A composite face effect for vertically divided faces

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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 judgements 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.

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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 analysed as isolated features (Rossion & Boremanse, 2008; Tanaka & Farah, 1993; Tanaka & Gordon, 2011). Support for this holistic integration is evident in the part–whole task, in which participants more accurately recognize 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 (Young et al., 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 (Murphy et al., 2017; Rossion, 2013).

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 suggests 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 (Hsiao & Cottrell, 2008; Peterson & Eckstein, 2012; Walker-Smith et al., 2013). 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 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 (Kamps et al., 2019; Liu et al., 2010; Tong et al., 2000; Zhang et al., 2012).

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; Strathie et al., 2012; Young et al., 1990). Of these, only two studies have directly investigated the effects of alignment on vertically divided 'vertical' composites (Liu et al., 2014; Liu & Behrmann, 2014). These have demonstrated that congruency between a relevant and irrelevant vertically divided face halves facilitates same/different judgements 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., Richler & Gauthier, 2013, 2014; Rossion, 2013), it has been suggested that theoretical conclusions regarding holistic integration must rely upon converging evidence across different paradigms (Boutet et al., 2021; Jin et al., 2024; Li et al., 2017, 2019).

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 (Bruce & Valentine, 1985; Ellis et al., 1987). 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 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 judgement 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 et al., 2014; Liu & Behrmann, 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; Figure 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 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 judgement, 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, Experiment 1a) in a comparable participant demographic, power analysis (Cohen's $d = 0.40$, power $= .95$, $\alpha = .05$) 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 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 30 px, and the right half upward by 30 px (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 30 px, and the lower half leftward by 30 px. 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 1.
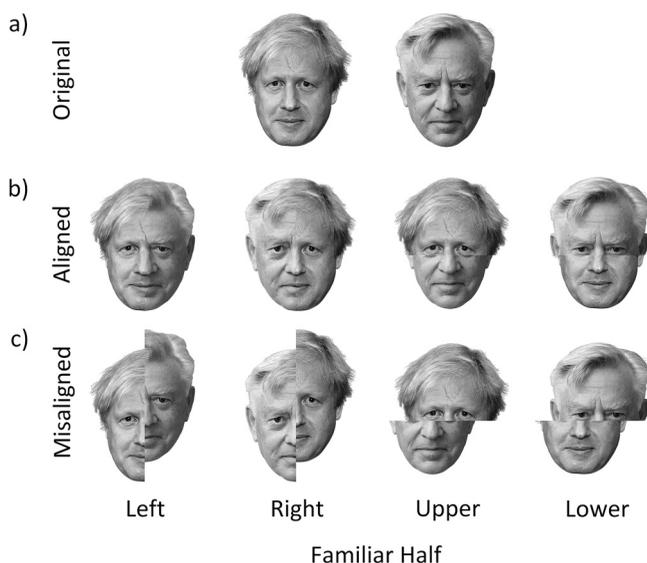

Figure 1. Example stimuli used in Experiments 1–4. (a) a familiar (left; former U.K. Prime Minister Boris Johnson) and unfamiliar face (right) used to construct a composite. (b) Aligned composites using these faces were divided vertically or horizontally. (c) Misaligned composites using these faces were 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 80 cm 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. 500 ms 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 (Bombari et al., 2014; Bradshaw & Nettleton, 1981), 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.

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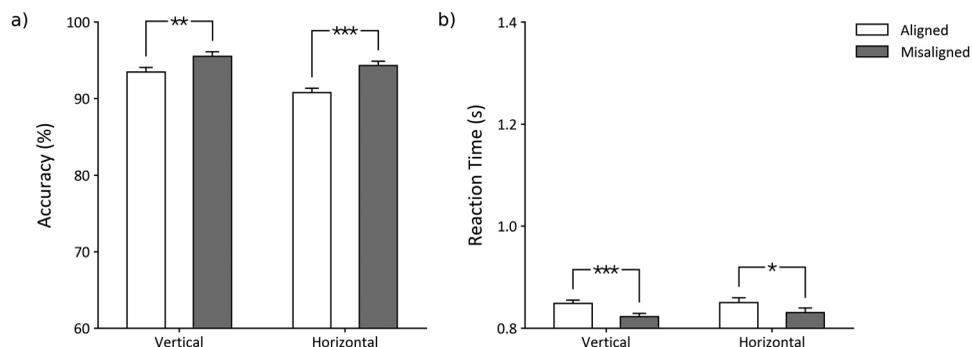
Figure 2. Experiment 1: (a) lower accuracy and (b) slower reaction times were evident for aligned compared to misaligned composites. This effect was evident for both vertical and horizontal composites. Error bars represent Cousineau's Y within-subject error values.

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 was preregistered (https://osf.io/tpgbj/?view_only=eb4b0e2a5b1d4057ac9a0693528ee52e). All data for this and subsequent experiments is publicly available on the Open Science Framework (https://osf.io/3y2kp/?view_only=5f1eb046809244a99aed7532fd1eed55). Our pre-registered hypotheses test the following predictions: H1) For horizontal composites, (i) lower accuracy of familiarity judgements 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 judgements 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 four tests within each experiment: Vertical accuracy, Vertical RT, Horizontal accuracy and 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 vertically 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 2.

For accuracy (Figure 2a), there was a statistically significant effect of alignment [$F(1, 63) = 50.43$, $p < .001$, $\eta_p^2 = 0.44$], and composite [$F(1, 63) = 5.18$, $p = .026$, $\eta_p^2 = 0.08$], 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 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 2b), the ANOVA showed only a statistically significant effect for alignment [$F(1, 63) = 15.26$, $p < .001$, $\eta_p^2 = 0.20$]. 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 1). For vertical composites (Aligned $M = 0.85$ s, $SD = 0.16$; Misaligned $M = 0.82$ s, $SD = 0.15$) and horizontal composites (Aligned $M = 0.85$ s, $SD = 0.21$; Misaligned $M = 0.83$ s, $SD = 0.18$), there was a slower reaction time for aligned images compared to misaligned images.

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 and 4. The 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 ($BF_{01} = 3.17$). 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 and 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 composites were presented. This was consistent with the approach used in previous studies examining the CFE using familiar faces (e.g., Chen et al., 2018; Fitousi, 2020; Robbins & McKone, 2003; Young et al., 1987). Image and identity priming of faces is known facilitate subsequent familiarity decision tasks (Bruce & Valentine, 1985; Ellis et al., 1987). 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

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	d_{avg}	BF_{10}
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

Bold *p*-values represent significant results ($p < .05$).

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.

Methods

Participants. Totally 69 participants were recruited for this experiment, although five 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 80 cm from a computer screen with the dimensions 544 mm ×306 mm (1920 px×1080 px). 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 was preregistered (https://osf.io/54vcf/?view_only = c7aeca96181f4e10aa1dd2799f72c7e1). Our pre-registered hypotheses test the following predictions: H1) For horizontal composites, (i) lower accuracy of familiarity judgements 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 judgements 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.

For accuracy (Figure 3a), there was a statistically significant effect of Alignment [$F(1, 63) = 36.28$, $p < .001$, $\eta_p^2 = 0.36$], and Composite [$F(1, 63) = 4.26$, $p = .043$, $\eta_p^2 = 0.06$], 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 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 3b), the ANOVA only showed a statistically significant effect for alignment [$F(1, 63) = 16.44$, $p < .001$, $\eta_p^2 = 0.21$]. 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 2). For vertical composites (Aligned $M = 0.97$ s, $SD = 0.27$; Misaligned $M = 0.93$ s, $SD = 0.23$) and horizontal composites (Aligned $M = 0.95$ s, $SD = 0.27$; Misaligned $M = 0.92$ s, $SD = 0.26$), there was a slower reaction time for aligned images compared to misaligned images.

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 and 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 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 ($BF_{01} = 4.31$). 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 and 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
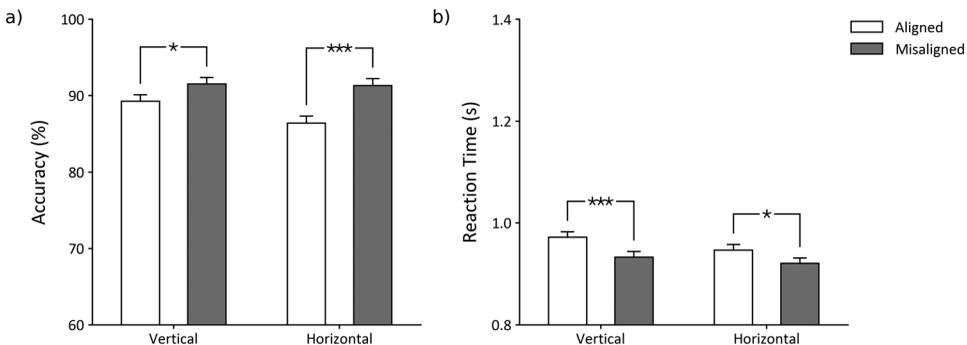
Figure 3. Experiment 2: (a) lower accuracy and (b) slower reaction times were evident for aligned compared to misaligned composites. This effect was evident for both vertical and horizontal composites. Error bars represent Cousineau's Y within-subject error values.

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	d_{avg}	BF_{10}
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

Bold *p*-values represent significant results (*p* < .05).

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 ($BF_{01} = 1.91$). 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 ($BF_{01} = 2.00$). 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 and 8.

Experiment 3

Experiments 1 and 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 and 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 produces more substantial and reliable CFEs than 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 (Prete & Tommasi, 2018; Rossion, 2014). Indeed, it has been suggested that the right hemisphere advantage may be due to greater specialisation for holistic processing (Bombari et al., 2014; Bradshaw & Nettleton, 1981). 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.

Methods

Participants. In total, 69 participants were recruited for this experiment, although five 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) 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 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 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 was preregistered (https://osf. io/akmpv/?view_only = bb6917f301934817b545edbf491b4e9d). Our pre-registered hypotheses test the following predictions: (H1) For horizontal composites, (i) lower accuracy of familiarity judgements 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 judgements 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 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 4.

For accuracy (Figure 4a), there was a statistically significant effect of alignment [$F(1, 63) = 32.79$, $p < .001$, $\eta_p^2 = 0.34$], and composite [$F(1, 63) = 5.14$, $p = .027$, $\eta_p^2 = 0.08$], 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). 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 4b), the ANOVA showed statistically significant effects for both alignment [$F(1, 63) = 14.81$, $p < .001$, $\eta_p^2 = 0.19$], and composite [$F(1, 63) = 47.63$, $p < .001$, $\eta_p^2 = 0.43$], 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). For vertical composites (Aligned $M = 0.98$ s, $SD = 0.32$; Misaligned $M = 0.92$ s, $SD = 0.34$) and horizontal composites (Aligned $M = 1.18$ s,
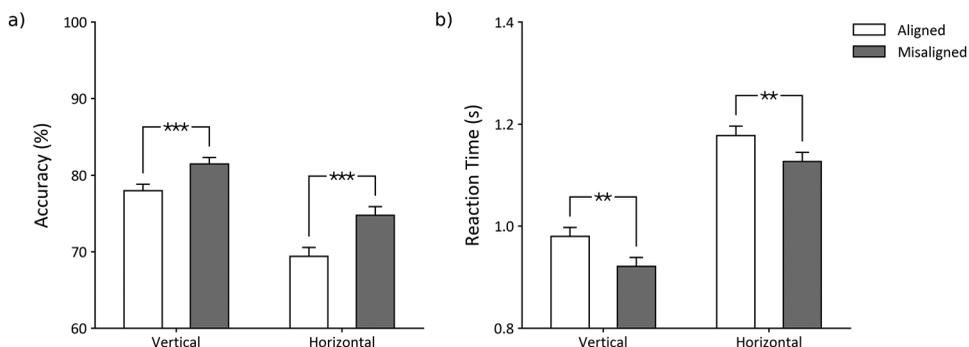
Figure 4. Experiment 3: (a) lower accuracy and (b) slower reaction times were evident for aligned compared to misaligned composites. This effect was evident for both vertical and horizontal composites. Error bars represent Cousineau's Y within-subject error values.

$SD = 0.32$; Misaligned $M = 1.13$ s, $SD = 0.27$), there was a slower reaction time for aligned images compared to misaligned images.

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 and 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 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 ($BF_{01} = 1.76$). 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 the 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 ($BF_{01} = 2.63$). 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 judgements 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 ($BF_{10} = 1.68$).

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 & Schiffrin, 1977; Shiffrin, 1988). In Experiment 4, we asked whether attention to a face half was necessary for 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 et al., 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

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	d_{avg}	BF_{10}
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

Bold p-values represent significant results ($p < .05$).

with the correct response (Jenkins et al., 2003; Lavie et al., 2003). However, other studies have shown that the ability to discriminate faces can be affected by attention (Palermo & Rhodes, 2002; Reinitz et al., 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.

Methods

Participants. Totally 66 participants were recruited for this experiment, although two 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, 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 (Hsiao & Cottrell, 2008; Peterson & Eckstein, 2012; Walker-Smith et al., 2013). 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 was preregistered (https://osf.io/j4mvk/?view_only=857dbb63ef404a47973bfbc419ebaa51). Our pre-registered hypotheses test the following predictions: (H1) For horizontal composites, (i) lower accuracy of familiarity judgements 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 judgements 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 5.

For accuracy (Figure 5a), there was a statistically significant effect of composite [$F(1, 63) = 73.86$, $p < .001$, $\eta_p^2 = 0.54$]. 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 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 statistically significant difference in recognition accuracy between aligned images and misaligned images.

For the reaction time (Figure 5b), the ANOVA showed a main effect of alignment [$F(1, 63) = 49.39$, $p < .001$, $\eta_p^2 = 0.44$], but not composite [$F(1, 63) = 1.46$, $p = .231$], with a significant interaction between alignment and composite [$F(1, 63) = 35.16$, $p < .001$, $\eta_p^2 = 0.36$]. To assess our pre-registered hypotheses, planned comparisons (paired sample *t*-tests) were conducted on the effect of alignment for each composite condition (Table 4). For vertical composites, there were faster reaction times for aligned images ($M = 0.92$ s, $SD = 0.21$) compared to misaligned images ($M = 0.87$ s, $SD = 0.17$). However, for horizontal composites, there was no significant difference between aligned images ($M = 1.11$ s, $SD = 0.35$) and misaligned images ($M = 1.16$ s, $SD = 0.33$).

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 and 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 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 ($BF_{10} = 27.31$). 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 and 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
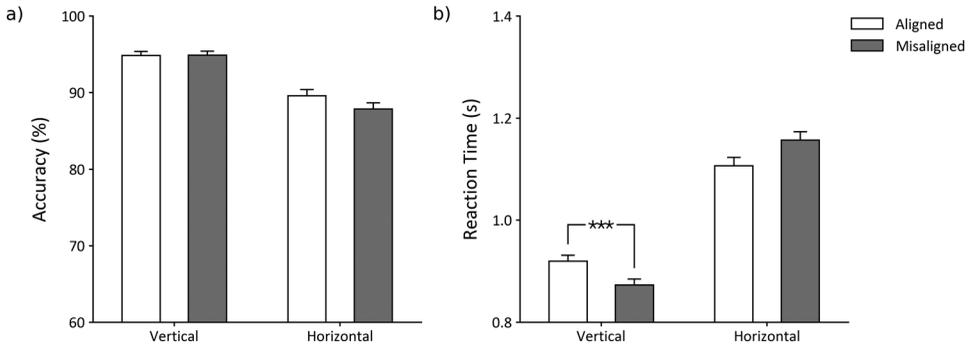
Figure 5. Experiment 4: (a) lower accuracy and (b) slower reaction times were evident for aligned compared to misaligned composites. This effect was evident for both vertical and horizontal composites. Error bars represent Cousineau's Y within-subject error values.

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	d_{avg}	BF_{10}
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.
Bold *p*-values represent significant results (*p* < .05).

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 ($BF_{10} = 1.60$). 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 the left and right familiar halves ($BF_{10} = 1.39$). 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 et al., 2014; Liu & Behrmann, 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 mis-aligned 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 (Kamps et al., 2019; Liu et al., 2010; Tong et al., 2000; 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; Frässle et al., 2016a, 2016b; Geiger et al., 2016; Quinn et al., 2024).

We found that the vertical CFE had the same magnitude as the horizontal CFE. Earlier assumptions of a weaker vertical composite effect 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 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 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 (Hsiao & Cottrell, 2008; Peterson & Eckstein, 2012; Walker-Smith et al., 2013). 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 et al., 2014). Moreover, while the decision to retain composites on-screen until judgements 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 in the composites prior to testing (e.g., Chen et al., 2018; Fitousi, 2020; Robbins & McKone, 2003; Young et al., 1987). The horizontal CFE has 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 (Bruce & Valentine, 1985; Ellis et al., 1987). 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 an identity-priming suggests that holistic integration occurs at an early stage of face processing, before identity-relevant information is analysed (Osborne & Stevenage, 2013; Richler et al., 2009). 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 judgements 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; Prete & Tommasi, 2018; Rossion, 2014; Verosky & Turk-Browne, 2012), which may reflect superior holistic processing (Bombari et al., 2014; Bradshaw & Nettleton, 1981). To test whether laterality affected the size of the CFE, we compared judgements of familiarity on the left and right side 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; Quinn & Wiese, 2023; Royer et al., 2018; 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 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 et al., 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 participants 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 condition. When accuracy and reaction time were integrated into balanced integration scores, neither the vertical or 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 (Boutet et al., 2021; Jin et al., 2024; Li et al., 2017; 2019). 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.

Author contribution(s)

Bartholomew P. A. Quinn: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Software; Visualization; Writing – original draft; Writing – review & editing.
A. Mike Burton: Conceptualization; Supervision; Writing – review & editing.
Timothy J. Andrews: Conceptualization; Methodology; Project administration; Supervision; Writing – review & editing.

Declaration of Conflicting Interests

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Ethical Approval and Informed Consent Statements

The Psychology Department Ethics Review Committee at the University of York approved our experiments (approval: 116) on 26 November 2021. All participants provided informed written consent before starting any experiment.

Data Availability

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

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Supplemental Material

Supplemental material for this article is available online.

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