [*t*(63) = -.3.47, *p* = .001, *d* = 0.65]. There was strong evidence in favour of a difference between vertical and horizontal composites (BF10 = 27.31). Comparison of CFE size was calculated for accuracy and reaction time measures independently, which showed no significant difference between composite division directions for accuracy (*p* = .092), but with a significant difference for reaction time (*p* < .001). Descriptive statistics and results from these comparisons are reported in Suppl. Tables 5 & 6.

Additionally, we examined any effects caused by the appearance of a familiar half in each visual field on BIS scores in a within-subjects comparison. Paired-sample *t*-tests showed no significant difference in BIS CFE magnitude when the familiar half appeared on the left (*M* = 0.10, *SD* = 1.08) vs. right (*M* = 0.20, *SD* = 0.76) half of the face [*t* = -0.56, *p* = .574]. There was weak evidence in favour of a lack of difference between left and right familiar halves (BF10 = 1.60). Equally, there was no significant difference between the familiar half appearing on the upper (*M* = -0.11, *SD* = 1.16) vs. the lower (*M* = -0.15, *SD* = 1.37) half of the face [*t* = 0.17, *p* = .866]. There was weak evidence in favour of a lack of difference between left and right familiar halves (BF10 = 1.39). This same lack of significant difference was shown in comparisons of the non-integrated dependent variables, the descriptive statistics and results of which of which are listed in Suppl. Tables 9 & 10.

# Discussion

The aims of this study were to determine the existence of a vertical CFE, and to compare the magnitude of this vertical CFE with the traditional horizontal CFE. Across four pre-registered experiments, we demonstrate a reliable CFE for vertically divided faces and show that its magnitude is comparable to the well-established horizontal CFE.

The CFE was first demonstrated by Young and colleagues (1987) and has been taken as evidence for the holistic integration of facial information. Here, we demonstrate that the CFE is not limited to ‘horizontal’ composites, composed of upper and lower halves of faces, but is equally evident in ‘vertical’ composites, composed of left and right halves of faces. Only a few other studies have examined a CFE using vertical composites (Liu & Behrmann, 2014; Liu *et al.*, 2014). However, none of these have demonstrated this effect in a naturalistic familiar face recognition paradigm, nor directly compared the CFE magnitude for vertical and horizontal composites. Our findings align with EEG studies showing interactions between evoked components in aligned but not misaligned facial composites, which have been interpreted as representing the binding of left and right face halves in posterior occipito-temporal cortex (Boremanse *et al.,* 2013). The relevance of these bound representations to analytic processing is demonstrable through evidence of preferential neural responses to fully integrated faces in higher-level face-selective regions (Tong *et al.*, 2000; Kamps *et al.*, 2019; Liu *et al.*, 2010; Zhang *et al.*, 2012). A possible mechanism for the integration of information across visual hemifields could be the strong interhemispheric connectivity between corresponding face regions in the brain (Davies-Thompson & Andrews, 2012; Quinn *et al.,* 2024; Frässle *et al.,* 2016a; 2016b; Geiger *et al.,* 2016).

We found that the vertical CFE had the same magnitude as the horizontal CFE. Earlier assumptions of a weaker vertical CFE may be due to the method used to construct the images. By combining familiar and unfamiliar faces, we were able to match the faces so that the features were effectively aligned without altering the appearance of the familiar faces. This would be consistent with the idea that some previous attempts to show a vertical CFE have been affected by difficulties in the alignment of features, which diminish naturalistic facial symmetry (Hole, 1994). These misalignments could influence the integration of the left and right halves of the face due to the sensitivity of the face processing system for horizontally oriented facial information (Dakin & Watt, 2009; Goffaux & Dakin, 2010). Before digital image manipulation software was readily available, vertical composite creation (e.g., Hole, 1994; Young *et al.,* 1990) may have inadvertently broken or reduced holistic integration due to even small featural misalignments (Laguesse & Rossion, 2013), or inconsistencies in the predicted sequence of horizontal information (Dakin & Watt, 2009), thereby generating biologically implausible composite faces (Taubert & Alais, 2009). With controlled featural and contrast alignment into plausible facial representations (see Figure 3.1), our results show that alignment of left and right halves into a composite creates a similar holistic representation as alignment of upper and lower halves.

The importance of integrating information from the left and right halves of the face is apparent when we consider how we attend to faces in natural viewing. Several studies have shown that we typically fixate at, or close to, the horizontal midpoint of the face (Peterson & Eckstein, 2012; Walker-Smith *et al.,* 2013; Hsiao & Cottrell, 2008). This leads to the left and right halves of the face projecting to opposite hemispheres, and being processed in anatomically distinct regions of the early visual brain (Hsiao *et al.*, 2008). Although none of our experiments monitored eye position or used brief presentations to minimise the effect of eye movements, fixation crosses were presented close to the naturalistic fixation point for frontally facing faces, and previous research has shown that these are reliable in maintaining fixation control (Jones & Santi, 1978; Posner, Nissen, & Ogden, 2014). Moreover, while the decision to retain composites on-screen until judgments were made likely resulted in overall high accuracy scores, evidence suggests that holistic (Richler *et al.*, 2009) and identity (Seeck *et al.* 1997; Tanaka *et al.*, 2006) processing occur rapidly after initial fixation. The consistent presence of a vertical CFE in reaction time measures throughout our experiments suggests that CFE magnitude was not overly affected by this choice.

To explore the processes underlying the vertical CFE, we asked whether prior exposure to the familiar faces was important to its production. Previous studies examining the CFE using familiar faces have commonly shown the familiar identities used to construct the composites prior to testing (e.g., Young *et al.*, 1987; Chen *et al.*, 2018; Fitousi, 2020; Robbins & McKone, 2003). The horizontal CFE is known to be subject to the effects of priming, such as for local versus global information (Ventura *et al.*, 2021). Priming or prior exposure to images of faces has also been shown to improve recognition judgements (Ellis *et al.*, 1987, Bruce & Valentine 1985). In the current study, we compared performance when participants were primed (Experiment 1) or unprimed (Experiment 2) with the familiar faces used in the composites. Our findings showed that priming did not have any significant effect on the magnitude of the vertical or horizontal CFE. The absence of identity-priming suggests that holistic integration occurs at an early stage of face processing, before identity-relevant information is analysed (Richler *et al.,* 2009; Osborne & Stevenage, 2013). This aligns with evidence from Liu and Behrmann (2014) and Liu *et al.* (2014), which provide similar indications of a vertical CFE for unfamiliar identity recognition. This may suggest that familiarity is less relevant to holistic integration than overall recognition processing (Johnston & Edmonds, 2009; Young & Burton, 2017), and an interesting issue for further study would be the extent to which the CFE differs between unfamiliar and familiar faces when directly compared.

Next, we asked whether there was a greater effect when judgments were focused on specific halves of the face. Previous studies have demonstrated a left visual field/right hemisphere bias in facial processing (Bourne & Hole, 2006, Verosky & Turk-Browne, 2012; Rossion, 2014; Prete & Tommasi, 2018), which may reflect superior holistic processing (Bradshaw & Nettleton, 1981; Bombari *et al.,* 2014). To test whether laterality affected the size of the CFE, we compared judgements of familiarity on the left and right sides of the face. Consistent with a previous finding by Liu and Behrmann (2014), a comparison of results from Experiments 2 and 3 shows that there was no difference in the size of the vertical CFE sizes between judgements focused on the right face half and the left face half. Although neuroimaging evidence suggests that holistic processing is reliant predominantly on processing within the right hemisphere (Schiltz *et al.*, 2010; Schiltz & Rossion, 2006), as supported by the apparently overall greater accuracy of judgements focused on the left half of the face, our results suggest that this does not produce a specific advantage in the binding of information for centrally presented faces. This may be explained by the visual information initially projecting to both hemispheres being relevant to the integrative process, and thus there is no advantage to focusing judgements on one visual field over the other. Comparison of horizontal CFE sizes between experiments 2 and 3 showed a greater BIS CFE size for judgements focused on the upper half of the face than the lower half of the face. While weak, this effect aligns with indications of a particular salience of features in the upper half of the face, particularly the eye-region, to recognition processing (McKelvie, 1976; Royer *et al.*, 2018; Quinn & Wiese, 2023; Tanaka & Farah, 1993), and is consistent with previous CFE studies (e.g., Wang *et al.*, 2023; 2019).

We also investigated the role of attention on the vertical CFE, to determine whether the holistic integration of faces is an automatic process or requires cognitive control. Previous studies have suggested that the absence of an effect of attention indicates the automaticity of face processing (Palermo & Rhodes, 2007; Yan, Young, & Andrews, 2017). We found a vertical CFE in Experiments 1-3, in which participants had to direct their attention to either the left or right side of the composite. In Experiment 4, participants were not instructed to attend to either face half, but were instead asked to indicate which half was familiar. Experiment 4 showed no difference in accuracy between aligned and misaligned vertical or horizontal composites. Vertical composites showed a significant increase in reaction time when aligned compared to when misaligned. In contrast, horizontal composites showed no difference between the aligned and misaligned conditions. When accuracy and reaction time were integrated into balanced integration scores, neither the vertical nor horizontal composites showed the predicted difference between aligned and misaligned conditions. The attenuation of CFE for vertical and horizontal composites in Experiment 4 suggests that attention to a specific face half is important and that the CFE is not fully automatic. While attenuated, the production of a reaction time CFE for vertical but not horizontal composites suggests that vertical composites are more resilient to changes in attentional paradigm.

Recent research has highlighted the need to corroborate evidence between different tasks indicative of holistic integration to draw theoretically sound conclusions (Jin *et al.*, 2024; Li *et al.*, 2017; 2019; Boutet *et al.*, 2021). Combined with results drawn from Liu and Behrmann (2014) and Liu *et al.*, (2014) which demonstrate a vertical CFE for unfamiliar faces using the complete design, our same finding using familiar faces and the partial design strongly suggest that left and right face halves are holistically integrated. While the complete design has been criticised for its ambiguity regarding if its results stem from facilitation or interference of irrelevant halves (Rossion, 2013), our findings clearly demonstrate the interference of irrelevant halves, indicating perceptual integration. While results from the complete design point towards evidence of the facilitative effects of integration on face processing, further evidence from paradigms exclusively demonstrating facilitation effects (e.g., Tanaka & Farah, 1993) for left and right face halves is needed to further consolidate our findings as evidence of holistic integration.

In conclusion, we found consistent evidence across four experiments for a CFE for vertically divided faces, which was consistent in magnitude with the traditional horizontal CFE. The magnitude of this effect was unaffected by priming or which half of the face was attended. However, the magnitude of the vertical CFE was attenuated when participants were not attending to a specific face half. The importance of these findings may be related to the fact that during normal fixation the left and right side of the face are initially processed in opposite hemispheres. More generally, these findings provide further evidence for the idea that facial information is processed holistically.

# Ending sections

## Code Availability

All analysis code and fully anonymised, coded data is available on the OSF. (https://osf.io/3y2kp/?view\_only=5f1eb046809244a99aed7532fd1eed55).

## Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

# References

Baudouin, J. Y., & Humphreys, G. W. (2006). Configural information in gender categorisation. *Perception*, *35*(4), 531-540.

Bombari, D., Preuss, N., & Mast, F. W. (2014). Lateralized Processing of Faces. *Swiss Journal of Psychology*.

Boremanse, A., Norcia, A. M., & Rossion, B. (2013). An objective signature for visual binding of face parts in the human brain. *Journal of vision*, *13*(11), 6-6.

Boutet, I., Nelson, E. A., Watier, N., Cousineau, D., Béland, S., & Collin, C. A. (2021). Different measures of holistic face processing tap into distinct but partially overlapping mechanisms. *Attention, Perception, & Psychophysics*, *83*, 2905-2923.

Bradshaw, J. L., & Nettleton, N. C. (1981). The nature of hemispheric specialization in man. *Behavioral and Brain Sciences*, *4*(1), 51-63.

Bruce, V., & Valentine, T. (1985). Identity priming in the recognition of familiar faces. *British Journal of Psychology*, *76*(3), 373-383.

Bruce, V., & Young, A. W. (2012). *Face perception*. Psychology Press.

Calder, A. J., Young, A. W., Keane, J., & Dean, M. (2000). Configural information in facial expression perception. *Journal of Experimental Psychology: Human perception and performance*, *26*(2), 527.

Chen, W., Ren, N., Young, A. W., & Liu, C. H. (2018). Interaction between social categories in the composite face paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *44*(1), 34.

Cheung, O. S., Richler, J. J., Palmeri, T. J., & Gauthier, I. (2008). Revisiting the role of spatial frequencies in the holistic processing of faces. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(6), 1327.

Dakin, S. C., & Watt, R. J. (2009). Biological “bar codes” in human faces. *Journal of vision*, *9*(4), 2-2.

Davies-Thompson, J., & Andrews, T. J. (2012). Intra-and interhemispheric connectivity between face-selective regions in the human brain. *Journal of neurophysiology*, *108*(11), 3087-3095.

DeBruine, L., & Jones, B (2017). *Face Research Lab London Set*. (Figshare 5047666; Version V5) [Data set]. Figshare

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G\* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior research methods*, *39*(2), 175-191.

Fitousi, D. (2020). Decomposing the composite face effect: Evidence for non-holistic processing based on the ex-Gaussian distribution. *Quarterly Journal of Experimental Psychology*, *73*(6), 819-840.

Frässle, S., Krach, S., Paulus, F. M., & Jansen, A. (2016a). Handedness is related to neural mechanisms underlying hemispheric lateralization of face processing. *Scientific reports*, *6*(1), 27153.

Frässle, S., Paulus, F. M., Krach, S., Schweinberger, S. R., Stephan, K. E., & Jansen, A. (2016b). Mechanisms of hemispheric lateralization: Asymmetric interhemispheric recruitment in the face perception network. *Neuroimage*, *124*, 977-988.

Garcia-Marques, T., Fernandes, A., Fonseca, R., & Prada, M. (2015). Social presence and the composite face effect. *Acta Psychologica*, *158*, 61-66.

Geiger, M. J., O'Gorman Tuura, R., & Klaver, P. (2016). Inter‐hemispheric connectivity in the fusiform gyrus supports memory consolidation for faces. *European Journal of Neuroscience*, *43*(9), 1137-1145.

Goffaux, V., & Dakin, S. C. (2010). Horizontal information drives the behavioral signatures of face processing. *Frontiers in psychology*, *1*, 143.

Harrison, M. T., & Strother, L. (2020). Does right hemisphere superiority sufficiently explain the left visual field advantage in face recognition?. *Attention, Perception, & Psychophysics*, *82*, 1205-1220.

Hole, G. J. (1994). Configurational factors in the perception of unfamiliar faces. *Perception*, *23*(1), 65-74.

Hsiao, J. H. W., & Cottrell, G. (2008). Two fixations suffice in face recognition. *Psychological science*, *19*(10), 998-1006.

Hsiao, J. H. W., Shieh, D. X., & Cottrell, G. W. (2008). Convergence of the visual field split: Hemispheric modeling of face and object recognition. *Journal of Cognitive Neuroscience*, *20*(12), 2298-2307.

Jenkins, R., Lavie, N., & Driver, J. (2003). Ignoring famous faces: Category-specific dilution of distractor interference. *Perception & Psychophysics*, *65*(2), 298-309.

Jin, H., Ji, L., Cheung, O. S., & Hayward, W. G. (2024). Facilitation and interference are asymmetric in holistic face processing. *Psychonomic Bulletin & Review*, 1-12.

Jones, B., & Santi, A. (1978). Lateral asymmetries in visual perception with and without eye movements. *Cortex*, *14*(2), 164-168.

Laguesse, R., & Rossion, B. (2013). Face perception is whole or none: disentangling the role of spatial contiguity and interfeature distances in the composite face illusion. *Perception*, *42*(10), 1013-1026

Lavie, N., Ro, T., & Russell, C. (2003). The role of perceptual load in processing distractor faces. *Psychological science*, *14*(5), 510-515.

Li, J., Huang, L., Song, Y., & Liu, J. (2017). Dissociated neural basis of two behavioral hallmarks of holistic face processing: The whole-part effect and composite-face effect. *Neuropsychologia*, *102*, 52-60.

Li, J., Song, Y., & Liu, J. (2019). Functional connectivity pattern in the core face network reflects different mechanisms of holistic face processing measured by the whole-part effect and composite-face effect. *Neuroscience*, *408*, 248-258.

Liesefeld, H. R., & Janczyk, M. (2019). Combining speed and accuracy to control for speed-accuracy trade-offs (?). *Behavior Research Methods*, *51*, 40-60.

Liesefeld, H. R., Fu, X., & Zimmer, H. D. (2015). Fast and careless or careful and slow? Apparent holistic processing in mental rotation is explained by speed-accuracy trade-offs. *Journal of experimental psychology: learning, memory, and cognition*, *41*(4), 1140.

Liu, T. T., & Behrmann, M. (2014). Impaired holistic processing of left-right composite faces in congenital prosopagnosia. *Frontiers in human neuroscience*, *8*, 750.

Liu, T. T., Hayward, W. G., Oxner, M., & Behrmann, M. (2014). Holistic processing for left–right composite faces in Chinese and Caucasian observers. *Visual cognition*, *22*(8), 1050-1071.

Ma, D. S., Kantner, J., & Wittenbrink, B. (2021). Chicago face database: Multiracial expansion. *Behavior Research Methods*, *53*, 1289-1300.

McKelvie, S. J. (1976). The role of eyes and mouth in the memory of a face. *The American Journal of Psychology*, 311-323.

Michel, C., Corneille, O., & Rossion, B. (2007). Race categorization modulates holistic face encoding. *Cognitive Science*, *31*(5), 911-924.

Murphy, J., Gray, K. L., & Cook, R. (2017). The composite face illusion. *Psychonomic Bulletin & Review*, *24*, 245-261.

Osborne, C. D., & Stevenage, S. V. (2013). Familiarity and face processing. *Quarterly Journal of Experimental Psychology*, *66*(1), 108-120.

Palermo, R., & Rhodes, G. (2002). The influence of divided attention on holistic face perception. *Cognition*, *82*(3), 225-257.

Palermo, R., & Rhodes, G. (2002). The influence of divided attention on holistic face perception. *Cognition*, *82*(3), 225-257.

Palermo, R., & Rhodes, G. (2007). Are you always on my mind? A review of how face perception and attention interact. *Neuropsychologia*, *45*(1), 75-92.

Peterson, M. F., & Eckstein, M. P. (2012). Looking just below the eyes is optimal across face recognition tasks. *Proceedings of the National Academy of Sciences*, *109*(48), E3314-E3323.

Peterson, M. F., & Eckstein, M. P. (2013). Individual differences in eye movements during face identification reflect observer-specific optimal points of fixation. *Psychological science*, *24*(7), 1216-1225.

Posner, M. I., Nissen, M. J., & Ogden, W. C. (2014). Attended and Unattended Processing Modes: The Role of Set for Spatial Location 1. In H. L. Pick & I. J. Saltzman (Eds.) *Modes of perceiving and processing information* (pp. 137-157). Psychology Press.

Prete, G., & Tommasi, L. (2018). Split-brain patients: Visual biases for faces. *Progress in Brain Research*, *238*, 271-291.

Quinn, B. P. A., Watson, D. M., Noad, K., & Andrews, T. J. (2024). Idiosyncratic patterns of interhemispheric connectivity in the face and scene networks of the human brain. *Imaging Neuroscience*, *2*, 1-20.

Quinn, B. P., & Wiese, H. (2023). The role of the eye region for familiar face recognition: Evidence from spatial low-pass filtering and contrast negation. *Quarterly Journal of Experimental Psychology*, *76*(2), 338-349.

Reinitz, M. T., Morrissey, J., & Demb, J. (1994). Role of attention in face encoding. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *20*(1), 161.

Richler, J. J., Mack, M. L., Gauthier, I., & Palmeri, T. J. (2009). Holistic processing of faces happens at a glance. *Vision research*, *49*(23), 2856-2861.

Richler, J. J., Mack, M. L., Gauthier, I., & Palmeri, T. J. (2009). Holistic processing of faces happens at a glance. *Vision research*, *49*(23), 2856-2861.

Robbins, R., & McKone, E. (2003). Can holistic processing be learned for inverted faces?. *Cognition*, *88*(1), 79-107.

Rossion, B. (2013). The composite face illusion: A whole window into our understanding of holistic face perception. *Visual Cognition*, *21*(2), 139-253.

Rossion, B. (2014). Understanding face perception by means of prosopagnosia and neuroimaging. *Frontiers in bioscience*, *6*(258), e307.

Rossion, B., & Boremanse, A. (2008). Nonlinear relationship between holistic processing of individual faces and picture-plane rotation: Evidence from the face composite illusion. *Journal of vision*, *8*(4), 3-3.

Rossion, B., Dricot, L., Devolder, A., Bodart, J. M., Crommelinck, M., De Gelder, B., & Zoontjes, R. (2000). Hemispheric asymmetries for whole-based and part-based face processing in the human fusiform gyrus. *Journal of cognitive neuroscience*, *12*(5), 793-802.

Royer, J., Blais, C., Charbonneau, I., Déry, K., Tardif, J., Duchaine, B., ... & Fiset, D. (2018). Greater reliance on the eye region predicts better face recognition ability. *Cognition*, *181*, 12-20.

Schiltz, C., & Rossion, B. (2006). Faces are represented holistically in the human occipito-temporal cortex. *Neuroimage*, *32*(3), 1385-1394.

Schiltz, C., Dricot, L., Goebel, R., & Rossion, B. (2010). Holistic perception of individual faces in the right middle fusiform gyrus as evidenced by the composite face illusion. *Journal of Vision*, *10*(2), 25-25.

Schneider, W., & Schiffrin, R. M. (1977). Automatic vs controlled processing. *Psychol Rev*, *84*, 1-64.

Seeck, M., Michel, C. M., Mainwaring, N., Cosgrove, R., Blume, H., Ives, J., ... & Schomer, D. L. (1997). Evidence for rapid face recognition from human scalp and intracranial electrodes. *Neuroreport*, *8*(12), 2749-2754.

Shiffrin, R. M. (1988). Attention. In R. C. Atkinson, R. J. Herrnstein, G. Lindzey, & R. D. Luce (Eds.), Stevens' handbook of experimental psychology: Perception and motivation; Learning and cognition (2nd ed., pp. 739–811). John Wiley & Sons.

Strathie, A., McNeill, A., & White, D. (2012). In the dock: Chimeric image composites reduce identification accuracy. *Applied Cognitive Psychology*, *26*(1), 140-148.

Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *The Quarterly Journal of Experimental Psychology Section A*, *46*(2), 225-245.

Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *The Quarterly Journal of Experimental Psychology Section A*, *46*(2), 225-245.

Tanaka, J. W., & Farah, M. J. (1993). Parts and wholes in face recognition. *The Quarterly Journal of Experimental Psychology Section A*, *46*(2), 225-245.

Tanaka, J. W., & Gordon, I. (2011). Features, configuration, and holistic face processing. *The Oxford handbook of face perception*, 177-194.

Tanaka, J. W., Curran, T., Porterfield, A. L., & Collins, D. (2006). Activation of preexisting and acquired face representations: the N250 event-related potential as an index of face familiarity. *Journal of cognitive neuroscience*, *18*(9), 1488-1497.

Tanaka, J. W., Kaiser, M. D., Butler, S., & Le Grand, R. (2012). Mixed emotions: Holistic and analytic perception of facial expressions. *Cognition & emotion*, *26*(6), 961-977.

Taubert, J., & Alais, D. (2009). The composite illusion requires composite face stimuli to be biologically plausible. *Vision Research*, *49*(14), 1877-1885.

Vieira, T. F., Bottino, A., Laurentini, A., & De Simone, M. (2014). Detecting siblings in image pairs. *The Visual Computer*, *30*, 1333-1345.

Walker-Smith, G. J., Gale, A. G., & Findlay, J. M. (2013). Eye movement strategies involved in face perception. *Perception*, *42*(11), 1120-1133.

Wang, Z., Ni, H., Zhou, X., Yang, X., Zheng, Z., Sun, Y. H. P., ... & Jin, H. (2023). Looking at the upper facial half enlarges the range of holistic face processing. *Scientific Reports*, *13*(1), 2419.

Wang, Z., Quinn, P. C., Jin, H., Sun, Y. H. P., Tanaka, J. W., Pascalis, O., & Lee, K. (2019). A regional composite-face effect for species-specific recognition: Upper and lower halves play different roles in holistic processing of monkey faces. *Vision research*, *157*, 89-96.

Westheimer, G. (1973). Saccadic eye movements. In V. Zickmund (Ed.), *The Oculomotor System and Brain Functions,* (pp. 59-77). Butterworth.

Yan, X., Young, A. W., & Andrews, T. J. (2017). The automaticity of face perception is influenced by familiarity. *Attention, Perception, & Psychophysics*, *79*, 2202-2211.

Young, A. W. (1982). Divided visual field studies of cerebral organisation. In J. G. Beaumont (Ed.), *Divided visual field studies of cerebral organisation* (pp. 11-27). Academic Press.

Young, A. W., & Burton, A. M. (2017). Recognizing faces. *Current Directions in Psychological Science*, *26*(3), 212-217.

Young, A. W., de Haan, E. H., Newcombe, F., & Hay, D. C. (1990). Facial neglect. *Neuropsychologia*, *28*(5), 391-415.

Young, A. W., Hellawell, D., & Hay, D. C. (1987). Configurational information in face perception. *Perception*, *16*(6), 747-759.

# A Composite Face Effect for Vertically Divided Faces

# Supplementary material

The present study uses a variety of face identities assumed to be ‘familiar’ to participants at the time of experimentation. While only identities which were indicated to be recognised in the recognition assessment block of experimentation were included in our analysis, we consider it relevant to provide a full list of celebrity identities and their recognition rates as supplementary data which may be of use to wider research and replication.

We suggest that there is little reason to believe that replacing these identities with other famous faces with greater relevance to future participants would have any effect on the composite face effect, and that assuring that there are sufficient consistently recognised identities to allow for effective analysis and comparison should take priority over using an identical set of stimulus identities in replication.

Suppl. Table 1.

*familiar identities used in experiments across the study, and their average recognition rates across all participants in each experiment (%).*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Identity | Role | Exp 1 Recog. | Exp 2 Recog. | Exp 3 Recog. | Exp 4 Recog. |
| Angelina Jolie | Actor | 82.8 | 92.2 | 81.3 | 75.0 |
| Arnold Schwarzenegger | Actor | 46.9 | 60.9 | 51.6 | 65.6 |
| Billie Eilish | Singer | 100.0 | 100.0 | 96.9 | 96.9 |
| Boris Johnson | Politician | 98.4 | 100.0 | 98.4 | 98.4 |
| Barack Obama | Politician | 98.4 | 100.0 | 100.0 | 98.4 |
| Brad Pitt | Actor | 75.0 | 71.9 | 67.2 | 71.9 |
| Bruce Willis | Actor | 25.0 | 37.5 | 28.1 | 93.8 |
| Chris Evans | Actor | 67.2 | 68.8 | 71.9 | 70.3 |
| David Attenborough | Other | 85.9 | 82.8 | 81.3 | 79.7 |
| David Beckham | Other | 85.9 | 84.4 | 65.6 | 81.3 |
| Daniel Radcliffe | Actor | 100.0 | 100.0 | 96.9 | 96.9 |
| Donald Trump | Politician | 100.0 | 100.0 | 100.0 | 98.4 |
| Drake | Singer | 87.5 | 87.5 | 93.8 | 84.4 |
| Ellen Degeneres | Other | 95.3 | 100.0 | 95.3 | 100.0 |
| Elon Musk | Other | 84.4 | 89.1 | 76.6 | 75.0 |
| Ed Sheeran | Singer | 100.0 | 100.0 | 100.0 | 100.0 |
| Emma Watson | Actor | 93.8 | 96.9 | 93.8 | 89.1 |
| Gordon Ramsay | Other | 96.9 | 98.4 | 95.3 | 93.8 |
| Hugh Jackman | Actor | 76.6 | 76.6 | 68.8 | 67.2 |
| Harry Styles | Singer | 100.0 | 98.4 | 98.4 | 100.0 |
| Jennifer Aniston | Actor | 98.4 | 98.4 | 95.3 | 93.8 |
| Justin Bieber | Singer | 100.0 | 100.0 | 98.4 | 93.8 |
| Joe Biden | Politician | 71.9 | 73.4 | 78.1 | 78.1 |
| Jeremy Clarkson | Other | 90.6 | 90.6 | 85.9 | 85.9 |
| Judi Dench | Actor | 64.1 | 67.2 | 68.8 | 64.1 |
| Johnny Depp | Actor | 100.0 | 98.4 | 96.9 | 93.8 |
| Jennifer Lawrence | Actor | 89.1 | 93.8 | 93.8 | 92.2 |
| Jennifer Lopez | Singer | 59.4 | 65.6 | 59.4 | 50.0 |
| Kim Kardashian | Other | 92.2 | 85.9 | 89.1 | 87.5 |
| Kate Middleton | Politician | 76.6 | 79.7 | 90.6 | 75.0 |
| Kanye West | Singer | 93.8 | 89.1 | 92.2 | 89.1 |
| Leonardo Dicaprio | Actor | 98.4 | 98.4 | 95.3 | 96.9 |
| Lady Gaga | Singer | 90.6 | 87.5 | 89.1 | 82.8 |
| Miley Cyrus | Singer | 100.0 | 96.9 | 98.4 | 92.2 |
| Morgan Freeman | Actor | 76.6 | 76.6 | 76.6 | 68.8 |
| Nicki Minaj | Singer | 93.8 | 89.1 | 87.5 | 87.5 |
| Prince William | Politician | 93.8 | 95.3 | 96.9 | 90.6 |
| Rowan Atkinson | Actor | 96.9 | 100.0 | 98.4 | 98.4 |
| Robert Downey Jr | Actor | 70.3 | 79.7 | 65.6 | 75.0 |
| Robert Pattinson | Actor | 89.1 | 93.8 | 90.6 | 87.5 |
| Rihanna | Singer | 95.3 | 95.3 | 96.9 | 62.5 |
| Simon Cowell | Other | 100.0 | 98.4 | 98.4 | 95.3 |
| Selena Gomez | Singer | 96.9 | 93.8 | 93.8 | 93.8 |
| Scarlett Johansson | Actor | 75.0 | 81.3 | 75.0 | 71.9 |
| Tom Cruise | Actor | 76.6 | 62.5 | 73.4 | 68.8 |
| Tom Hanks | Actor | 79.7 | 79.7 | 67.2 | 70.3 |
| Theresa May | Politician | 87.5 | 82.8 | 84.4 | 79.7 |
| Taylor Swift | Singer | 98.4 | 100.0 | 98.4 | 96.9 |
| Will Smith | Actor | 95.3 | 98.4 | 95.3 | 98.4 |
| Zendaya | Actor | 100.0 | 98.4 | 98.4 | 100.0 |

In addition, we report the minimum, maximum and median exclusions of identities featured in each experiment. Any participant who did not recognise at least 50% of the featured faces was excluded from further analysis.

Suppl. Table 2.

*Range and median number of exclusions of identities per participant for each experiment, based on incorrect identifications in the recognition block.*

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Minimum Exclusions** | **Maximum Exclusions** | **Median Exclusions** |
| *Experiment 1* | 0 | 22 | 5 |
| *Experiment 2* | 0 | 24 | 4 |
| *Experiment 3* | 0 | 25 | 5.5 |
| *Experiment 4* | 0 | 23 | 5 |

We additionally provide a full report of all descriptive data and statistical testing results from all experiments which has been summarized in the main body of the manuscript for brevity. This encompasses Balanced Integration Scores (BIS) scores for the main analysis of the effects of alignment, which are reported as divided accuracy and median reaction time scores in the main manuscript; and median and median reaction time scores for comparisons between horizontal and vertical composites, and between experiments, which are reported as BIS in the main manuscript.

Suppl. Table 3.

*Descriptive statistics for Balanced Integration Scores (BIS) for individual alignment conditions across all experiments.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Experiment** |  | **Aligned M** | **Aligned SD** | **Misaligned M** | **Misaligned SD** |
| *Experiment 1* |  |  |  |  |
|  | Vertical | 0.07 | 1.04 | -0.43 | 0.87 |
|  | Horizontal | 0.54 | 1.68 | -0.18 | 1.43 |
| *Experiment 2* |  |  |  |  |
|  | Vertical | 0.16 | 1.25 | -0.3 | 1.02 |
|  | Horizontal | 0.46 | 1.58 | -0.32 | 1.23 |
| *Experiment 3* |  |  |  |  |
|  | Vertical | -0.32 | 1.61 | -0.67 | 1.66 |
|  | Horizontal | 0.7 | 1.03 | 0.28 | 0.89 |
| *Experiment 4* |  |  |  |  |
|  | Vertical | -0.8 | 0.97 | -0.97 | 0.75 |
|  | Horizontal | 0.66 | 1.41 | 1.11 | 1.53 |

Suppl. Table 4.

*Results of paired sample t-tests comparing Aligned with Misaligned composite BIS across all experiments.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | ***df*** | ***t*** | ***p*** | ***davg*** | ***BF10*** |
| *Experiment 1*  |  |  |  |  |  |
|  | Vertical composite | 63 | 4.62 | **<.001** | 0.52 | >100 |
|  | Horizontal composite | 63 | 6.06 | **<.001** | 0.46 | >100 |
| *Experiment 2*  |  |  |  |  |  |
|  | Vertical composite | 63 | 3.79 | **<.001** | 0.41 | 70.22 |
|  | Horizontal composite | 63 | 5.46 | **<.001** | 0.55 | >100 |
| *Experiment 3*  |  |  |  |  |  |
|  | Vertical composite | 63 | 5.54 | **<.001** | 0.21 | >100 |
|  | Horizontal composite | 63 | 5.12 | **<.001** | 0.43 | >100 |
| *Experiment 4*  |  |  |  |  |  |
|  | Vertical composite | 63 | 1.79 | .078 | 0.19 | 0.62 |
|  | Horizontal composite | 63 | -3.20 | **.002** | 0.31 | 13.29 |

Suppl. Table 5.

*Descriptive statistics for Accuracy (%) and Median Reaction Time (RT; s) measures for CFE size (Aligned – Misaligned) for horizontal and vertical composites independently across all experiments.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Experiment** |  | **Accuracy M** | **Accuracy SD** | **RT M** | **RT SD** |
| *Experiment 1* |  |  |  |  |
|  | Vertical | -2.06 | 4.90 | 0.03 | 0.05 |
|  | Horizontal | -3.53 | 4.62 | 0.02 | 0.08 |
| *Experiment 2* |  |  |  |  |
|  | Vertical | -2.28 | 6.96 | 0.04 | 0.09 |
|  | Horizontal | -4.90 | 7.41 | 0.03 | 0.09 |
| *Experiment 3* |  |  |  |  |
|  | Vertical | -3.47 | 6.89 | 0.06 | 0.14 |
|  | Horizontal | -5.35 | 9.45 | 0.05 | 0.15 |
| *Experiment 4* |  |  |  |  |
|  | Vertical | -0.05 | 4.36 | 0.05 | 0.09 |
|  | Horizontal | 1.75 | 6.64 | -0.05 | 0.14 |

Suppl. Table 6.

*Results of paired sample t-tests comparing Accuracy and RT Median CFE sizes (Aligned – Misaligned) between horizontal and vertical composites across all experiments*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | ***df*** | ***t*** | ***p*** | ***davg*** | ***BF10*** |
| *Experiment 1*  |  |  |  |  |  |
|  | Accuracy | 63 | -1.65 | .105 | 0.31 | 0.49 |
|  | RT Median | 63 | -0.5 | .623 | 0.09 | 0.15 |
| *Experiment 2*  |  |  |  |  |  |
|  | Accuracy | 63 | -1.95 | .056 | 0.36 | 0.80 |
|  | RT Median | 63 | -0.85 | .398 | 0.14 | 0.19 |
| *Experiment 3*  |  |  |  |  |  |
|  | Accuracy | 63 | -1.36 | .179 | 0.23 | 0.33 |
|  | RT Median | 63 | -0.34 | .733 | 0.05 | 0.15 |
| *Experiment 4*  |  |  |  |  |  |
|  | Accuracy | 63 | 1.71 | .092 | 0.32 | 0.54 |
|  | RT Median | 63 | -5.69 | **<.001** | 0.83 | >100 |

Suppl. Table 7.

*Descriptive statistics for Accuracy (%) and Median Reaction Time (RT; s) measures for CFE size (Aligned – Misaligned) of horizontal and vertical composites for comparison across experimental pairings.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Comparison** |  | **Vertical M**  | **Vertical SD** | **Horizontal M** | **Horizontal SD** |
| **Accuracy** |  |  |  |  |
| *Priming*  |  |  |  |  |
|  | Experiment 1 | -2.28 | 6.96 | -4.9 | 7.41 |
|  | Experiment 2 | -2.06 | 4.9 | -3.53 | 4.62 |
| *Half Attendance* |  |  |  |  |
|  | Experiment 2 | -2.28 | 6.96 | -3.47 | 6.89 |
|  | Experiment 3 | -4.9 | 7.41 | -5.35 | 9.45 |
| **Median Reaction Time** |  |  |  |  |
| *Priming* |  |  |  |  |
|  | Experiment 1 | 0.04 | 0.09 | 0.03 | 0.09 |
|  | Experiment 2 | 0.03 | 0.05 | 0.02 | 0.08 |
| *Half Attendance* |  |  |  |  |
|  | Experiment 2 | 0.04 | 0.09 | 0.03 | 0.09 |
|  | Experiment 3 | 0.06 | 0.14 | 0.05 | 0.15 |

Suppl. Table 8.

*Results of independent sample t-tests comparing Accuracy and RT Median CFE sizes (Aligned – Misaligned) of horizontal and vertical composites for across experimental pairings.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | ***df*** | ***t*** | ***p*** | ***davg*** | ***BF10*** |
| **Accuracy** |  |  |  |  |  |
| *Priming* |  |  |  |  |  |
|  | Vertical  | 126 | -0.21 | .836 | 0.04 | 0.193 |
|  | Horizontal | 126 | -1.25 | .213 | 0.22 | 0.384 |
| *Half Attendance* |  |  |  |  |  |
|  | Vertical  | 126 | 0.97 | .333 | 0.17 | 0.290 |
|  | Horizontal | 126 | 0.30 | .766 | 0.05 | 0.197 |
| **Median Reaction Time** |  |  |  |  |  |
| *Priming* |  |  |  |  |  |
|  | Vertical  | 126 | 1.06 | .290 | 0.19 | 0.315 |
|  | Horizontal | 126 | 0.44 | .663 | 0.08 | 0.206 |
| *Half Attendance* |  |  |  |  |  |
|  | Vertical  | 126 | -0.94 | .348 | 0.17 | 0.282 |
|  | Horizontal | 126 | -1.14 | .257 | 0.20 | 0.340 |

Suppl. Table 9.

*Descriptive statistics for Accuracy (%) and Median Reaction Time (RT; s) measures for basic dependent variable comparisons of individual familiar halves for comparison across experiment 4 comparisons.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Comparison** | **Aligned M** | **Aligned SD** | **Misaligned M** | **Misaligned SD** |
| *Accuracy*  |  |  |  |  |
|  | Left | 95.20 | 5.91 | 94.63 | 5.92 |
|  | Right | 94.43 | 5.86 | 95.05 | 5.00 |
|  | Up | 89.12 | 11.05 | 88.89 | 7.84 |
|  | Down | 88.99 | 11.71 | 87.30 | 10.39 |
| *Median Reaction Time* |  |  |  |  |
|  | Left | 0.95 | 0.29 | 0.89 | 0.21 |
|  | Right | 0.91 | 0.21 | 0.87 | 0.19 |
|  | Up | 1.13 | 0.41 | 1.16 | 0.41 |
|  | Down | 1.18 | 0.49 | 1.17 | 0.38 |

Suppl. Table 10.

*Results of independent sample t-tests comparing Accuracy and RT Median CFE sizes (Aligned – Misaligned) of individual familiar halves for comparison across experiment 4 comparisons.*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | ***df*** | ***t*** | ***p*** | ***davg*** | ***BF10*** |
| *Accuracy* |  |  |  |  |  |
|  | Vertical (Left:Right)  | 63 | 0.95 | .692 | 0.18 | 0.211 |
|  | Horizontal (Up:Down) | 63 | -0.78 | .692 | 0.15 | 0.183 |
| *Median Reaction Time* |  |  |  |  |  |
|  | Vertical (Left:Right)  | 63 | 0.33 | .743 | 0.06 | 0.144 |
|  | Horizontal (Up:Down) | 63 | -1.39 | .341 | 0.23 | 0.340 |