The importance of the eye region for familiar face recognition: Evidence from spatial low-pass filtering and contrast inversion

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Abstract

What information is required for effective familiar face recognition? Accurate recognition for contrast chimeras – contrast positive eyes in contrast negative faces – suggests a salience of the eye-region for activating representations relevant to facial recognition. However, event-related potentials show that contrast chimeras undergo effortful face detection, and inefficient representation repetition priming, compared to unfiltered faces. It was unclear if efficient access to the eye-region alone was insufficient to effectively activate these representations, or if inefficiency in earlier face detection caused knock-on disruption. Evidence for the latter is supported by blur chimeras – unfiltered eyes in blurred faces – which are efficiently detected and elicit more typical repetition priming. However, no direct within-subjects comparison of blur and contrast chimeras' electrophysiological correlates has been made to date. Moreover, it has yet to be reliably established if un-filtering blurred faces' eye-regions provides a recognition advantage comparable to contrast chimeras. To address this, this dissertation provided direct behavioural and electrophysiological comparisons between chimeras.

Behavioural experiments showed that the recognition advantage between blur chimeras and contrast chimeras was comparable, unmanipulated eye-regions initiating holistic integration across both manipulations. Electrophysiological comparisons demonstrated that contrast chimeras were detected less efficiently than blur chimeras, suggesting that knock-on disruption caused delayed repetition priming, although blur chimeras underwent effortful representation activation. While both chimeras elicited identity repetition priming, this was more inefficient than unfiltered faces. Our results suggest that while detailed information within the eye-region is sufficient to activate recognition-relevant representations, indicating an important role for eye-region cues, efficiently accessed information in the remainder of the face facilitates this process in typical recognition. Despite chimeras inaccurately reflecting real-world face recognition, their comparison provided valuable means to investigate the information required to effectively and efficiently complete the serial stages of recognition, demonstrated here through support of several theoretical accounts of face detection and representation activation.

The importance of the eye region for familiar face recognition:

Evidence from spatial low-pass filtering and contrast inversion

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Statement of Copyright

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Chapter 1

General Introduction

1.1 Face Recognition

Despite the considerable changes in appearance that an individual face may undergo (Adini, Moses, & Ullman, 1997), humans are remarkably accurate at recognizing known faces (see Johnston & Edmonds, 2009; Young & Burton, 2017 for reviews). We can identify familiar individuals from previously unseen photographs, or across a wide range of manipulations that can dramatically distort or degrade the appearance of facial characteristics (e.g. Bruce, 1982; Hole, George, Eaves, & Rasek, 2002; Burton, Wilson, Cowan, & Bruce, 1999). The robust accuracy of this ability, compounded with the importance of face recognition for human social interaction, has led to the claim that we are 'face experts' (Diamond & Carey, 1986). However, this expertise does not extend to all faces (see Young & Burton, 2018) as unfamiliar faces are significantly more challenging to recognize than familiar faces, particularly from novel images, or when degraded (see Burton & Jenkins, 2011; Hancock, Bruce, & Burton, 2000 for reviews). This much is evident from card-sorting tasks, wherein even marginal differences from known images of unfamiliar faces causes substantial overestimation of presumed identities, whereas familiar faces are accurately categorized (Jenkins & Burton, 2011; Balas & Pearson, 2017). Combined with behavioural results from typical face recognisers, findings from participants with prosopagnosia (face-blindness; e.g. Malone, Morris, Kay, & Levin, 1982), and significant differences in neurophysiological brain responses (e.g. Collins, Robinson, & Behrmann, 2018) and skin conductance (e.g. Ellis, Quayle, & Young, 1999) in response to familiar and unfamiliar faces have suggested that familiar and unfamiliar faces are qualitatively different in how they are processed (Hancock et al., 2000; Megreya & Burton, 2006).

1.1.1 The cognitive model

Understanding the disparity between the recognition of familiar and unfamiliar faces has been shaped by Bruce and Young's (1986) seminal cognitive model. This model proposed that facial recognition progresses through a series of stages. While subsequent findings have elaborated upon this model (e.g. Calder & Young, 2005), evidence for this serial framework has been upheld across contemporary research (see Schweinberger & Burton, 2011; Schweinberger & Neumann, 2016 for reviews). The model proposes that recognition is initiated by the structural encoding of a perceived face into an expression-independent description. This description is then matched with a representation of a known face in memory. If successfully matched, this allows for the subsequent attachment of relevant semantic information, culminating in name recall. Based on this model, the qualitative difference between familiar and unfamiliar face recognition was hypothesized to arise due to the differences in their respective ability to successfully match a perceived face with the representation of a known face. Without established representations, recognition of unfamiliar faces is reliant on memory of any previously experienced images, which have limited utility in identifying a face under novel conditions.

1.1.2 Face recognition units

To be effectively recognized, a face must remain distinguishable from other faces, despite potentially only minor differences in featural layout (Taschereau-Dumouchel, Rossion, Schyns, & Gosselin, 2010); and be recognized across a wide variety of conditions that may drastically alter its appearance (Aldini et al., 1997; Jenkins, White, Van Montfort, & Burton, 2011). The Bruce and Young (1986) model posits that accurate distinction and recognition across ambient facial changes, (such as lighting, viewing angle, and viewing distance; e.g. Troje & Kersten, 1999) must rely on the existence of robust representations of faces in memory, termed 'Face Recognition Units' (FRUs). The robustness of an FRU allowing it to accurately identify a face despite potential variations has been repeatedly highlighted as the core element that separates familiar from unfamiliar face recognition (Bruce & Young, 1986; Burton, Bruce, & Hancock, 1999; Burton, Bruce, & Johnston, 1990; Etchells, Brooks, & Johnston, 2016; Burton, Jenkins and Schweinberger, 2011).

Contemporary research has hypothesized FRU robustness is mediated by repeated exposure to an individual face (Burton, Jenkins, Hancock, & White, 2005; Zimmermann & Eimer, 2013. In particular, that increased exposure to the natural multidimensional variability of a face assists in identifying its invariant aspects, persistent throughout within-person variability (Burton, Kramer, Ritchie & Jenkins, 2016). Empirical evidence supports this hypothesis, indicating that exposure to larger variations in learned images facilitates subsequent recognition (Murphy, Ipser, Gaigg, & Cook, 2015; Ritchie & Burton, 2017; Menon, White, & Kemp, 2015; Robins, Susilo, Ritchie, & Devue, 2018). Increased exposure to within-person variability has therefore been suggested to allow for better identification through establishing an FRU composed of the robustly invariant elements of a face, which can match a known face across many potential changes (Kramer, Young & Burton, 2018). Due to their lack of exposure to variable conditions, the invariant elements of unfamiliar faces cannot be effectively isolated. Without a robust FRU formed from these to match a perceived face with, unfamiliar face recognition becomes challenging and effortful (Kemp, Towell & Pike, 1997; White, Kemp, Jenkins, Matheson, & Burton, 2014), and is dependent on potentially variable characteristics of previously experienced images, becoming ineffectual for novel conditions (Bruce et al., 1999; Hancock et al., 2000; Bruce, Henderson, Newman, & Burton, 2001).

1.2 How do we recognize a face?

While effective matching of FRUs provides a comprehensive and compelling explanation for the difference between familiar and unfamiliar face recognition, contemporary research has yet to define the precise invariant information necessary to build or activate an FRU. Early research suggested that faces were recognized through comparison of the metric distances within and between facial features on a 2D plane – so-called ‘second-order configurations’ (Diamond & Carey, 1986; Maurer, Le Grand, & Mondloch, 2002). Though still upheld by some contemporary research, empirical evidence has shown that manipulations which alter 2D metric distances – including facial shape-normalization (Burton et al., 2005; Russell & Sinha, 2007), global stretching (Hole, et al., 2002; Sandford & Bindemann, 2020), and perceptual distance (Noyes & Jenkins, 2017), have little effect on recognition accuracy, which suggests that second-order configural information is unlikely to be a reliable cue for real-world recognition (see Burton, Schweinberger, Jenkins, & Kaufmann, 2015).

Instead, most contemporary research assumes that cues indicative of the 3D shape of facial and featural geometry, and pigmentation (or surface reflectance) properties of the skin, consisting of its albedo, hue, and texture, are of predominant use for facial recognition. Empirical evidence has demonstrated that 3D shape (e.g. Bruce et al., 1991) or pigmentation (e.g. Bruce & Langton, 1994) cues presented in isolation are sufficient to recognize faces at above-chance levels, and can therefore be assumed to play complementary roles in recognizing faces (O’Toole, Vetter, & Blanz, 1999; Russell, Sinha, Biederman, & Nederhouser, 2006). The relative dominance of 3D shape and pigmentation cues in their contribution to recognition has been heavily debated, with contemporary theories suggesting that reliance is not fixed, but rather based on familiarity (Kaufmann & Schweinberger, 2008; 2012) and individual ability (Kaufmann, Schulz, & Schweinberger, 2013; Itz, Golle, Luttmann, Schweinberger, & Kaufmann, 2017). Despite this flexibility, findings from these studies, combined with results from principle components analyses (Hancock, Burton, & Bruce, 1996), and indicators of better recognition accuracy in isolation (Bruce & Langton, 1994; Russell & Sinha, 2007), have suggested that pigmentation cues are overall more informative of identity, and are therefore relied upon more in effective familiar face recognition.

1.2.1 Blurring/Low-pass filtering

While familiar face recognition is resilient to many changes, examining manipulations which reduce recognition has proven invaluable in exploring the necessary information to recognize a face. Spatial frequency filtering has long been established as the basic mechanism by which luminance contrasts are extracted in early face perception, building up information relevant to cues such as edges indicative of surface textures and features (Marr & Hildreth, 1980), or depth cues indicating 3D-geometry (Marshall, Burbeck, Ariely, Rolland, & Martin, 1996). The visual system rapidly breaks down spatial frequency information into discrete channels (De Valois & De Valois, 1988; Sowden & Schyns, 2006): Low-spatial frequency information (LSF), composed of coarse global information such as broad contrast patterns; and high-spatial frequency information (HSF), composed of detailed local information such as fine textures. Both LSF and HSF play respective roles in face perception, largely determined by the task at hand (Oliva & Schyns, 1997; Schyns, 1998; Schyns & Oliva, 1997; 1999; but see also Parker, Lishman, & Hughes, 1996). While the exact role played by specific spatial frequency bandwidths is not fully understood, it is widely assumed that LSF information is primarily useful for between-category discrimination, such as detecting the typical contrast patterns indicative of a face, as opposed to different visual objects, within the visual field (Halit, De Haan, Schyns, & Johnson, 2006). HSF information is of greater use for within-category discrimination, reliant on the distinction of fine-scale differences in pigmentation, shape, and contrast, such as in individual face recognition (see Ruiz-Soler & Beltran, 2005 for review).

It is therefore unsurprising that face recognition incorporates a broad bandwidth of spatial frequencies, optimally functioning within a mid-spatial frequency (MSF) bandwidth from 8-16 cycles-per-image (cpi; Costen, Parker and Craw, 1994; Parker & Costen, 1999). The importance of HSF information to face recognition is evident from the detriment caused by low-pass filtering, or ‘blurring’ a face (see Figure 1) – reducing it to purely LSF information below 8cpi (Costen et al., 1994; Bachmann, 1991; Bhatia, Lakshminarayanan, Samal & Welland, 1995; Näsänen, 1999). Lowering the cut-off further has been shown to decrease recognition accuracy incrementally, until faces become no longer distinguishable at around 2cpi (Hanso, Bachmann, & Murd, 2010). The detriment caused by loss of HSF, combined with face recognition’s overall sensitivity to spatial frequency (Collin, Liu, Troje, McMullen, & Chaudhuri, 2004; Yue, Tjan, & Biederman, 2006), suggests a particular salience of HSF to accurately defining detailed edges and textures needed to encode 3D shape and pigmentation cues used for effective FRU activation (Vuilleumier, Armony, Driver, & Dolan 2003; Loftus & Harley, 2005). Without HSF, recognition via LSF information is limited to coarse shadows, useful for the detection of faces, but implicit only of unrefined facial and featural geometry (Goffaux & Rossion, 2006; Goffaux, Hault, Michel, Vuong, & Rossion, 2005).

1.2.2 Contrast negation

Not all recognition detriments stem from the reduction of spatial frequency bandwidths available in a face. Contrast negation (see Figure 1) – the reversal of luminance and hue – causes a significant reduction in face recognition accuracy, even for familiar faces (Galper, 1970; Galper & Hochberg, 1971; Johnston, Hill, & Carman, 1992; White, 2001; Kramer, Jenkins, Young, & Burton, 2017), despite preserving the same geometric and spectral information as a positive counterpart (Gilad, Meng, & Sinha, 2009). Notably, contrast negation affects recognition for faces to a significantly greater degree than for non-face objects (Nederhouser, Yue, Mangini, & Biederman, 2007; Vuong, Peissig, Harrison, & Tarr, 2005), suggesting that it actively impairs FRU activation. While the exact means by which contrast negation achieves this are unclear, nonetheless, contrast negation appears to inhibit the ability to use information relevant to recognizing faces.

A study by Kemp, Pike, White, and Musselman (1996) which examined the components of contrast negation in isolation demonstrated that this impairment stems from the inversion of luminance, while manipulation of hue in isolation had little effect on recognition accuracy. While the inversion of luminance was initially assumed to predominantly impair usage of shading patterns indicative of 3D shape cues (Johnston et al., 1992; Kemp et al., 1996), subsequent research has demonstrated that contrast negated faces maintain a significant recognition detriment even if stereopsis cues to 3D shape, unaffected by contrast negation, were also available (Liu, Collin and Chaudhuri, 2000). Contrast negation's recognition detriment is therefore presumed to primarily affect the use of pigmentation cues, reinforcing their importance for effective familiar face recognition (Liu et al., 2000; Russell et al., 2006). In particular, Russell et al. (2006) highlighted the inversion of the numerous and varied detailed pigmentation cues within the eye-region as being a particularly relevant to contrast negation's recognition deficit.

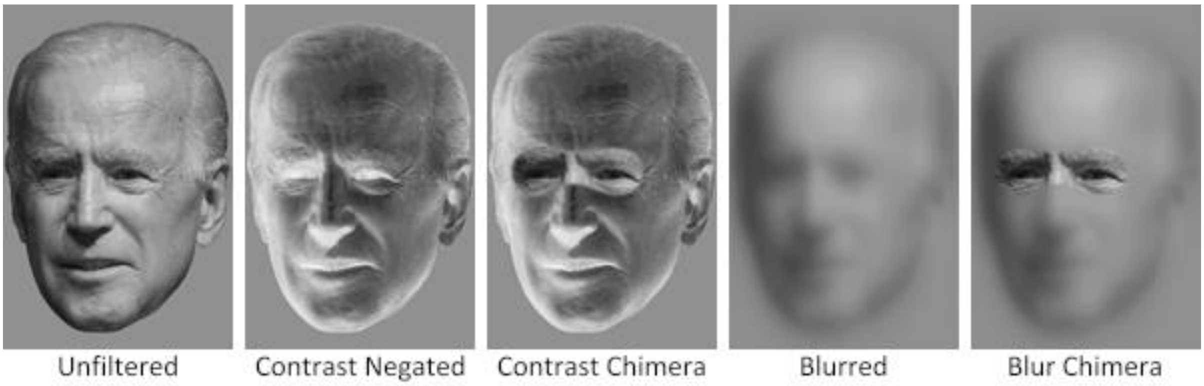

Figure 1. Examples of the five primary filtering manipulations of faces used across the present dissertation's experiments.

1.3 The Importance of the eye-region to recognition

Combining the features of multiple individuals' faces into a composite whole makes it challenging to identify the individual component identities (e.g. Young, Hellawell & Hay, 1987). This has led to the assumption that faces are processed holistically – as a unified Gestalt – unlike other objects which are processed through analysis of their component features (Rossion 2013; Farah, Wilson, Drain, &

Tanka, 1998; Richler & Gauthier, 2014). Although these holistic representations rely on incorporation of all features, multiple studies have suggested that the eye-region appears to play a uniquely salient role for effective face encoding. Electroencephalographic evidence (Rousselet, Ince, Rijsbergen, & Schyns, 2014; Schyns et al., 2007) has aligned with evidence from computational models (Tsao & Livingstone, 2008; Ullman, Vidal-Naquet, & Sali, 2002), and primate-based neural activation studies (Ohayon, Freiwald, & Tsao, 2012; Issa & DiCarlo, 2012), to indicate that the eyes act as an anchor point for early face detection, outward from which the other features are holistically integrated.

As well as being used in the initial detection of a face, thereby initiating the structural encoding process, the eye-region is known to contain a wide range of information relevant to social functioning (see Itier & Batty, 2009 for review), including indication of emotion (e.g. Schyns, Petro, & Smith, 2007), directed attention (e.g. Langton, Watt, & Bruce, 2000), gender, (e.g. Schyns, Bonnar, & Gosselin, 2002), as well as identity (Farkas, 1994, p. 3-56). The importance of the eye-region (including the eyebrows; Sadr, Jarudi, & Sinha, 2003) to recognition is equally evident from their masking, which caused a significant detriment to recognition accuracy, whereas masking of other features had little effect (McKelvie, 1976). This has been further reinforced with evidence that greater reliance on the eye-region in recognition tasks predicts better recognition accuracy (Royer et al., 2018), and that ineffectual use of eye-region cues may underlie clinical face-recognition disorders (Schwarzer et al., 2007; Caldara et al., 2005). As such, Russell et al.'s (2006) claim that the eye-region is particularly susceptible to contrast negation is easily understood. The inability to effectively use pigmentation cues within the eye-region, unsurprisingly, has a substantial negative impact on matching an internalized representation of a face to an FRU, but also on effectively detecting and structurally encoding a face from the visual field (see Fisher, Towler, & Eimer, 2016a).

1.3.1 Contrast Chimeras

While detailed cues in and around the eyes provide information relevant to recognition, the broad region of typically stable low luminance surrounding them (Braje, Legge, & Kersten, 2000; Sinha, 2002) appears equally relevant. Despite not inverting pigmental cues, like contrast negation, lighting a face from below inverts the typical ordinal contrast relationship between the sunken, darker eye-region and its lighter pronounced surroundings (cheeks, brow), which negatively affects recognizability (Johnston et al., 1992). Emphasising the importance of this ordinal contrast relationship, when restored through contrast negation of a below-lit face, recognition accuracy rises significantly (Liu, Collin, Burton, & Chaudhuri, 1999).

A similar effect can be achieved by restoring the eye-region of a negative contrast face to positive contrast. A study by Gilad et al., (2009), terming these 'contrast chimeras' (see Figure 1), demonstrated that they were recognized significantly better than contrast negative faces. Further research by Sormaz, Andrews and Young (2013) showed that this effect was uniquely produced by the eye-region, as restoring other facial features to positive contrast provided no significant recognition advantage. Interestingly, it was demonstrated that this 'chimera advantage' in recognition was not simply due to restored use of recognition cues within the eyes, which were recognized comparatively poorly in isolation or in dark silhouettes. Moreover, Sormaz et al., (2013) also provided evidence that the contrast positive eyes were holistically integrated with contrast negative information from the rest of the face. Based on these findings, contrast chimeras have been concluded to operate via the restoration of the typical ordinal contrast relationship of the eye-region, inverted by negation. Through restoration of typical ordinal contrast, cues in the negative face-region can be holistically integrated with eye-region cues to allow effective FRU matching, and thereby, face recognition (Sormaz et al., 2013; Fisher, Towler and Eimer 2016a; 2016b). Largely influenced by results from contrast chimeras, the importance of pigmentation information from the eye-region has been suggested as particularly salient to the activation of FRUs. As such, the eye-region has been hypothesized to form an anchor-point around which FRUs are built and activated (see Bruce and Young, 2013, p. 269).

1.4 Electroencephalographic correlates of face perception

A recent study by Wiese, Chan, and Tüttenberg (2019a) has raised doubt on this conclusion, questioning if findings drawn from this highly artificial stimulus type were reflective of real-world face processing. Specifically, their study drew attention to the process by which cues in the contrast negative face area are made usable, which would not be required by typical processing. They suggested that if FRUs are built around the eyes, contrast chimeras should show similar processing efficiency to typical faces. If processing for contrast chimeras required extra stages to decode negative contrast information, then this should reflect in inefficient processing. This question was explored using electroencephalography to examine the amplitude and latency of event-related potentials (ERPs) – electrophysiological responses to stimuli and events (Sur & Sinha, 2009) – associated with different face recognition processing stages.

1.4.1 The N250r

Wiese et al.'s (2019a) study examined the N250r ERP effect, assumed to index the activation of an FRU by a familiar face. The N250r derives from the N250, a negative polarity ERP over the right occipitotemporal scalp at 200ms-300ms, which responds preferentially to faces (Tanaka, Curran, Porterfield, & Collins, 2006), and is elicited at a more negative amplitude for familiar faces (Gosling & Eimer, 2011). For unmanipulated faces, when presented in succession as a matching identity prime and target pair, the amplitude of the repeated target N250 (N250r) is more negative (Schweinberger, Pfütze, and Sommer, 1995; Schweinberger, Huddy, & Burton, 2004). While the N250r is particularly strong when elicited by two identical images of a face, critically, it is also produced by two differing images of the same identity, provided that said identity is familiar to the viewer (Schweinberger, Pickering, Jentzsch, Burton, & Kaufman, 2002). The image-independent, identity- specific N250r is assumed to reliably represent the pre-activation of an FRU by the prime facilitating the re-activation of the same FRU by the target. As such, elicitation of an N250r provides a reliable indicator of the efficient FRU activation evident in typical recognition (see Schweinberger & Neumann, 2016 for review).

Wiese et al.'s (2019a) findings showed only limited indications of reliable repetition priming as indicated by the N250r for contrast chimeras, with the only N250r produced (Experiment 3) elicited in a delayed time window, and with a considerably smaller effect size than unmanipulated faces. This indicated that contrast chimeras were not matched with FRUs efficiently, requiring more time to activate them with less potency than unfiltered faces. Based on this result, they concluded that contrast chimeras did not elicit real-world face recognition, and that FRUs did not contain more detailed information from the eye-region, relative to the rest of the face.

1.4.2 The N170

While a convincing argument, examination of a second result from Wiese et al.'s (2019a) study makes it unclear if the limited repetition priming elicited by contrast chimeras is necessarily due to inefficient FRU activation. Evidence of contrast chimeras' inefficient processing earlier in the serial stream of face recognition offers an alternate possibility that chimera FRU matching was disrupted due to knock-on effects, rather than the inability to activate FRUs from access to cues in the eyes alone.

The N170 is a face-sensitive negative ERP component, identifiable at the occipitotemporal scalp at 130ms-200ms after stimulus presentation (see Eimer, 2011; Rossion & Jacques 2012 for reviews). The N170 responds with a higher amplitude to faces with a normally arranged alignment of internal facial features (eyes, above centralized nose, above mouth; so-called 'first-order configurations'; Maurer et al., 2002) than other categories of stimuli, including faces with the alignment of features scrambled (Bentin, Allison, Puce, Perez, & McCarthy, 1996). Critically, the N170 does not respond differently based on the familiarity of a face (Bentin & Deouell, 2000; Eimer, 2000), and is therefore assumed to represent a processing stage prior to FRU matching. As such, the N170 has been widely assumed to represent the detection of a face (Bentin et al., 1996; Ganis, Smith, & Schendan, 2012; Schweinberger & Neumann, 2016), and the initiation of the structural encoding mechanism (Eimer, 2000; 2011; Bruce and Young, 1986).

Wiese et al.'s (2019a) contrast chimeras elicited significantly delayed, more negative amplitude N170 ERPs. Both of these features have been suggested to be indicative of inefficient and effortful processing, indicated by their presence in atypically presented faces which are hard to recognize, such as contrast negated (e.g. Itier & Taylor, 2002), or upside down faces (e.g. Jemel, George, Chaby, Fiori, & Renault, 1999). Critically, given the serial nature of recognition processing, difficulties at an earlier stage can have a knock-on effect, passing inefficiency onto later stages of processing. Evidence has suggested that even low-level image differences early in processing can cause disruption of subsequent processing stages (e.g. Kendall et al., 2016; Tobimatsu & Celesia, 2006; Nakashima et al., 2008). For a contrast chimera prime, disrupted face detection may therefore knock on to both delay and reduce the potency of FRU pre-activation. As such, if a matching identity contrast chimera target is presented, then not only will this be subject to similar inefficiency due to knock-on effects from disrupted detection, but will also receive far less facilitation from the limited pre-activation of the FRU by the prime. This combination may therefore be responsible for delaying and reducing indicators of N250r identity repetition priming, making them less potent, non-significant, or potentially appearing non-existent, if pushed out of typically examined time windows.

Without the ability to isolate the N250r from potential knock-on effects from a disrupted N170, it therefore becomes difficult to identify the efficacy of chimeras at matching FRUs. While contrast chimeras are undeniably more inefficiently processed than typical faces, it is unclear from these results if this process affects primarily face detection and encoding, which results in a knock-on effect on otherwise efficient FRU matching; or if both detection/encoding and FRU matching are inefficiently conducted. As such, Wiese et al.'s (2019a) conclusion requires further investigation, and the unique significance of the eye-region to FRU activation should be reconsidered. A considerable limitation in doing so, however, is the necessity to eliminate potential knock-on effects from early perceptual processing stages of a chimera stimulus, which Wiese et al.'s (2019a) results suggest would prove challenging for examination of contrast chimeras alone.

1.4.3 Blur Chimeras

Research incorporating chimeras has, as yet, almost entirely focused on contrast chimeras, giving the impression that the advantage produced by restoration of the eyes is unique to contrast negation. However, a recent study by Quinn, Talfourd-Cook, and Wiese (2021) has utilized a novel stimulus composed of unfiltered eyes in an otherwise low-pass filtered face – so called 'blur chimeras' (see Figure 1) as a means to investigate ERPs while controlling for knock-on effects. Given the rapid processing of LSF information (Crouzet, Kirchner, and Thorpe, 2010; Hochstein and Ahissar, 2002), its use in face detection (Awasthi, Friedman, & Williams, 2011; Richler, Mack, Gauthier, & Palmeri, 2009), and evidence suggesting that blurred faces produced close-to-typical N170 ERPs (Flevaris, Robertson, & Bentin, 2008), this study assumed that a blur chimera would elicit a similar N170 to an unfiltered face, thereby allowing examination of an N250r free from knock-on effects.

Examination of the N170, illustrated in Figure 2, revealed that fully blurred faces elicited higher amplitude N170 ERPs than unfiltered faces, contrary to expectations, undergoing effortful processing (also found in other studies e.g. Halit et al., 2006). As anticipated, blur chimeras elicited a statistically similar amplitude N170 ERP to unfiltered faces, thereby removing potential knock-on effects of effortful face detection to FRU matching.

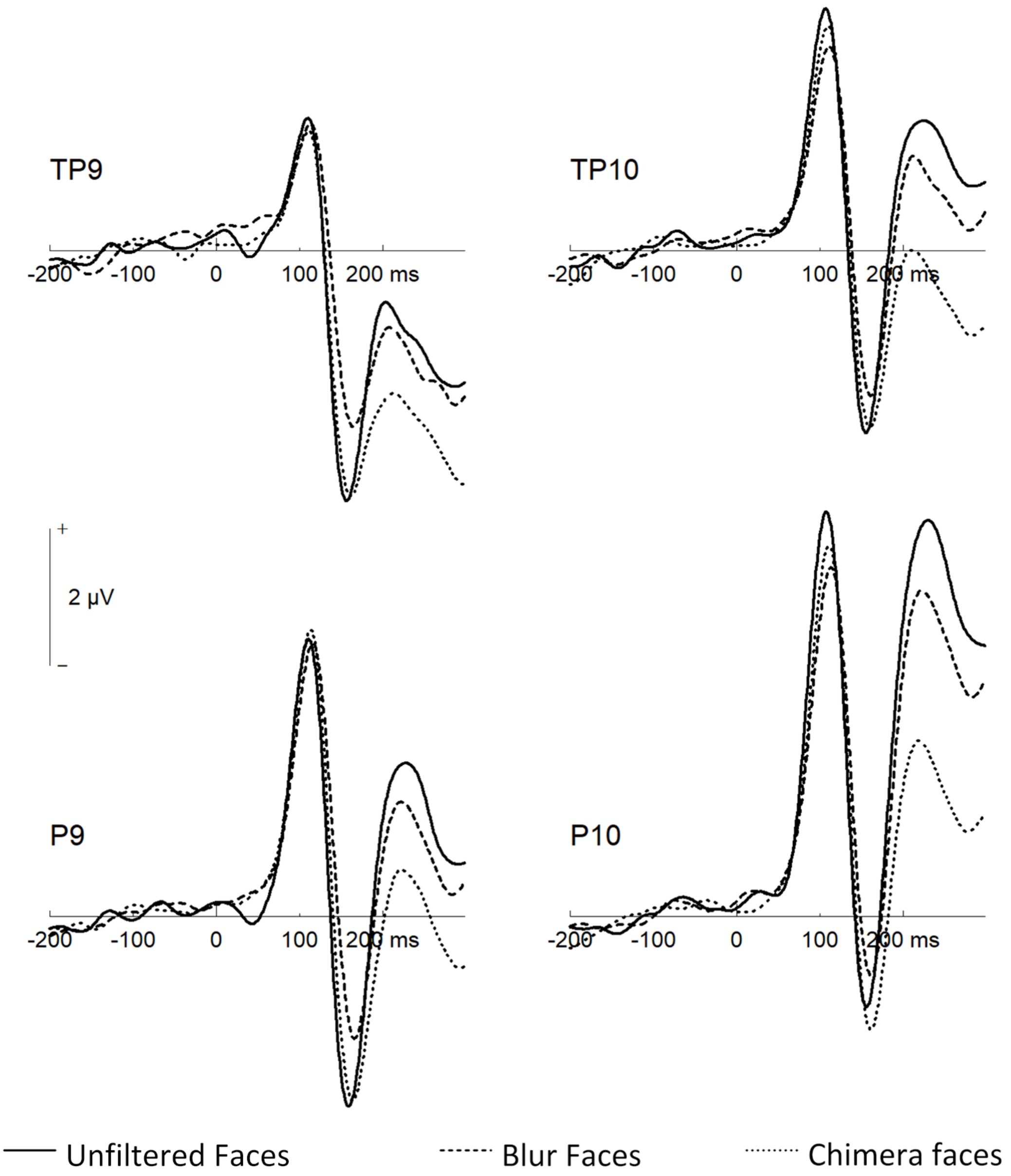

Figure 2. Grand average ERPs for unfiltered, blurred, and blur chimera prime stimuli at occipito-temporal electrodes P9/P10, and temporal electrodes TP9/TP10 from Quinn et al. (2021).

Similarly to Wiese et al.'s (2019a; Experiment 3) contrast chimeras, as illustrated in Figure 3, blur chimeras produced evidence of delayed N250r identity repetition priming, with a significantly enhanced target N250 ERPs compared to prime N250 ERPs only in the later time window (300ms-400ms). However, unlike contrast chimeras, blur chimeras also exhibited a significant trend of repetition priming in the earlier time window (200ms-300ms) and were elicited with a notably larger effect size than was produced by Wiese et al.'s (2019a) contrast chimeras. This result suggested that while FRUs can be activated from cues in the eye-region alone, detailed HSF and MSF cues from the filtered face-region facilitated this process. However, contrast chimeras preserve HSF and MSF information in the contrast negated face-region, so should presumably be matched with FRUs more easily than blur chimeras if the restoration of the eye-region's ordinal contrast relationship restores utility to contrast negated cues (Sormaz et al., 2013). As such, blur chimeras' indications of more efficient face detection and larger repetition priming effects than contrast chimeras, despite a loss of MSF/HSF information, strongly pointed towards contrast chimeras' delayed, reduced N250r as resulting from earlier inefficiency.

Figure 3. Effects of repetition priming for unfiltered, blurred, and blur chimera faces from Quinn et al. (2021). (a) Illustration of face conditions and sample stimuli. (b) Grand average ERPs of target stimuli at occipito-temporal electrodes P9/P10, and temporal electrodes TP9/TP10. Vertical dotted lines indicate the 240ms-300ms and 300ms-400ms N250r time windows respectively.

1.5 Aims of the present study

Evidence from blur chimeras has therefore suggested that contrast chimeras may not be ideal to examine the information necessary to activate FRUs. Despite this, due to the novelty of blur chimeras as a stimulus, several questions must be resolved before firm conclusions can be drawn from comparisons between these and contrast chimeras.

First, while results from Quinn et al. (2021) indicated an N250r for blur chimeras, but not for fully blurred faces, indicative of FRU activation, this did not appear to translate into a behavioural advantage, with no significant differences found between recognition accuracy between the two. This did not align with the Bruce and Young (1986) model, in which evidence of superior FRU activation as indexed by image-independent N250r identity repetition priming for blur chimeras should have translated to higher recognition accuracy than the fully blurred faces in which repetition priming was absent. However, behavioural results from this study are dubious. The priming paradigm used in Quinn et al. (2021) study was largely insensitive to accuracy differences, due to identity repetition both within and between trials. Moreover, Due to both the small sample size used for an ERP study, and the absence of effective controls in assessing accurate recognition, we consider that these behavioural results were inadequate to accurately indicate if the FRU activation from blur chimeras reflected a significant recognition advantage above fully blurred faces, in the same manner as contrast chimeras. Moreover, even if a recognition advantage was evident for blur chimeras, without an extensive behavioural examination of the conditions required for its elicitation, it was unclear if this advantage was reliant on the same eye-based integrative mechanism as contrast chimeras. To resolve this, the present dissertation (Experiments 1-3) aimed to provide a thorough behavioural examination of blur chimeras. As such, Experiment 1 examined if the un-filtering of the eye-region provided a significant recognition ‘chimera advantage’ above fully blurred faces. If a recognition advantage was evident for blur chimeras, Experiment 2 would aim to identify if the presence of an unmanipulated eye-region produced a recognition advantage through a comparable mechanism for both chimeras, based on their properties demonstrated by Sormaz et al. (2013). As well as a direct recognition accuracy comparison with contrast chimeras, this experiment would examine if the chimera advantage for blur chimeras was uniquely produced by access to cues in the eye-region, or if this translated to other features. In addition, we aimed to indicate if this advantage relied on integration of information from the whole face, or just from detailed cues in the eyes alone, through a comparison of recognition accuracy with eyes in silhouette. Finally, Experiment 3 would use a novel combined manipulation blur+contrast chimera, to indicate if this was also capable of producing a chimera advantage above a fully blurred negative contrasted face. In doing so, we aimed to identify if the chimera advantage was reliant on integration of the same cues from the manipulated face-regions across both chimeras, or if the chimera advantage was flexible in the cues which could be used.

Second, due to a disparity between results drawn from contrast and blur chimeras, the unique salience of the eye-region to activating FRUs is still uncertain. While ERP results from blur chimeras provide indication that the absence of an N250r produced by contrast chimeras (Wiese et al., 2019a) is due to disrupted early perceptual processing reflected in an enhanced N170, this remains somewhat speculative as these results have not yet been replicated. As such, Experiment 4 sought to assess the replicability of the results generated by Wiese et al. (2019a, Experiment 3) and Quinn et al. (2021). In addition, this study provided the first direct comparison of the ERP correlates of contrast and blur chimeras. In doing so, we aimed to identify significant differences between the amplitude and latency of the N170 produced by different chimeras to establish if differences in N250r production could be more clearly attributed to disrupted detection/encoding. Resolution of the disparity between different types of chimeras and further comparisons with unfiltered faces would also provide clearer understanding of the efficiency with chimeras processing at various stages of face perception, and indicate a more conclusive solution regarding the unique contribution of the eye-region to FRU activation.

Finally, if suitable behavioural similarities can be established, and differences in ERP production can be effectively explained, comparisons between chimeras may reveal new information about the information required for effective recognition, which we suggest is unlikely to be fully clarified by examination of a single type of chimera in isolation. Behavioural comparison of chimeras with fully filtered faces will provide a clearer picture of the information necessary to initiate a chimera recognition advantage. Comparison of both the behavioural and electrophysiological similarities and differences between contrast and blur chimeras will further establish what information is integrated with the eye-region from the manipulated surrounding face when structurally encoding well recognized holistic representations. Comparison of the electrophysiological similarities and differences between chimeras and unmanipulated faces will provide a novel methodology to explore the information necessary to effectively and efficiently complete the stages of face detection/encoding, and FRU activation.

Chapter 2

What cues are used during familiar face recognition?

Evidence for the flexible integration of coarse and detailed spatial information with the eye-region

Paper submitted to British Journal of Psychology, currently under review.

2.1 Abstract

What information is used for familiar face recognition? While previous research suggests a particular importance of the eye-region, information from the rest of the face also needs to be holistically integrated. What type of information is used in conjunction with the eyes is largely unclear. We present three experiments in which participants were asked to recognise so-called face chimeras, in which the eye-region was not manipulated while the rest of the face was either presented in negative contrast (contrast chimeras), or low-pass filtered (blur chimeras). We show (i) that both chimeras are recognised substantially better than fully negative or blurred faces, (ii) that the newly introduced blur chimera advantage is specific to the eye-region but cannot be explained by cues available in this part of the face alone, and (iii) that a combination of negative contrast and blurring outside of the eye-region eliminates the chimera advantage. We conclude that either detailed pigmentation (in contrast chimeras) or coarse 3D shape information (in blur chimeras) is used in combination with the eye-region for effective face recognition. Importantly, our findings suggest that the face recognition system can flexibly use either information, depending on availability.

2.2 Introduction

Humans are highly accurate and efficient at identifying familiar individuals from their faces (e.g., Young & Burton, 2017; Wiese et al., 2019b). However, despite considerable research, it is not completely understood what information is extracted from a face to accomplish this. On the one hand, empirical evidence suggests that the eye-region is more important for familiar face recognition relative to other parts of the face (Gilad et al., 2009). On the other hand, faces are processed holistically rather than in a piece-meal fashion (e.g., Young et al., 1987; Tanaka & Farah, 1993), and information from the rest of the face needs to be integrated with the eye-region for efficient and effective recognition. How exactly these integrational processes work and what type of information they require is largely unknown. The present study examined these questions by manipulating spatial frequency and contrast information of familiar faces, while, in the critical conditions, keeping the eye-region unaffected.

Previous research has shown that contrast negation – the reversal of an image's luminance and hue – substantially diminishes familiar face recognition (e.g. Galper, 1970; Kramer et al., 2017). It has further been demonstrated that luminance inversion has a substantial disruptive effect when manipulated in isolation, while isolated hue inversion has not (Kemp et al., 1996). Moreover, while the effect was initially assumed to result from the disruption of shading information indicative of 3D shape (e.g. Johnston et al., 1992; Kemp et al., 1996), contrast negation also substantially affects pigmentation, or surface reflectance – incorporating albedo, hue, and texture. Although 3D shape and pigmentation cues have complimentary roles in face recognition (O'Toole et al., 1999; Russell, et al., 2006), both computational modelling approaches (Hancock et al., 1996) and experimental examinations of recognition from shape and pigmentation cues in isolation (Bruce & Langton, 1994; Russell & Sinha, 2007) suggest that the latter are more informative of identity. Consequently, empirical evidence also suggests that the effect of contrast negation on familiar face recognition is primarily driven by the disruption of pigmentation information (Liu et al., 2000; Russell et al., 2006). Of relevance, contrast negation preserves most of the information of a positive counterpart (such as the original spatial frequency spectrum, see below). The effect therefore seems to inhibit the use of recognition cues, rather than eliminating them (see Sormaz et al., 2013, for a related discussion).

As noted above, the eye-region appears to play a critical role in familiar face recognition (Gilad et al., 2009). Previous research has demonstrated that masking the eyes (and eyebrows; Sadr et al., 2003) lowers recognition accuracy more than masking other features (e.g. McKelvie, 1976). Similarly, Russell et al. (2006) concluded that contrast inversion of fine-detailed pigmentation patterns throughout this area (e.g. iris/sclera; eyebrow/forehead) is particularly disruptive to face recognition. In addition, both human (Rousselet et al., 2014) and primate electrophysiological studies (Issa & DiCarlo, 2012; Ohayon et al., 2012), as well as computational modelling approaches (Tsao & Livingstone, 2008; Ullman et al., 2002) suggest that the eyes represent an initial anchor point for facial detection, outward from which diagnostic information from other features is integrated. However, surprisingly little is known about what information from other features is necessary for these integrational processes, and in turn effective face recognition.

While fine-grained contrast changes in the eye-region are clearly relevant to familiar face recognition, research has also demonstrated the importance of broad contrast relationships formed between the darker, sunken eye sockets, and the surrounding brighter face-regions (i.e. cheeks, forehead). This ordinal contrast relationship is stable across naturally occurring lighting conditions and viewpoints (Braje et al., 2000). However, when this relationship is diminished or inverted by lighting a face from below, recognition accuracy is negatively affected (e.g. Johnston et al., 1992). Conversely, recognition is largely restored when a below-lit face is additionally contrast inverted, which re-establishes the darker eye-region (Liu, et al., 1999). This evidence is further reinforced by research using so-called contrast chimeras.

Contrast chimeras – a positive eye-region in an otherwise negative contrast face – are substantially easier to recognise than their fully negative counterparts (Gilad, et al., 2009; Sormaz et al., 2013; see also Wiese et al., 2019a; Fisher at al., 2016b). This dramatic increase in recognition accuracy caused by a comparatively small part of the face, compounded by a significantly lesser advantage produced by rendering other features in positive contrast (Sormaz et al., 2013, experiment 1), again points towards the specific salience of the eye-region to effective recognition. The chimera advantage might initially be interpreted as arising from the availability of recognition cues within the eye-region alone. Evidence has shown, however, that isolated eyes or eyes in dark silhouettes are recognized substantially more poorly than contrast chimeras (Gilad et al., 2009; Sormaz et al., 2013, experiment 2), and that the chimera advantage is reliant on the holistic integration of the positive eye-region with the contrast negative remainder of the face (Sormaz et al., 2013, experiment 3). Consequently, the chimera advantage has been explained by suggesting that familiar face representations are holistic, but built around the eyes, and that the positive eye-region enables access to recognition cues in the surrounding face, which are else inhibited by contrast negation (see also Bruce & Young, 2012, p. 269). Others have suggested that chimeras are recognised more accurately because they restore the ordinal contrast relationship with a relatively darker eye-region relative to surrounding areas, and thus abolish the detrimental effect of contrast inversion (Gilad et al., 2009).

Based on this suggestion, one might assume that intact ordinal contrast relations across the face are necessary for accurate face recognition. At the same time, however, face recognition can be disrupted even when ordinal contrast is kept intact. Removing high- (HSF) and mid-spatial frequencies (MSF) through low-pass filtering (blurring) limits an image to only coarse low-spatial frequency (LSF) information. Face recognition has been shown to operate preferentially at 8-16 cycles-per-image (cpi) (see Ruiz-Soler & Beltran, 2005 for review). Consequently, low-pass filtering faces below an 8cpi cut-off degrades recognition accuracy incrementally (Costen et al., 1996; Parker & Costen, 1999, Näsänen, 1999). Of note, however, blurring keeps the broad ordinal contrast information of the face largely intact.

In summary, blurring and contrast negation affect faces differently in at least two ways. First, blurring actively removes detailed (i.e., HSF and MSF) cues from a face, whereas spatial frequency information is preserved by contrast negation. Second, while contrast negation disrupts broad ordinal contrast relationships, blurring does not, as it retains the overall (albeit coarser) patterns of shading of an unfiltered face. Previous research (Gilad et al., 2009; Sormaz et al., 2013) has suggested that i) the chimera advantage is based on the restoration of typical ordinal contrast relationships, and that ii) chimeras restore access to cues in the contrast negative face-region used for typical face recognition. These cues are likely in the HSF and MSF range, as these frequency bands carry substantial identity information. Based on these assumptions, an unmanipulated eye-region in a blurred face should not substantially improve recognition relative to fully blurred faces, as i) both fully filtered and blur chimera images retain typical ordinal contrast relationships, and ii) blur chimeras lack HSF and MSF recognition cues in the filtered face-region.

To test these suggestions, the present study examined participants' face recognition with contrast and blur chimeras in a series of three experiments. Experiment 1 examined a relatively large group of participants to establish the basic chimera effect for spatially low-pass filtered faces. Experiment 2 then directly compared the recognition of blur and contrast chimeras while at the same time investigating the holistic nature of the effect and its specificity to the eye-region. Finally, Experiment 3 tested face recognition with combined blur and contrast manipulations to test whether the observed chimera advantages reflected the flexible use of fine versus coarse information available in the manipulated part of the stimuli, or whether it alternatively could be explained by some other non-tested type of information which is unaffected by these manipulations.

2.3 Experiment 1

Experiment 1 was designed to establish initial evidence of a potential blur chimera recognition advantage effect. We reasoned that if the re-establishment of ordinal contrast relationships was a necessary pre-requisite for chimera effects, and if the integration of the eye-region with the rest of the face required HSF/MSF information, then no advantage for blur chimeras relative to fully filtered images should be observed. Alternatively, if some of the information preserved in blur chimeras (such as coarse 3D shape cues) could be used in combination with the eye-region, then these stimuli should be recognised more accurately than fully blurred faces.

2.3.1 Method

2.3.1.1 Participants

Prior to data collection, the required sample size was calculated using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007), assuming a medium effect size for an independent-samples *t* test (difference between blur faces and chimera faces, Cohen's *d* = 0.5, power = .80, two-tailed α = .05). This power analysis revealed a minimum sample size of 64 participants per group. The effect size was assumed to be smaller than that generated by contrast chimeras (see Sormaz et al., 2013) due to the less detrimental effect of moderate low-pass filtering than negative contrast on recognition accuracy (Sandford, Sarker, & Bernier, 2018). A total of 191 undergraduate students were tested, 15 of which were excluded due to insufficient familiarity with the presented celebrity faces (less than 20 correct identifications in the unfiltered face condition, see below), or for not having followed the instructions outlined in the experiment. 176 participants (153 female, mean age = 19.4 years, *SD* = 1.2) were retained in the final sample (see Appendix A for a detailed breakdown of retained participant demographics divided by condition). Participants were divided pseudo-randomly into two groups, each consisting of 88 participants, resulting in an achieved power of .99 with the above parameter values. All participants provided written informed consent and were compensated with participant pool credit. The experiment was approved by the ethics committee of Durham University's Psychology department.

2.3.1.2 Stimuli

84 images, comprising of two different images of 42 celebrities (i.e. actors, politicians, musicians) were collected using Google Image search. Images were standardized using Adobe Photoshop CS6 (Version 13.0.1; www.adobe.com). Faces were cropped from backgrounds, converted to greyscale, and pasted onto a uniform grey background. Cropped faces were scaled to a standardized size of 228x342 pixels.

One image of each of the 42 celebrities was not manipulated further ('Unfiltered faces'). The second image was spatially low-pass filtered using FourierImage (2017 version; www.nasanen.info; low-pass Butterworth Filter, filter exponent: 5, Cut-off frequency: 7cpi) to create 'Blur faces'. In addition, 'Blur chimeras' of each celebrity's second image were created by fitting lemniscates with smoothed edges around the eyes and eyebrows of each face (Adobe Photoshop CS6; Refine Edge Tool, Smooth: 70, Feather: 4.5px, Shift Edge: 12%) and leaving the selected region unfiltered (akin to Gilad et al., 2009). Exemplars of the three image conditions are depicted in Figure 4.

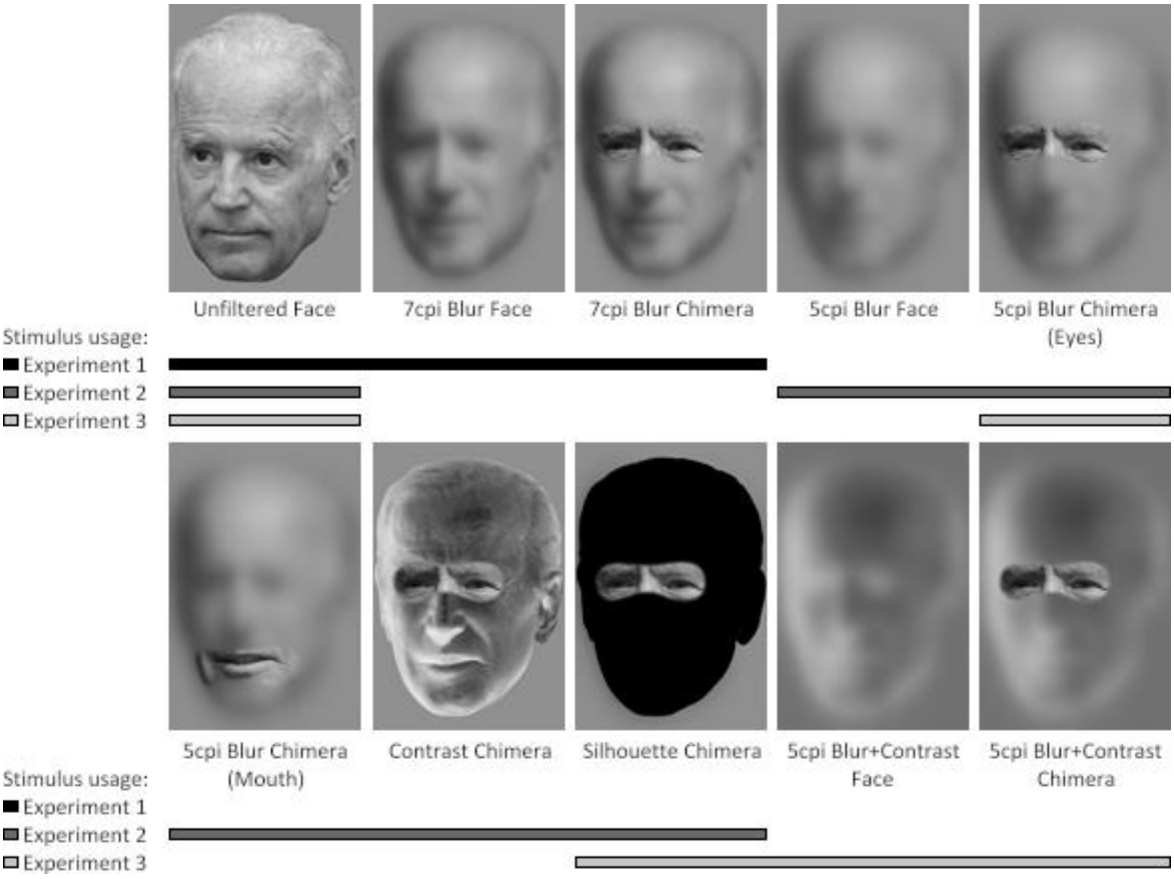

Figure 4. Examples of the ten manipulations used in Experiment 1-3 for one celebrity (U.S. President Joe Biden), with indicators of stimulus usage across experiments. Note that a different image was used for the unfiltered face stimulus of each identity.

2.3.1.3 Procedure

The experiment was programmed in PsychoPy (Version 2020.2.10; www.psychopy.org), and presented online via Pavlovia (www.pavlovia.org), allowing participants to take part using their personal computers. Participants were pseudo-randomly allocated to one of two image manipulation conditions, either featuring blur faces or blur chimeras.

The experiment began with a practice block featuring four faces from two celebrity identities not used elsewhere in the experiment (two unfiltered faces, and two in the participant's relevant image manipulation condition) to familiarize them with the task. For the first block of testing, participants then either viewed 40 trials featuring blur faces or blur chimeras, depending on their group, with each celebrity presented once in random order. Trials started with a white fixation cross in the centre of the screen (500ms), followed by a face in the same location. 500ms after stimulus onset, a text box and prompt appeared, requesting participants to indicate if they recognised the depicted individual. If participants did recognize the individual, they were asked to type in the depicted individual’s name, stage name, or relevant identity-specific information (e.g. a specific role they had played in a film). Else, they were prompted to press the ‘up arrow’ key to move on to the next trial. All participants then completed a second block featuring the previously unseen images of the same 40 celebrities in the unfiltered face condition presented in randomized order. Participants were again requested to identify each of the faces using the text box.

Participants were assumed to have recognized a face if they provided an accurate name or identity-specific information about the depicted individual. The proportion of correct target identification was calculated by dividing the number of correct responses in the unfiltered face condition by the number of correct responses in the blur face/chimera condition (see Appendix B for an example of coded participant responses). In a small number of instances, participants recognized a face in the blur face/chimera condition, but not in the unfiltered face condition. These were treated as recognition across both conditions. For statistical analysis, an independent samples *t*-test was conducted. Confidence intervals and bias-corrected effect size measures (d_{unb}; see Cumming, 2014) are reported.

The study design, hypotheses, and analysis plan for the experiments presented here were not preregistered. All data is publicly available on the Open Science Framework website (https://osf.io/cd4zv/). Celebrity faces are not made publicly available for copyright reasons, but examples (licensed under the Creative Commons Public Domain Mark 1.0 license) are given in Figure 4.

2.3.2 Results

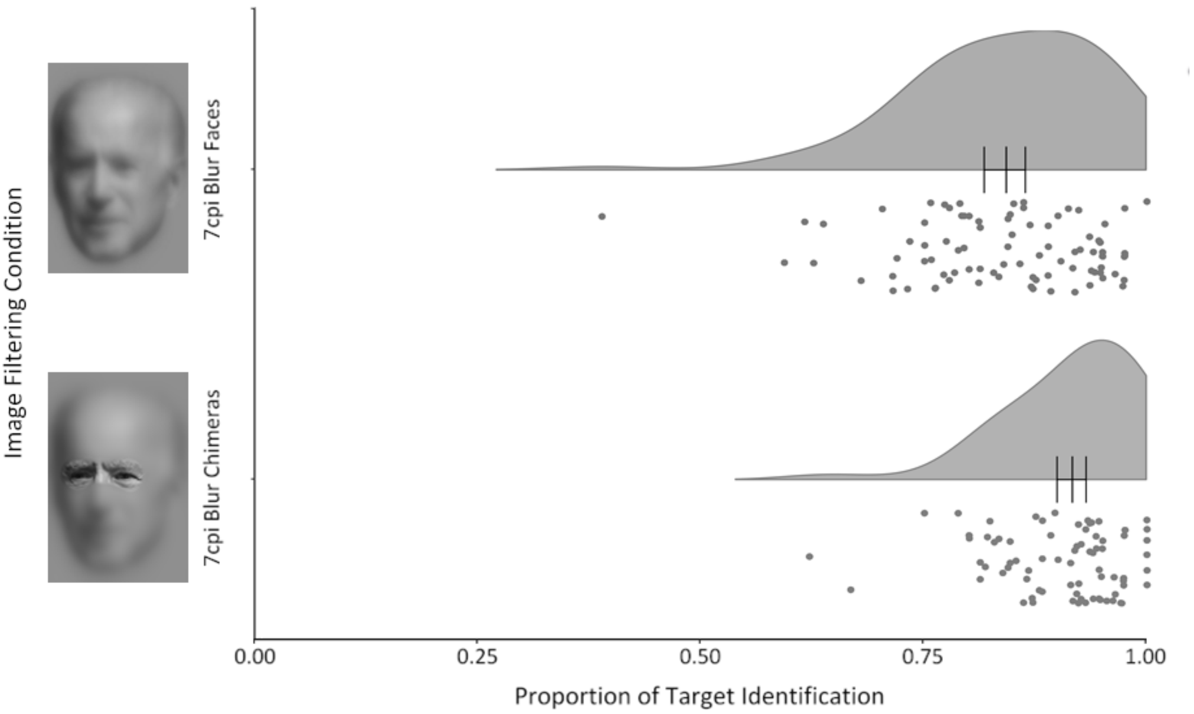

Figure 5. Mean (vertical lines) and individual (dots) proportions of correct target identification for the Blur Face and Chimera Face conditions. Error bars reflect 95% confidence intervals.

Results are depicted in Figure 5, and are listed in full in Appendix C. Levene's test demonstrated that variances between Blur Faces and Blur Chimeras were not equal, $F = 9.16$, $p = .003$. Accordingly, a t statistic not assuming homogeneity of variance was calculated. The independent samples t-test indicated that participants in the Blur Chimeras condition ($M = 0.92$, $SD = 0.08$) had a significantly higher proportion of correct target identifications than participants in the Blur Faces condition ($M = 0.84$, $SD = 0.11$), $t(156.24) = 5.31$, $p < .001$, $d_{\text{unb}} = .80$, 95% CI [0.50, 1.12].

2.3.3 Experiment 1 Discussion

Experiment 1 demonstrates that an unfiltered eye-region in an otherwise blurred face provides a significant enhancement in recognizability relative to fully blurred faces. This finding shows that the chimera advantage is not limited to contrast negation, but extends to other manipulations which on the one hand reduce recognizability but on the other hand leave ordinal contrast relationships intact. This chimera advantage therefore cannot be explained by the restoration of such relationships.

In addition, results from blur chimeras provide initial information regarding the usage of information from the filtered face-region. Previous studies have highlighted that detailed recognition cues are preserved in contrast negated faces and have presumed that the holistic integration of this information with the unmanipulated eye-region is responsible for the chimera advantage (Sormaz et al., 2013). By filtering HSF and MSF information, blurring eliminates recognition cues based on spatial detail (Vuilleumier et al., 2003; Loftus & Harley, 2005), however retains others, such as broad contrast information indicative of coarse 3D shape (Hayes, 1988; Hayes, Concetta, Morrone, & Burr, 1986). The recognition advantage for blur chimeras, as observed in Experiment 1, implies that this preserved information, in combination with an unmanipulated eye-region, facilitates recognition. Together with previous findings, the present results may suggest that an intact eye-region allows the holistic integration of a variety of cues from the manipulated face-region.

Before any firm conclusions can be drawn, however, a number of limitations need to be addressed. First, previous studies have indicated that isolated eyes, or positive eyes on dark silhouettes, are poorly recognized when compared to unfiltered faces (e.g. 42%/36% accuracy in Sormaz et al., 2013), but their recognition rate had not been established in comparison to the current experimental manipulations. It is therefore possible that the chimera advantage in Experiment 1 was driven by the unfiltered eye-region alone. Second, from Experiment 1 alone, the specificity of the observed effect to the eye-region is unclear. Establishing no significant recognition advantage from an unfiltered mouth-region in an otherwise blurred face would support the idea that the blur chimera advantage is indeed specific to the eyes (as found in contrast chimeras). Finally, previous studies suggest that moderate low-pass filtering is less deleterious to face recognition than contrast negation (e.g. Sandford et al., 2018). To directly compare blur and contrast chimeras, it would therefore be beneficial to examine both within experimental conditions that result in similar recognition rates. Experiment 2 was designed to resolve these limitations from our first experiment.

2.4 Experiment 2

In Experiment 2, we directly compared recognition performance for contrast and blur chimeras. We further examined whether a blur chimera advantage would still be observed with more severe low-pass filtering. Reducing the low-pass filter cut-off (resulting in more severe blurring) has been shown to incrementally decrease recognition accuracy (e.g. Parker & Costen, 1999), and it was therefore assumed that the use of a 5cpi filter would give a more comparable results to contrast negation. In addition to contrast chimeras, unfiltered eyes in facial silhouettes (silhouette chimeras) and mouth chimeras were examined to test both the holistic nature of the blur chimera effect and its specificity to the eye-region. If the blur chimera effect was driven by the holistic integration of the eye-region with coarse 3D shape information from the rest of the face, neither silhouette nor mouth chimeras should show clear recognition advantages over fully blurred faces.

2.4.1 Method

2.4.1.1 Participants

The required sample size was estimated based on the effect size observed in Experiment 1 using G*Power (Faul et al., 2007), assuming a large effect size for the difference between any two of the tested conditions (independent samples t-test, d = 0.8, power = .80, two-tailed α = .05). This revealed a required sample size of 24 participants per group. A total of 163 undergraduate students were tested, 33 of which were excluded due to insufficient familiarity with the presented celebrities faces (N < 20 correct identifications in the unfiltered face condition). 130 participants (116 female, mean age = 19.6 years, SD = 1.1), 26 per group, were retained in the final sample (see Appendix A for a detailed breakdown of retained participant demographics divided by condition). All participants provided written informed consent and were compensated with participant pool credit. The experiment was approved by the ethics committee of Durham University's Psychology department.

2.4.1.2 Stimuli

84 images, comprising of two different images of 42 celebrities not used in Experiment 1 were collected and standardized as described above. As before, one image per celebrity was not edited and used in the 'Unfiltered faces' condition. The second image was used for the five image manipulation conditions. 'Blur faces' and 'Blur chimeras (eyes)' were created analogously to Experiment 1, with the exception of using a filter cut-off frequency of 5cpi instead of 7cpi. 'Blur chimeras (mouth)' were created using the 5cpi blur chimera (eyes) images as a template and moving the unfiltered lemniscate from the eye-region to the mouth region of each face. This procedure was applied individually to each stimulus, so that mouth chimeras retained the same number of unfiltered pixels as eye chimeras. 'Contrast chimeras' and 'Silhouette chimeras' were created by replacing the 5cpi low-pass filtered image behind the unfiltered eye layer with an unfiltered face rendered in negative contrast or 0% luminance respectively. Exemplars are depicted in Figure 4.

2.4.1.3 Procedure

The experiment was conducted analogously to Experiment 1, the only exception being that for each group, one of the five novel image manipulation conditions was used in block 1.

2.4.2 Results

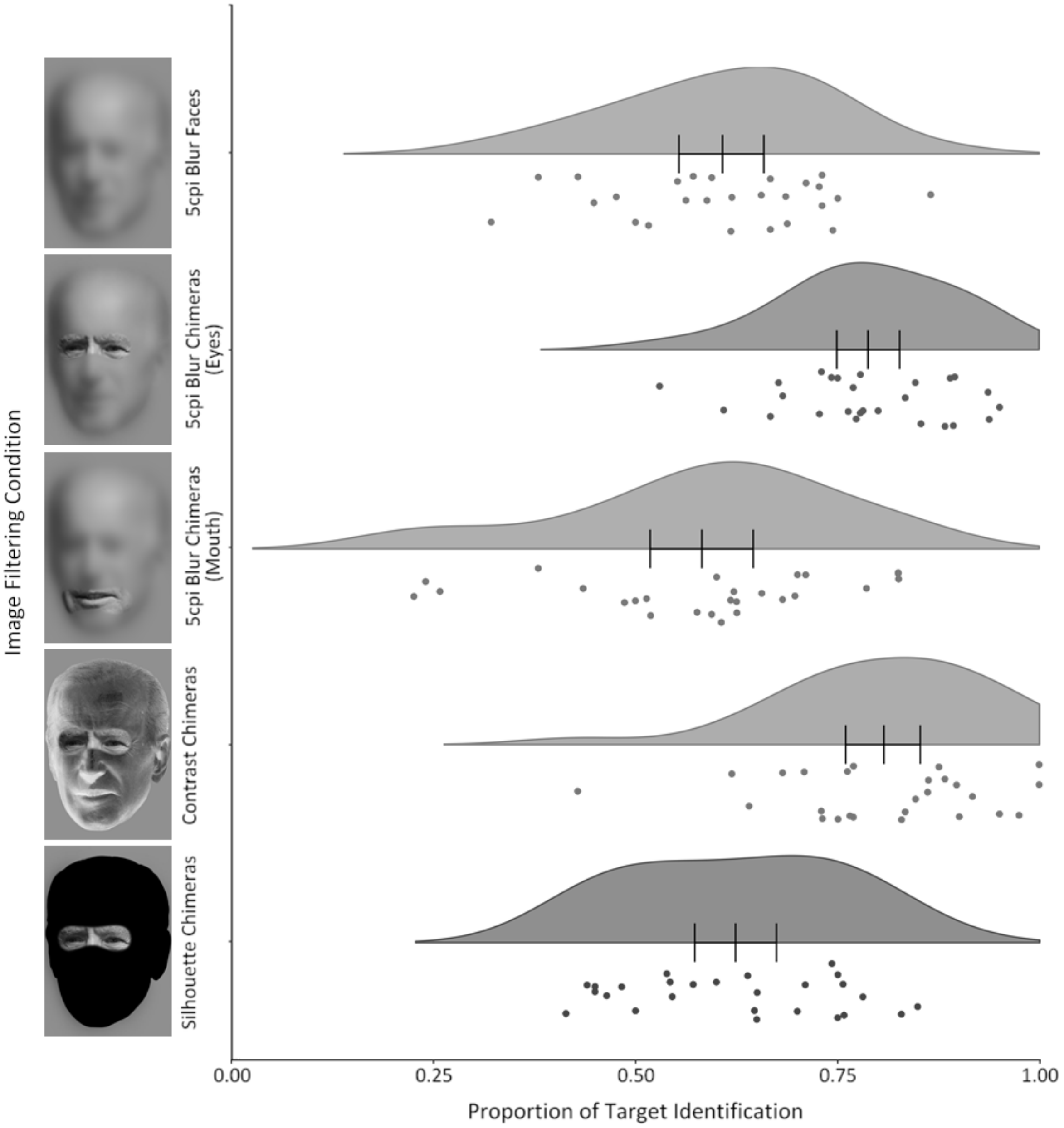

Figure 6. Mean (vertical lines) and individual (dots) proportions of correct target identification for five image manipulation conditions. Error bars reflect 95% confidence intervals.

Results are depicted in Figure 6 and are listed in full in Appendix D. A one-way independent-measures ANOVA revealed a significant difference in the proportion of correct target identifications between the five image manipulation conditions, $F(4,125) = 16.30$, $p < .001$, $\eta^2 = .37$. Follow-up comparisons (Table 1) yielded no significant difference between blur chimeras (eyes) ($M = 0.79$, $SD = 0.10$) and contrast chimeras ($M = 0.81$, $SD = 0.13$). Both of these groups had significantly higher proportions of correct target identifications than participants in the blur chimeras (mouth) condition ($M = 0.58$, $SD = 0.17$), the silhouette chimeras condition ($M = 0.62$, $SD = 0.13$), and the blur faces condition ($M = 0.61$, $SD = 0.13$), between which there was also no significant difference.

As one prediction for Experiment 2 was that blur and contrast chimeras would not differ in their recognition rates, an additional Bayesian independent-samples t-test was conducted. This test yielded moderate evidence for the null hypothesis, $BF_{01} = 3.01$ (error = 0.02%).

Table 1

Independent-samples comparisons of the effects of image filtering condition on proportion of correct target identification scores in Experiment 2.

Effect	M_{diff}	95% CI	*t*(50)	*p*	d_{unb}	95% CI
Blur faces vs. blur chimeras (eyes)	0.18	[0.11, 0.25]	5.52	<.001	1.51	[0.94, 2.21]
Blur faces vs. blur chimeras (mouth)	-0.03	[-0.11, 0.06]	-0.61	.904	-0.17	[-0.73, 0.38]
Blur faces vs. contrast chimeras	0.20	[0.13, 0.27]	5.54	<.001	1.51	[0.94, 2.22]
Blur faces vs. silhouette chimeras	0.02	[-0.06, 0.09]	0.44	.123	0.12	[-0.43, 0.68]
Blur chimeras (eyes) vs. blur chimeras (mouth)	-0.21	[-0.28, -0.13]	-5.26	<.001	-1.44	[-2.13, -0.87]
Blur chimeras (eyes) vs. contrast chimeras	0.02	[-0.05, -0.09]	0.60	.953	0.16	[-0.39, 0.73]
Blur chimeras (eyes) vs. silhouette chimeras	-0.16	[-0.23, -0.10]	-4.96	<.001	-1.36	[-2.04, -0.79]
Blur chimeras (mouth) vs. contrast chimeras	-0.23	[-0.31, -0.14]	-5.36	<.001	-1.46	[-2.16, -0.90]
Blur chimeras (mouth) vs. silhouette chimeras	0.04	[-0.04, 0.13]	0.99	.329	0.27	[-0.28, 0.84]
Contrast chimeras vs. silhouette chimeras	-0.18	[-0.26, -0.11]	-5.04	<.001	-1.38	[-2.06, -0.81]

2.4.3 Experiment 2 Discussion

Experiment 2 found that those participants who viewed blur chimeras (eyes) or contrast chimeras were considerably more accurate than participants in any other condition, which replicates our and others' previous results. These findings further suggest that the recognition advantage for blur chimeras is driven by a combination information from the unmanipulated eye-region and the manipulated rest of the face. Moreover, recognition accuracy between contrast and blur (eyes) chimeras did not differ, suggesting a comparable degree of holistic integration for the two conditions.

Experiment 2 yielded a clear blur chimera advantage, even though the filter cut-off frequency was lower than in Experiment 1. Information from the filtered parts of the face in 5cpi chimeras were still useful for face recognition, even though performance in the fully filtered condition was considerably worse than in Experiment 1. The stricter limitations on the availability of HSF and MSF information in Experiment 2 strengthen the interpretation that the blur chimera advantage does not arise through the integration of detailed recognition cues. Instead, coarse 3D shape information seems sufficient to generate the observed recognition advantage.

Experiment 2 further contains control conditions to exclude alternative interpretations of our results. First, mouth chimeras were recognized no better than fully blurred faces, suggesting that blur chimeras, like contrast chimeras, are specifically reliant on the eye-region. Second, the clear recognition advantage for blur chimeras over silhouette chimeras provides strong evidence that the recognition of blur chimeras does not simply reflect the use of detailed cues in the eye-region alone. Finally, contrast chimeras and 5cpi blur chimeras were recognized with highly similar accuracy. While previous research on contrast chimeras has suggested that the integrated information consists of detailed recognition cues in the manipulated part of the face, evidence of comparable processing for blur chimeras implies that spatially coarse information can be similarly advantageous.

We interpret these findings as suggesting that the face recognition system is to some extent flexible in adapting to the specific type of information that is available for holistic integration. In other words, spatially more fine-grained information seems to be used in contrast chimeras, while coarse 3D shape information appears to be used for blur chimeras. Alternatively, the same information could be used in both types of chimeras. This would suggest, however, that whatever cue is extracted from the manipulated part is neither affected by low-pass filtering nor contrast negation, and it should therefore still be available in an image that is both blurred and presented in negative contrast. Experiment 3 was designed to test these alternative explanations of the two chimera advantages.

2.5 Experiment 3

Experiment 3 aimed to identify whether the same or different cues in the manipulated face-regions are used to facilitate recognition across both blur and contrast chimeras. If the unmanipulated eye-region enabled the usage of the same type of cues across both chimera conditions, then the combination of the two image manipulations should keep this cue intact. Accordingly, we would expect a clear recognition advantage for combined blur and contrast chimeras, both over fully manipulated stimuli and eyes in dark silhouettes. If, however, different and complimentary cues in the manipulated face-region were used by blur and contrast chimeras, then we would expect recognition-relevant cues to be eliminated by combining the two image manipulations. Accordingly, combined blur and contrast chimeras should not yield a clear recognition advantage over silhouette chimeras, which provide cues from the eye-region alone.

2.5.1 Method

2.5.1.1 Participants

Based on the power analysis for Experiment 2, a total of 57 additional participants were tested. Of these, 5 were excluded due to insufficient familiarity with the celebrities (see Experiment 2). 52 participants (43 female, mean age = 20.2 years, *SD* = 1.3), 26 per group, were retained in the final sample (see Appendix A for a detailed breakdown of retained participant demographics divided by condition). All participants provided written informed consent and were compensated with participant pool credit. The experiment was approved by the ethics committee of Durham University's Psychology department.

2.5.1.2 Stimuli

Experiment 3 used the same stimulus set as Experiment 2. To create blur+contrast faces, images from the 5cpi blur face condition in Experiment 2 were contrast inverted. The same unfiltered eye lemniscates used in Experiment 2 were layered on top of these images to create blur+contrast chimeras'. Exemplars are depicted in Figure 4.

2.5.1.3 Procedure

Participants either saw blur+contrast faces or blur+contrast chimeras in block 1. Other than this change, the experiment was conducted analogously to Experiments 1 and 2. In addition to direct comparisons of the two conditions introduced in Experiment 3, blur+contrast faces and chimeras were compared to blur chimera (eyes) and silhouette chimera conditions from Experiment 2.

2.5.2 Results

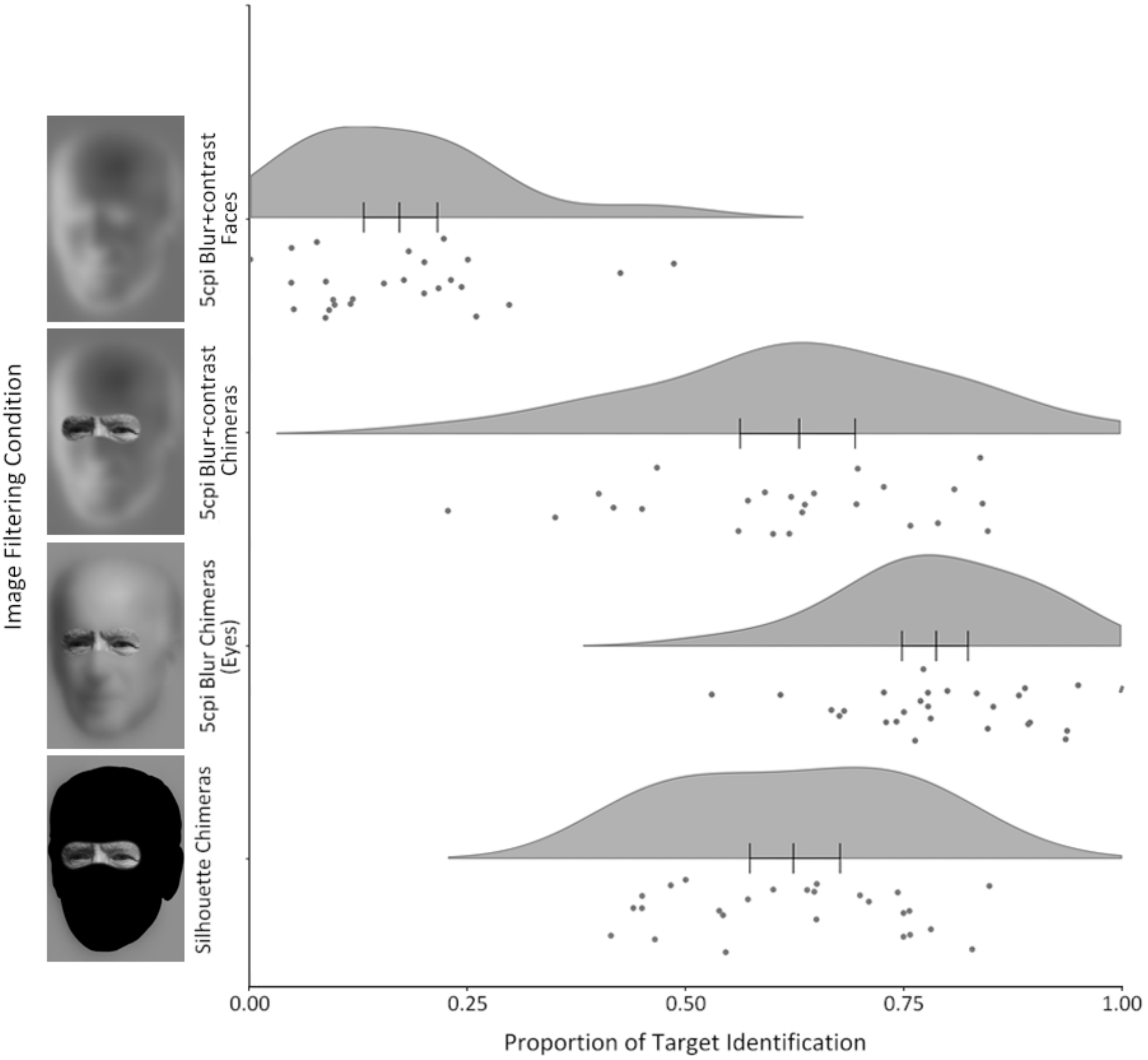

Figure 7. Mean (vertical lines) and individual (dots) proportions of correct target identification for five image manipulation conditions. Error bars reflect 95% confidence intervals.

Results are depicted in Figure 7 and are listed in full in Appendix E. A one-way independent-measures ANOVA revealed a significant effect, *F*(3,100) = 101.17, $p < .001$, $\eta^2 = .75$. Follow-up comparisons (see Table 2) indicated that participants in the blur+contrast face group (*M* = 0.17 , *SD* = 0.12) had significantly lower proportions of correct target identifications than those in the blur+contrast chimera (*M* = 0.63, *SD* = 0.18), blur chimera (eyes) (*M* = 0.79, *SD* = 0.10), and silhouette chimera (*M* = 0.62, *SD* = 0.13) groups. Proportions of correct target identifications in the blur+contrast chimera group were significantly lower than scores from participants in the blur chimera (eyes) group, while, critically, revealing no difference from the scores of participants in the silhouette chimera condition.

To more directly test the prediction of no difference between blur + contrast chimeras and silhouette chimeras (against the alternative hypothesis of better recognition in the former condition), an additional Bayesian independent-samples t-test was conducted, which revealed moderate evidence for the null hypothesis, $BF_{0+} = 3.21$ (error = 0.01%).

Table 2

Independent-samples comparisons of the effects of image filtering condition on proportion of target identification scores.

Effect	M_{diff}	95% CI	*t*(50)	*p*	d_{unb}	95% CI
Blur+contrast faces vs. blur+contrast chimeras	0.46	[0.38, 0.54]	11.13	<.001	3.04	[2.34, 4.00]
Blur+contrast faces vs. blur chimeras (eyes)	0.62	[0.56, 0.68]	20.25	<.001	5.53	[4.50, 7.01]
Blur+contrast faces vs. silhouette chimeras	0.45	[0.38, 0.52]	13.17	<.001	3.60	[2.83, 4.66]
Blur+contrast chimeras vs. blur chimeras (eyes)	0.16	[0.08, 0.24]	3.92	<.001	1.07	[0.52, 1.72]
Blur+contrast chimeras vs. silhouette chimeras	0.01	[-0.08, 0.09]	0.15	.88	0.04	[-0.51, 0.60]

2.5.3 Experiment 3 Discussion

While combined blur and contrast chimeras were recognized more accurately than combined fully blurred and contrast-negative faces, they yielded no advantage over silhouette chimeras. This finding suggests that a combination of blurring and contrast negation severely disrupted the integrational processes reflected in the recognition advantage for simple contrast and blur chimeras. It therefore appears that the face recognition system can flexibly make use of different and complimentary information from the manipulated part of the image to increase recognition performance in simple contrast and blur chimeras.

We note that it remains possible that the combination of the two image manipulations had an additive effect on the same singular cue, decreasing its utility to a level at which it was no longer available for holistic integration. However, given the considerable differences between the means by which blurring and contrast negation affect recognition cues, this possibility seems unlikely. By contrast, it appears more plausible that an unmanipulated eye-region allows integration of detailed fine-contrast and pigmentation cues in the case of contrast chimeras, whereas the available coarse 3D shape information is integrated in the case of blur chimeras.

2.6 General Discussion

What information in an image is used for familiar face recognition? While previous research on contrast chimeras has demonstrated a particularly important role of the eye-region, it has also shown that additional information from the rest of the face needs to be integrated for accurate and efficient face recognition. The present series of experiments provides novel evidence on how these integrational processes come into play. In three consecutive experiments, we tested face recognition using blur and contrast chimeras, and demonstrate that neither the availability of HSF/MSF information in the manipulated parts of the image nor the restoration of ordinal contrast information per se are essential for cue integration. Instead, the face recognition system appears to be able to flexibly use either fine-detailed pigmentation or more coarse 3D shape cues, depending on availability. These findings are discussed in more detail below.

First, and at some variance with previous suggestions (Gilad et al., 2009; Sormaz et al., 2013), the present experiments indicate that the re-establishment of ordinal contrast relationships is insufficient to explain all of the observed chimera advantages. The broad contrast relationship of lower luminance in the eye-region compared to its surroundings is clearly important to recognizing faces. This is evident from the recognition deficit caused by contrast negation (e.g. Galper, 1970) or lighting from below (e.g. Johnston et al., 1992), and the substantial reduction of these deficits by contrast chimeras (e.g. Gilad et al., 2009) and contrast inversion of faces lit from below (e.g. Liu et al., 1999). However, broad contrast patterns are preserved in LSF images (Hayes, 1988; Hayes et al. 1986), and ordinal contrast relationships are therefore maintained both in fully blurred faces and blur chimeras. The advantage of the latter over the former condition therefore suggests that restoration of typical ordinal contrast information is not necessary to elicit this chimera effect.

Relatedly, previous research has suggested that detailed contrast information and pigmentation are used as the primary cues for familiar face recognition (Bruce & Langton, 1994; Russell et al., 2006; Kaufmann & Schweinberger, 2012). At the same time, contrast negation impairs facial recognizability despite retaining spatial frequency information (Gilad et al., 2009). Rather than eliminating these detailed cues, contrast negation has been suggested to reduce access to them (Liu et al., 2000; Russell et al., 2006), which in turn would be restored by contrast chimeras (Gilad et al., 2009; Sormaz et al., 2013). Blurring, however, substantially reduces or eliminates HSF/MSF cues. Evidence of a recognition advantage for blur chimeras therefore clearly indicates that access to HSF/MSF information is not a necessary prerequisite for the effect. Instead, alternative cues must be extracted and integrated with the eye-region in these stimuli.

The present study did not directly explore the nature of these alternative cues, but coarse 3D shape information appears to be a viable candidate. While less precise in low-pass filtered images, preserved shading patterns have been shown to provide a recognisable approximation of 3D geometry and relations for objects (Hayes, 1988; Hayes et al., 1986). Moreover, coarse spatial information has been demonstrated to be integral to tasks such as facial detection (Goffaux & Rossion, 2006; Goffaux et al., 2005) and recognition of certain emotional expressions (e.g.

Vuilleumier et al., 2003). While research has emphasised the importance of pigmentation cues for familiar face recognition (e.g. Bruce & Langton, 1994; Russell & Sinha, 2007), 3D shape cues also contribute, and enable face recognition at above chance levels when presented in isolation (e.g. Bruce et al., 1991). While low-pass filtering eliminates the detailed edge and shading information of complex 3D shapes, our results from blur chimeras may suggest that detailed information from the eye-region can be used in combination with coarse 3D shape cues from the filtered face-region to allow for effective recognition.

However, and similar to the above discussion of HSF/MSF cues, the ability of the face recognition system to make use of 3D shape information for holistic integration does not mean that this type of information must be available in the manipulated part of the image. It appears more likely that different cues can be used in different circumstances. This idea was tested in our third experiment. We assumed that if the recognition advantage of blur and contrast chimeras relied on identical cues in the manipulated face-region, then these cues should be unaffected by both contrast negation and low-pass filtering. Accordingly, if the two manipulations were combined, it should still be possible to observe a chimera advantage. Critically, however, combined blur and contrast chimeras were not recognized better than silhouette chimeras, which suggests that any advantage over fully manipulated images was most probably related to cues from the eye-region itself rather than to the integration of cues from the manipulated face-region. We conclude that different and complementary cues are integrated from the manipulated face-regions of simple blur and contrast chimeras respectively, and that the face recognition system is able to use them flexibly based on availability.

Finally, we note that our findings caution the use of blurring manipulations to isolate particular features of a face. Using similar stimuli to our blur chimeras, a recent study by Mohr, Wang and Engell (2018) concluded that familiar face recognition can be achieved by feature-based processing of the eye-region, rather than holistic integration. Indications from the present study, however, suggest that coarse information from the filtered face-region is effectively used in conjunction with the eyes. Therefore, the alternative interpretation of integration of blurred information with the eye-region appears more plausible.

In conclusion, the present study provides evidence for the integration of the eye-region with other parts of the face during familiar face recognition. Importantly, it seems that different types of recognition cues can be used in different circumstances, dependent on their availability. While the manipulations tested here suggest that both coarse 3D shape information and detailed HSF/MSF cues can be used, this listing is not necessarily exhaustive. Instead, the present results contribute to our understanding of familiar face recognition by demonstrating the flexibility of the involved processes and, by inference, the richness of the underlying facial representations.

Chapter 3

Are unfiltered eyes informative enough to efficiently recognize a face?

Electrophysiological comparisons of chimera faces reveal inefficiency at different stages of recognition processing.

3.1 Abstract

High recognition accuracy for contrast chimeras – contrast positive eyes in an otherwise contrast negative face – has informed the hypothesis that internalized representations relevant for facial recognition are built around the eyes. However, event-related brain potentials elicited by contrast chimeras have revealed delayed, reduced N250r repetition priming compared to unfiltered faces (Wiese et al., 2019a), implying that efficient access to the eye-region alone was insufficient to effectively activate these representations. Evidence of more efficient repetition priming from blur chimeras – unfiltered eyes in an otherwise blurred face – (Quinn et al., 2021) has suggested that contrast chimeras' inefficiency is due to knock-on effects from earlier effortful face detection, indicated by an enhanced N170. Here, we tested this speculative claim by directly comparing blur and contrast chimeras. We hypothesized that if contrast chimeras' inefficient N250rs were due to knock-on effects, this should be reflected in an enhanced N170 and delayed, less potent N250r priming compared to blur chimeras and unfiltered faces. Participants were presented with 240 prime/target pairs of celebrity faces, as unfiltered faces, contrast chimeras, or blur chimeras. In half of the pairs, identity was repeated, while the other half were non-repeated.

Unfiltered pairs provided a typical prime N170, and an N250r demonstrating identity repetition priming. Blur chimeras elicited a comparable N170 and showed identity repetition priming across the same time windows as unfiltered faces. Comparatively, contrast chimeras demonstrated an enhanced, delayed N170, and reduced, delayed N250r production. We concluded that contrast chimeras inefficient N250r production was due to knock-on effects from earlier face detection, rather than the inability to activate representations relevant for recognition. While information in the eye-region was sufficient to elicit repetition priming with lower potency than unfiltered faces, indications of effortful processing for blur chimeras suggested that activating face representations is facilitated by detailed information from outside the eye-region.

3.2 Introduction

Humans' ability to recognize familiar faces remains robustly accurate across a wide range of viewing conditions (see Johnston & Edmonds, 2009; Young & Burton, 2017 for reviews). This ability does not extend to unfamiliar faces, which prove challenging to recognize beyond known images (see

Hancock et al., 2000; Burton & Jenkins, 2011 for reviews). Physiological evidence (e.g. Ellis et al. 1999) and double dissociations in neuropsychological cases (e.g. Malone et al., 1982) have established qualitative differences between the two, suggesting that familiarity fundamentally transforms the recognition process (Megreya & Burton, 2006). Behavioural (e.g. Dunn, Ritchie, Kemp, & White, 2019) and neurophysiological (e.g. Bentin & Deouell, 2000) evidence has illustrated that the early stages of detecting and structurally encoding a face are largely unaffected by familiarity. This appears logical, given that a face must be detected before it can be recognized or not. Accordingly, cognitive architecture models of recognition such as Bruce and Young (1986) place structural encoding, the process initiated by detecting a face, prior to recognition in the serial ordering of processing stages.

Models have suggested that the accuracy of familiar face recognition relies on the matching of a detected face to a robust facial representation in memory. These representations, termed 'face recognition units' (FRUs; Bruce & Young, 1986) were hypothesized to be constructed from repeated exposures to the natural within-person variability of an individual face (Jenkins et al., 2011). Increasing experience of the variable aspects of a face due to different environments allowing for more effective isolation of the invariant aspects, constructing an increasingly robust FRU (Burton, et al., 2005). The advantage provided by robust FRUs has been illustrated with faces learned from more varied images, which elicited superior recognition subsequently, even for novel images (e.g. Andrews, Jenkins, Cursiter, & Burton, 2015; Ritchie & Burton, 2017). When an FRU has been activated by a perceived familiar face, relevant semantic information can be retrieved, culminating with name recall (Burton & Bruce, 1992). Without the availability of a robust FRU, unfamiliar face recognition remains effortful and image-specific (Hancock et al., 2000). While FRUs effectively explain familiar face recognition's flexibility across within-person variability, they are not immune to disruption. Contrast negation – the reversal of luminance and hue – proves an exception to face recognition's typical resilience, significantly reducing recognition accuracy (e.g. Galper, 1970; Johnston et al., 1992; Kramer et al., 2017). A study by Kemp et al. (1996) highlighted that luminance inversion was largely responsible for this detriment, reducing recognition rates in isolation, while hue inversion had little effect. Contrast negation's ability to disrupt recognition for familiar faces suggests that its effects impair the use of cues necessary to effectively activate FRUs.

While the specific nature of these cues is still unclear, contemporary research has highlighted 3D shape and pigmentation (albedo, hue, and surface texture) information as having relevance to facial recognition (Russell et al., 2006). While 3D shape (e.g. Bruce et al., 1991) or pigmentation (e.g. Bruce & Langton, 1994) cues in isolation are sufficient to recognize faces at above-chance levels, experimental evidence has suggested that typically, greater reliance is placed upon pigmentation cues for recognition of familiar faces (e.g. Russell & Sinha, 2007; Hancock et al., 1996). Importantly, contrast negative images preserve the same spectral and geometric information as their positive counterparts (Gilad et al., 2009), and therefore its deleterious effect does not derive from elimination of 3D shape or pigmentation cues. Rather, contrast negation has been suggested to impair access to recognition cues through the inversion of typical luminance patterns (Kemp et al., 1996; Russel et al., 2006). Early studies assumed that the reversal of shadows primarily restricted the use of 3D shape cues (e.g. Kemp et al., 1996). However, a study by Liu et al. (2000) demonstrated that contrast negation still disrupted recognition when unaffected stereopsis cues to 3D shape were also provided, suggesting that the disruption of pigmentation is more relevant to the reduction of recognition accuracy (Russel et al., 2006).

Due to the large quantity of detailed pigmentation cues in and around the eyes (see Itier & Batty, 2009 for review), disruption of the eye-region has been highlighted as being particularly salient towards the effects of negative contrast (e.g. Russell et al., 2006). Indeed, contrast inversion of the eyes alone is sufficient to cause a significant disruption to typical recognition processing (Fisher et al., 2016a). In addition to pigmentation cues, disruption of the ordinal contrast relationship of the eye-region with its surroundings has also been implicated as a critical element of contrast negation's effects. Due to the eyes' sunken position in the skull, the eye-region retains a stable darker luminance relative to its surroundings throughout most naturally occurring lighting and viewing conditions (Braje et al., 2000). The importance of this ordinal contrast to recognition is clearly demonstrated through its inversion by lighting a face from below, which significantly reduces recognition accuracy (Johnston et al., 1992). When typical ordinal contrast of the eye-region is restored, either through contrast negation of a below-lit face (e.g. Liu et al., 1999), or through the creation of a 'contrast chimera' via the addition of a positive eye-region to a contrast negated face (e.g. Gilad et al., 2009), recognition accuracy significantly increases. The increase to recognition accuracy caused by restoring this comparatively small region of the overall face to positive contrast suggests that inversion of this typically stable contrast relationship is significant in contrast negation's deleterious effect.

Given that rendering facial features other than the eyes in positive contrast has little effect on recognition rates (Sormaz et al., 2013) it might initially be assumed that the recognition advantage afforded to contrast chimeras is provided by restored use of recognition cues in the positive eye-region alone. The eyes are undeniably important to recognition: reliance on eye-region cues has been shown to enhance recognition accuracy (Royer et al., 2018), and an inability to effectively rely on them has been suggested to underly recognition deficits like prosopagnosia (Caldara et al., 2005). However, Sormaz et al. (2013) demonstrated that contrast chimeras are recognized significantly better than eye-regions in isolation or dark silhouettes. In addition, they also showed that this advantage is reliant on a matching identity between filtered and unfiltered face-regions. Both pieces of evidence suggested that the chimeric recognition advantage is reliant on holistic integration of cues from the filtered face-region. Based on these findings, Sormaz et al. (2013) proposed that the restoration of the eye-region's typical contrast relationship through positive contrast restored the utility of recognition cues in the filtered face area, typically inhibited by contrast negation. Evidence of the importance of the eyes and their surrounding contrast relationships from contrast chimeras has been influential in reinforcing contemporary theories that the eye-region is uniquely salient to the activation of FRUs, forming an anchor point around which they are built (e.g. Sormaz et al., 2013; Fisher et al., 2016a; 2016b; Bruce & Young, 2013, p. 269). While convincing, the credibility of this hypothesis relies heavily on evidence drawn from behavioural studies. Moreover, while recognition rates for chimeras are undoubtably high (91% - Gilad et al., 2009; 76% - Sormaz et al., 2014), they are less well recognized than unfiltered faces. These factors call into question if chimeras are processed in the same manner as unfiltered faces. Without evidence indicative of similar neurophysiological activity between the two, conclusions and theories drawn from the behavioural results of chimeras may not be applicable to real-world face recognition.

An electroencephalographic study by Wiese et al. (2019a) has questioned this exact issue. Their study demonstrated that familiar contrast chimeras did not reliably elicit an N250r, the event-related potential (ERP) assumed to index the activation of an FRU by a familiar face, which was only produced in a delayed time window when compared to a typical N250r, and with a smaller effect size (experiment 3). The N250r derives from the N250 – a negative amplitude ERP occurring 200ms-400ms post-stimulus presentation (Tanaka et al., 2006), which responds to faces, but not non-face objects, and exhibits a more negative amplitude for familiar faces (Gosling & Eimer, 2011). When identity-paired prime and target faces are presented in rapid succession, the amplitude of the repeated target N250 (N250r) is enhanced (Schweinberger et al., 1995; Schweinberger, Huddy, & Burton, 2004). Critically, the N250r is image-independent only for familiar faces, and can be elicited by two different images of the same identity (Schweinberger et al., 2002). This image-independent, identity-specific N250r is assumed to correlate with activation of the target FRU, facilitated by the initial FRU activation by the prime. The N250r therefore produces a reliable indicator of the efficient activation of an FRU which is sufficiently robust to recognize a face (see Schweinberger & Neumann, 2016 for review). Wiese et al., (2019a) concluded that the limited evidence of delayed, low-potency N250r identity repetition priming for contrast chimeras indicated inefficient FRU activation, providing counterevidence to the idea that the eye-region has a unique salience to activating FRUs, and instead indicating that other facial areas are of equal importance.

However, a recent study from Quinn et al. (2021) has shown that 'blur chimeras' – unfiltered eyes in an otherwise blurred face – are capable of eliciting a more efficient N250r than contrast chimeras. Evidence suggests that faces are optimally recognized at spatial frequencies between 8-16 cycles-per-image (cpi), integrating LSF, MSF, and HSF information (see Ruiz-Soler & Beltran, 2005 for review). Low-pass filtering (blurring) a face – limiting it to only LSF information below the 8cpi threshold – decreases recognition accuracy incrementally (e.g. Parker & Costen, 1999; Näsänen, 1999), until faces can no longer be reliably detected below around 2cpi (e.g. Hanso et al., 2010). Unlike contrast negation, blurring actively reduces the amount of spatial frequency information available in an image, through elimination of HSF and MSF by the 8cpi cut-off, leaving only coarse LSF information available for use. Because precise 3D shape and detailed pigmentation cues rely upon MSF and MSF information to be accurately perceived and encoded (Vuilleumier et al., 2003), it is unsurprising that elimination of these spatial frequencies leads to a significant recognition detriment. Although not directly compared, blur chimeras produced evidence which appeared to indicate more efficient, higher potency activation of FRUs than contrast chimeras. This greater efficacy suggested that the deficit in FRU activation for contrast chimeras may have been due to other factors than an inability to effectively activate FRUs from efficient access to cues in the eyes alone. A possible solution for the apparently disparate results between contrast and blur chimeras comes from comparison of a processing stage prior to FRU activation.

The N170 is a negative ERP appearing 130ms-200ms post-stimulus presentation. It responds to patterns resembling the standard layout of a face's internal features (so-called 'first-order configurations' ; Maurer et al., 2002) with a greater amplitude than other stimulus categories, including faces with scrambled featural alignment (Bentin et al., 1996). The N170 is unaffected by familiarity (Bentin & Deouell, 2000), and was therefore assumed to pre-empt the recognition stage of face processing. Based on these properties, the N170 has been assumed to index the detection of a face within the visual field, and the initiation of a structural encoding mechanism (Eimer, 2000; 2011). While Quinn et al. (2021) showed that blur chimeras elicited a statistically comparable N170 to unfiltered faces, the N170 generated by Wiese et al.'s (2019a) contrast chimeras were delayed and more negative in amplitude when compared to unfiltered faces, indicative of effortful, inefficient face detection processing (Sadeh & Yovel, 2010). Given the serial nature of recognition processing (Bruce & Young, 1986) earlier inefficiency may have knock-on effects into subsequent stages, an example being uncontrolled differences in facial images' luminance and contrast affecting the amplitude and latency of the P1 ERP, knocking-on to affect the N170 (Nakashima et al., 2008a;

2008b). As such, Wiese et al.'s (2019a) delayed N250r may not reflect the inability of contrast chimeras to effectively activate FRUs, but may result from inefficiencies in facial detection and structural encoding of a prime knocking-on to limit or delay FRU pre-activation, which in turn fails to significantly facilitate FRU re-activation for a target. Reinforcing this rationale, blur chimeras elicit typical N170s, indicative of efficient earlier processing. Without the restrictions of the knock-on effect suggested for contrast chimeras, blur chimeras appear capable of activating FRUs with more potent N250r ERPs than contrast chimeras, and with indications of less delay. Knock-on effects provide a plausible explanation for the apparent difference between chimeras' efficiency and potency at identity repetition priming. However, this explanation relies upon evidence of a significant difference in the efficiency of N170 amplitude and latency between contrast and blur chimeras, which is currently speculative, as no study to date has directly compared the two.

The present study aimed to rectify this by directly comparing the N170 and N250r ERPs elicited by contrast and blur chimeras in a within-subjects design, with the addition of an unfiltered face to establish how and if chimeras differed from typical recognition processing. In addition, we aimed to assess the reliability of the results produced by Wiese et al. (2019a) and Quinn et al. (2021), considered necessary to make a strong case for this argument. The novelty of blur chimeras means that there is little-to-no other research with which to indicate the reliability of Quinn et al.'s (2021) initial findings. While some studies have used similar stimuli, such as Mohr et al., (2018), the lack of information provided in their paper regarding the blurring spatial frequency used, and how the un-filtered eyes were incorporated into blurred stimuli, makes for unreliable comparability with results from Quinn et al.'s (2021) blur chimeras. Equally, research into the N250r produced by contrast chimeras is also largely limited to Wiese et al.'s (2019a) study. While the N170 ERP elicited by contrast chimeras has been more thoroughly examined, results have not been entirely consistent. Studies by Fisher et al. (2016b) and Gandhi, Suresh, and Sinha (2012) have both produced evidence that contrast chimeras can produce N170 ERPs with a comparable amplitude and latency to typical faces. While this may simply reflect stimulus-level differences between experimental methodology (see Fisher et al., 2016b), in making a case for knock-on effects influencing the production of an N250r, the reliability of an atypical N170 must first be clearly established.

Based on an assumed replication of the findings of Wiese et al. (2019a) and Quinn et al. (2021), we expected to show evidence of an N250r for unfiltered face targets, with blur chimera targets showing significant (or indicating a significant trend) N250r priming within the same time windows. Contrast chimera targets would be assumed to elicit delayed, less potent N250r ERPs. We also expected to find comparable amplitude and latency prime N170 ERPs for unfiltered faces and blur chimeras, but with contrast chimera primes indicating inefficient processing during face detection, with a significantly enhanced and delayed N170. If reliable evidence of these results was produced, this would indicate that the detriment to contrast chimera repetition priming was likely due to inefficiency at an earlier stage, causing limited and inefficient pre-activation of FRUs, thereby knocking-on to create ineffectual re-activation facilitation. If this reasoning for contrast chimera N250r inefficiency could be combined with clear evidence of efficient FRU activation for blur chimeras, then solid grounding would be provided to re-establish the hypothesis that FRUs are especially reliant on cues from the eye-region for activation.

3.3 Method

3.3.1 Participants

Based on replication of Wiese et al.'s (2019a) methodology, twenty-six Durham University undergraduate students were tested, two of whom were excluded due to insufficient familiarity with the selected unfiltered celebrity faces ($N < 20$ trials in the unfiltered face condition, see below). Accordingly, 24 participants (19 female, mean age = 19.8 years, $SD = 1.4$) were retained in the final sample. A modified Edinburgh Handedness Inventory (Oldfield, 1971) indicated that 23 of the participants reported dominant right-handedness, with one participant reporting dominant left-handedness (mean laterality quotient = 75.0, $SD = 30.3$; see Appendix F). All participants reported normal or corrected-to-normal vision, no known neurological disorders, no scalp wounds, and none currently took any psychoactive medications. All participants provided written informed consent. Participants were compensated with participant pool credit, and the experiment was approved by the ethics committee of the Durham University Psychology department.

3.3.2 Stimuli

252 images, comprising of six different images of 42 celebrities (e.g. actors, politicians, musicians) were collected using Google Image search (see Figure 8 for examples). Images were standardized using Adobe Photoshop CS6 (Version 13.0.1; www.adobe.com). Faces were cropped from backgrounds, converted to greyscale, and pasted onto a uniform grey background. Cropped faces were standardized to 190x285 pixels (corresponding to 5.1° x 8.0° visual angle at 75cm viewing distance) for prime stimuli, and 228x342 pixels (corresponding to 6.4° x 9.6° visual angle) for target stimuli.

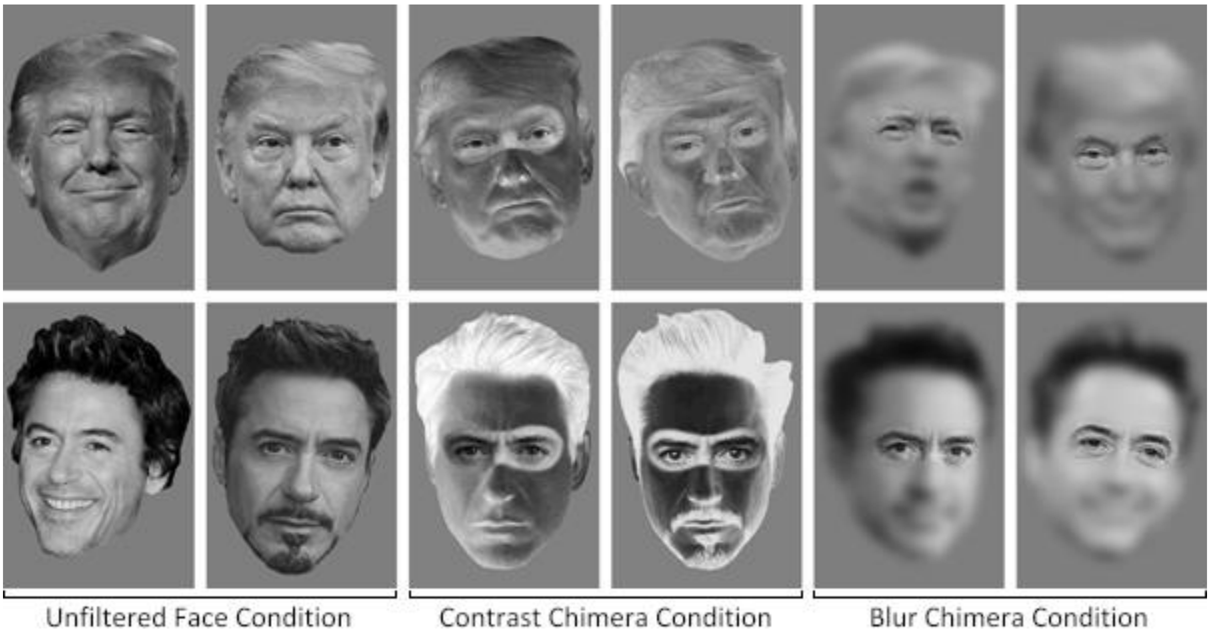

Figure 8. Examples of six standardized face stimuli in three possible image filtering conditions for two celebrity identities: Donald Trump (top row) and Robert Downey Jr. (bottom row).

‘Unfiltered face’ images were not edited further. ‘Contrast chimera’ images were first rendered in full negative contrast negative. Positive contrast in the eye-region was preserved by cropping a lemniscate shape containing the eyebrows and lateral canthi of both eyes from an unfiltered face image and overlaying it onto the matching contrast chimera face. The edge region between the unfiltered eye-region and negative contrast face was smoothed using the Adobe Photoshop CS6 ‘Refine Edge’ tool (Smooth: 70; Feather: 4.5px; Shift Edge: -12%). ‘Blur chimera’ images were spatially low-pass filtered using FourierImage (2017 version; www.nasanen.info; low-pass Gaussian Filter, filter exponent: 5, Cut-off frequency: 7cpi), over-layering the unfiltered face eye-region. For both contrast chimera and blur chimera images, the same edge-smoothed cut-out eye lemniscate was used (see Figure 8).

3.3.3 Procedure

Stimuli were combined into prime/target pairs so that prime filtering conditions (unfiltered faces, contrast chimeras and blur chimeras) were always followed by target images with matching filtering conditions. Prime and target images could either show different images of the same identity (repeated condition) or a pair of faces with differing identities (non-repeated Condition).

The experiment consisted of four experimental blocks, each composed of 60 trials. Each block featured 10 repeated pairs and 10 non-repeated pairs for each of the three image filtering conditions. Each celebrity appeared six times in prime face images, and six times in target face images (three times repeated, three times non-repeated). Each of the 12 possible (six prime and six target) different face images per identity was used so that no image was repeated or unused across the 240 trials. Assignment of specific images to conditions was counterbalanced with six versions across participants. Stimuli were presented using E-Prime (Version 2.0.10.92; www.pstnet.com).

Participants were seated in a sound-attenuated, electrically shielded chamber. Participants' heads were positioned in chin rest positioned 75cm opposite from a 34cmx27cm LCD monitor. This allowed for presentation of target images at a width of 6.4° visual angle, equal to that used by Näsänen (1999) to establish a consistent low-pass filter effect of 7cpi. Participants were instructed to attend to the screen at all times and remain as still as possible throughout the experiment to avoid unnecessary movement artefacts. Participants were provided with a four-key keypad to rate familiarity with target faces (*1 = completely unfamiliar; 2 = appears familiar, but with no identity-specific information; 3 = identity-specific information, but with no name information* (e.g. 'This is the American President')*; 4 = name information available* (e.g. 'This is Donald Trump'). Each trial began with a red fixation cross, displayed for 1000ms, followed by a prime face (500ms), a green fixation cross (500ms), and a target face (1000ms), after which the four familiarity response options appeared below the target faces (see Figure 9). Target and familiarity responses remained on screen until a keypress was registered.

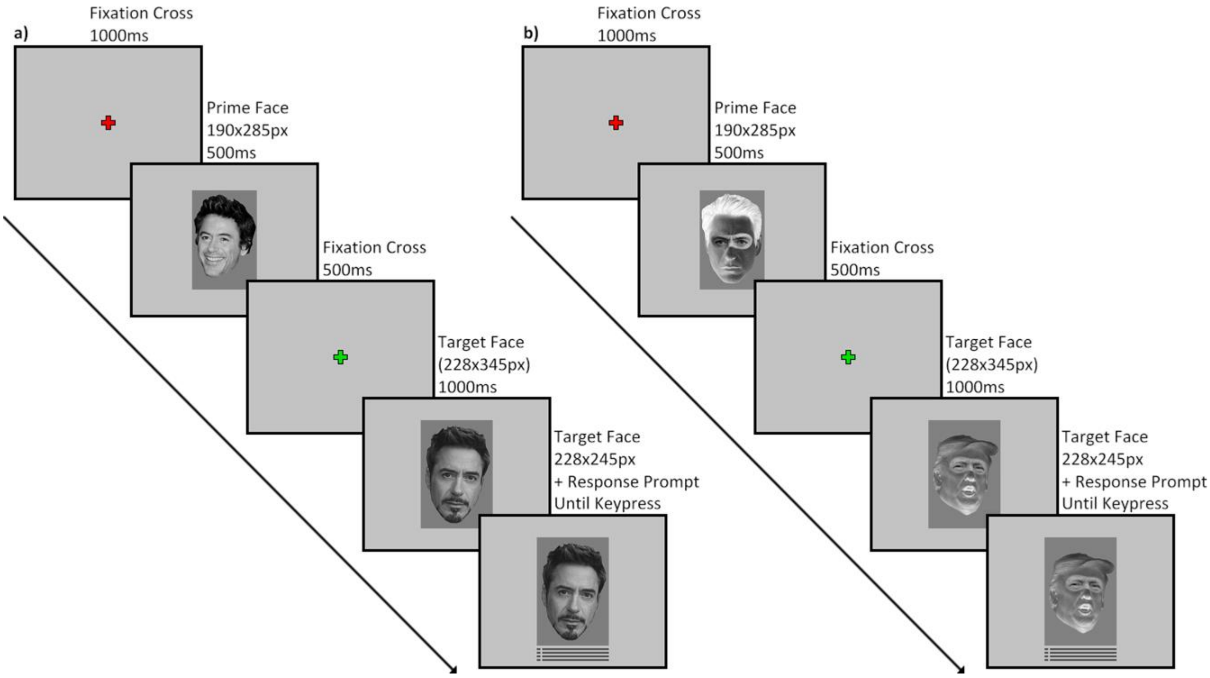

Figure 9. Illustration of two example trial stimulus sequences: a) Unfiltered face image filtering condition, repeated Trial; b) Contrast chimera image filtering condition, non-Repeated trial.

3.3.4 EEG Recording and Analysis

64-channel EEG was recorded from sintered Ag/AgCl electrodes mounted in a CW-1809 Waveguard cap (Eemagine; Berlin, Germany), using an ANT Neuro EEGo amp (ANT Neuro; Enschede, the Netherlands). EEG was recorded continuously, with a 1024 Hz sampling frequency from DC to 120 Hz. An electrode on the forehead (AFz) served as ground, and CPz was the recording reference. Recording sites corresponded to an extended 10-20 system (see Figure 10).

Blink artefacts were corrected using the algorithm implemented in BESA Research software (Version 6.3, Gräfelfing, Germany; Berg and Scherg, 1994). EEG was subsequently segmented from -200ms to 500ms relative to prime onset, and -200ms until 1000ms relative to target onset, with the first 200ms set as the baseline. Artefact rejection was conducted using an amplitude threshold of 100 µV, and a gradient criterion of 75 µV. For target stimuli, only trials in which participants indicated that they had recognized the face (rating familiarity as 3 or 4) were analysed.

Remaining trials were recalculated to the common average reference and averaged according to each experimental condition. Mean amplitudes from 140ms-180ms (N170), 200ms-300ms (N250r) and 300-400ms (late N250r) were analysed at occipito-temporal electrodes P9/P10 and TP9/TP10 using repeated-measures analyses of variance (ANOVAs). In addition, a priori hypotheses (indicated above) were further examined using paired-samples *t*-tests. Where the sphericity assumption was violated, a Greenhouse-Geisser correction was applied. Confidence intervals and effect size measures (d_{unb}; see Cumming, 2014) were reported for all ERP image filtering condition and repetition effects. A Bias-corrected Cohen's *d* was calculated using the average standard deviation, rather than the difference between sample standard deviations, as the denominator for all analyses.

The study design, hypotheses, and analysis plan for the experiments presented here were not preregistered. All data is publicly available on the Open Science Framework website (https://osf.io/bs3cq/).

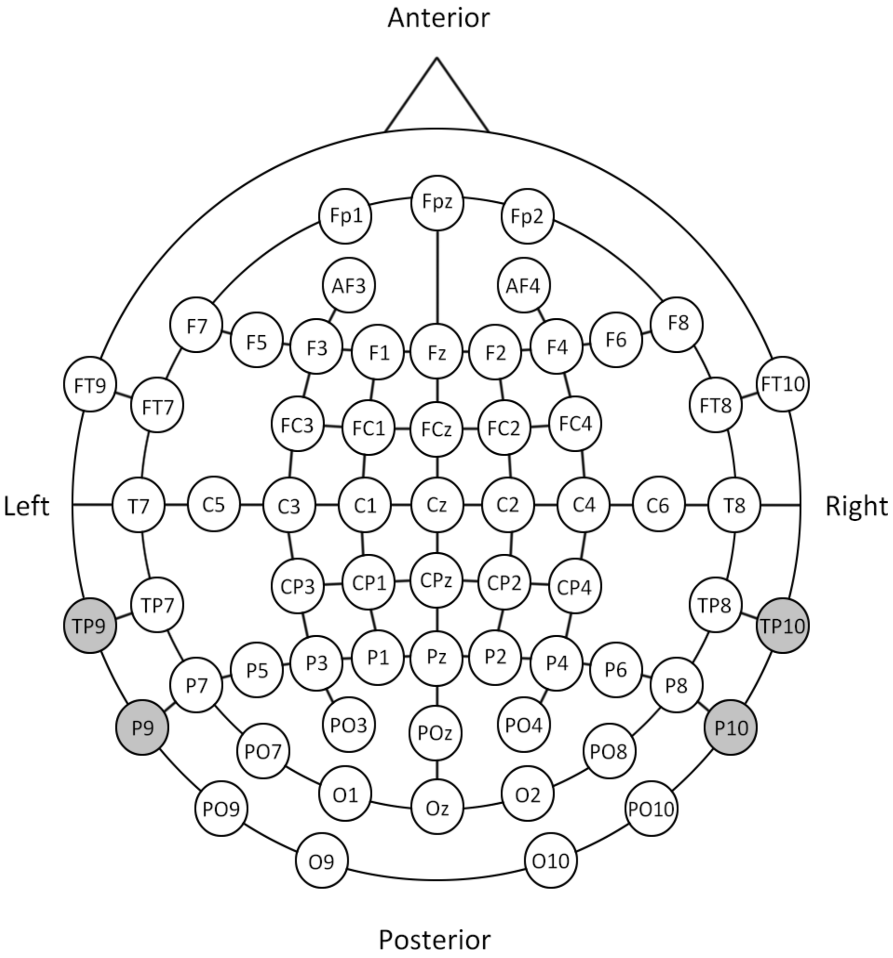

Figure 10. EEG electrode layout. Relevant recording electrodes for this experiment (P9/TP9 and P10/TP10) are shaded.

3.4 Results

3.4.1 Performance

Participants were assumed to have recognized a given target face if they indicated knowledge of identity-specific semantic information (response option 3), or the name of the depicted individual (response option 4). Mean proportions of target identification based on these familiarity ratings are reported in Table 3.

Table 3

Proportion of target identification (mean and standard deviation) across conditions.

	Unfiltered faces		Contrast chimeras		Blur chimeras	
Experiment	Repeated	Non-repeated	Repeated	Non-repeated	Repeated	Non-repeated
M	.92	.92	.87	.85	.90	.88
SD	.09	.08	.13	.13	.10	.11

A repeated-measures ANOVA with the within-subject factors of repetition and image filtering condition were conducted on the performance data.

A significant main effect for repetition, $F(1,23) = 5.02$, $p = .035$, $\eta^2p = .18$, indicated higher proportions of target identification for repeated targets ($M = 0.90$, $SD = 0.10$) than non-repeated targets ($M = 0.89$, $SD = 0.10$). There was also a significant main effect for image filtering, $F(1.44, 33.22) = 12.60$, $p < .001$, $\eta^2p = .98$. Post hoc paired-samples *t*-tests (See Table 4) revealed that Unfiltered Faces ($M = 0.92$, $SD = 0.08$) were recognised significantly more accurately than both Contrast Chimeras ($M = 0.86$, $SD = 0.13$) and Blur Chimeras ($M = 0.89$, $SD = 0.10$). Blur Chimeras were also recognized significantly more accurately than Contrast Chimeras. The ANOVA revealed no significant interaction, $F(2,46) = 0.97$, $p = .386$, $\eta^2p = .04$.

Table 4

Paired-samples comparisons of the effects of image filtering condition on performance

Effect	M_{diff}	95% CI	$t(23)$	p	d_{unb}	95% CI
Unfiltered faces vs. Contrast chimeras	0.06	[0.03, 0.09]	4.05	<.001	0.53	[0.31, 0.79]
Unfiltered faces vs. Blur chimeras	0.03	[0.01, 0.04]	3.66	.001	0.30	[0.16, 0.46]
Contrast chimeras vs. Blur chimeras	-0.03	[-0.05, -0.01]	-2.53	.019	-0.24	[-0.45, -0.07]

3.4.2 Event-related Potentials

Prime N170

A repeated-measures ANOVA with the within-subject factors hemisphere, site and image filtering condition on the prime N170 amplitudes (140ms-180ms; see Figure 11) revealed a significant main effect of image filtering, $F(2,46) = 10.38$, $p < .001$, $\eta^2p = .29$ (see Figure 11). Follow up paired-samples *t*-tests (see Table 5) indicated that both unfiltered faces ($M = -0.32$, $SD = 2.86$) and blur chimeras ($M = -0.73$, SD = 2.54) generated significantly less negative amplitudes than contrast chimeras ($M = -1.48$, $SD = 2.88$). There was no significant difference between the N170 amplitudes of unfiltered faces and blur chimeras.

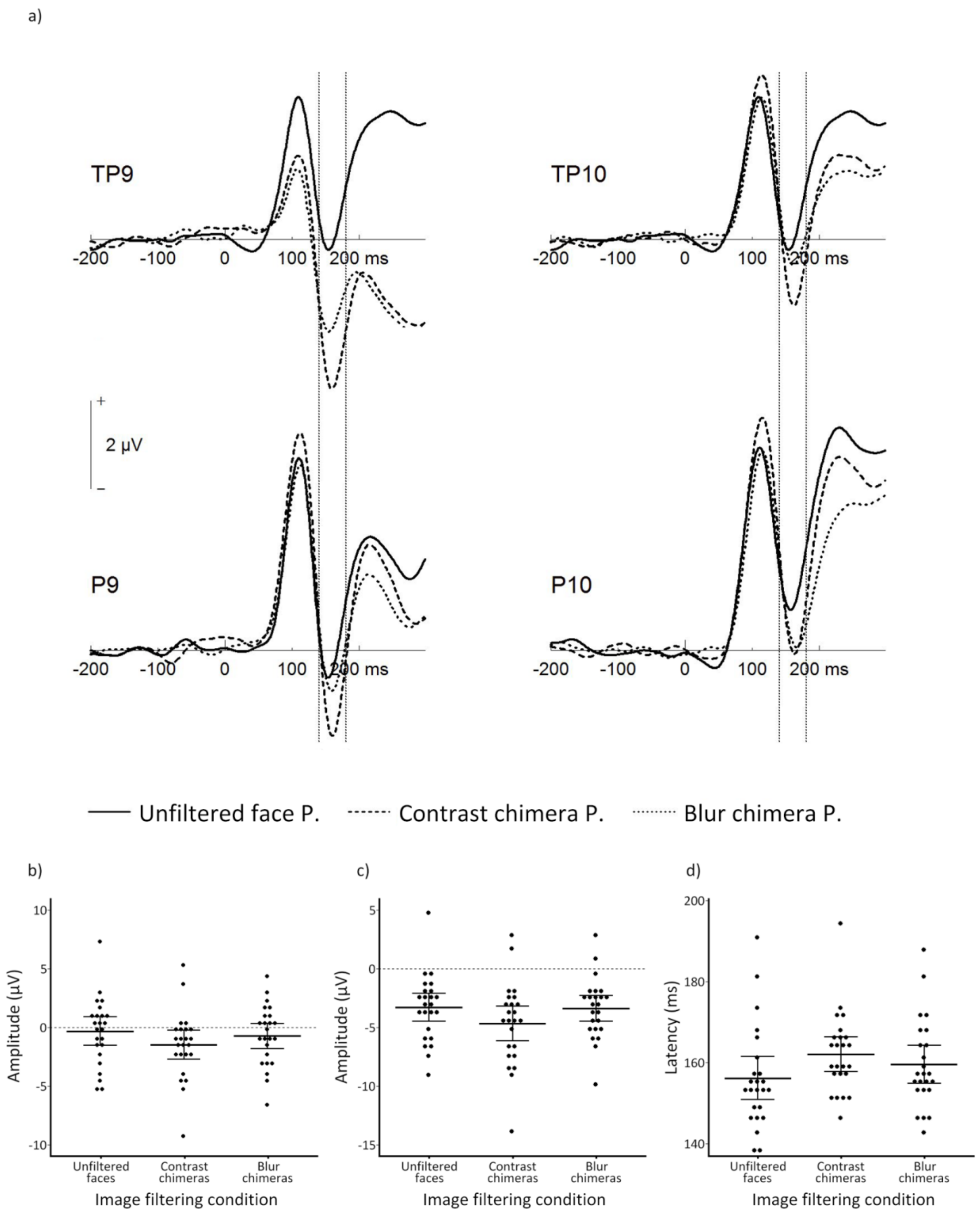

Figure 11. (a) Grand average ERPs for prime stimuli at electrodes P9/P10 and TP9/TP10. Vertical dotted lines indicate the 140ms-180ms N170 time window. (b) Mean (+/- 95% confidence intervals) and individual participants' prime N170 (140ms-180ms) amplitudes at electrodes P9/P10/TP9/TP10. (c) Mean (+/- 95% confidence intervals) and individual participants' prime peak-to-peak amplitude differences (N170 – P1) at electrodes P9/P10/TP9/TP10. (d) Mean (+/- 95% confidence intervals) and individual participants' prime N170 latency at TP9/TP10.

Table 5

Paired-samples comparisons of the effects of image filtering condition on the N170 amplitudes of prime and target faces (140ms-180ms)

ERP	Effect	M_{diff}	95% CI	*t*(23)	*p*	d_{unb}	95% CI
Prime N170 (140ms-180ms)							
	Unfiltered faces vs. Contrast chimeras	1.16 µV	[0.57, 1.76]	4.04	<.001	.40	[0.20, 0.64]
	Unfiltered faces vs. Blur chimeras	0.42 µV	[-0.08, 0.91]	1.75	.094	.15	[-0.02, 0.33]
	Contrast chimeras vs. Blur chimeras	-0.75 µV	[-1.26, -0.24]	-3.02	.006	-.27	[-0.47, -0.10]
P1 difference corrected prime N170 (N170 – P1)							
	Unfiltered faces vs. Contrast chimeras	1.37 µV	[0.72, 2.01]	4.37	<.001	.42	[0.24, 0.64]
	Unfiltered faces vs. Blur chimeras	0.10 µV	[-0.26, 0.45]	0.57	.574	.03	[-0.08, 0.16]
	Contrast chimeras vs. Blur chimeras	-1.27 µV	[-1.82, -0.72]	-4.77	<.001	-.40	[-0.58, -0.27]

As amplitude differences between image filtering conditions were evident in the P1 (80ms-129ms; see Figure 11), an additional analysis was carried out which corrected for N170 amplitudes for differences in P1 (mean N170 amplitude - mean P1 amplitude). A repeated-measures ANOVA yielded a significant main effect of image filtering, *F*(1.46,33.55) = 17.63, *p < .001*, *η²p* = .43 (see Figure 11). Follow up paired-samples *t*-tests (see Table 5) indicated that both unfiltered faces (*M* = -3.29, *SD* = 2.85) and blur chimeras (*M* = -3.39, SD = 2.63) generated a significantly smaller amplitude difference than contrast chimeras (*M* = -4.66, *SD* = 3.52). There was no significant difference between the amplitude difference for unfiltered faces and blur chimeras.

A repeated-measures ANOVA with the within-subjects factors hemisphere and image filtering condition on N170 latency at electrodes TP9 and TP10 revealed a significant effect of image filtering, *F*(2,46) = 11.98, *p* < .001, *η²p* = .99 (see Figure 11). Post hoc paired-samples *t*-tests (see Table 6) revealed that unfiltered faces (*M* = 156.19, *SD* = 12.70) peaked significantly earlier than contrast chimeras (*M* = 162.13, *SD* = 10.11) and blur chimeras (*M* = 159.58, *SD* = 11.00). Blur chimeras also peaked significantly earlier than contrast chimeras.

Table 6

Paired-samples comparisons of N170 latency for prime and target faces at TP9 and TP10.

ERP	Effect	M_{diff}	95% CI	*t*(23)	*p*	d_{unb}	95% CI
Prime N170							
	Unfiltered faces vs. Contrast chimeras	-5.94 ms	[-8.22, -3.65]	-5.38	<.001	-.51	[-0.74, -0.33]
	Unfiltered faces vs. Blur chimeras	-3.40 ms	[-6.13, -0.66]	-2.57	.017	-.28	[-0.52, -0.07]
	Contrast chimeras vs. Blur chimeras	2.54 ms	[0.03, 5.05]	2.09	.048	.24	[0.01, 0.48]

N250r

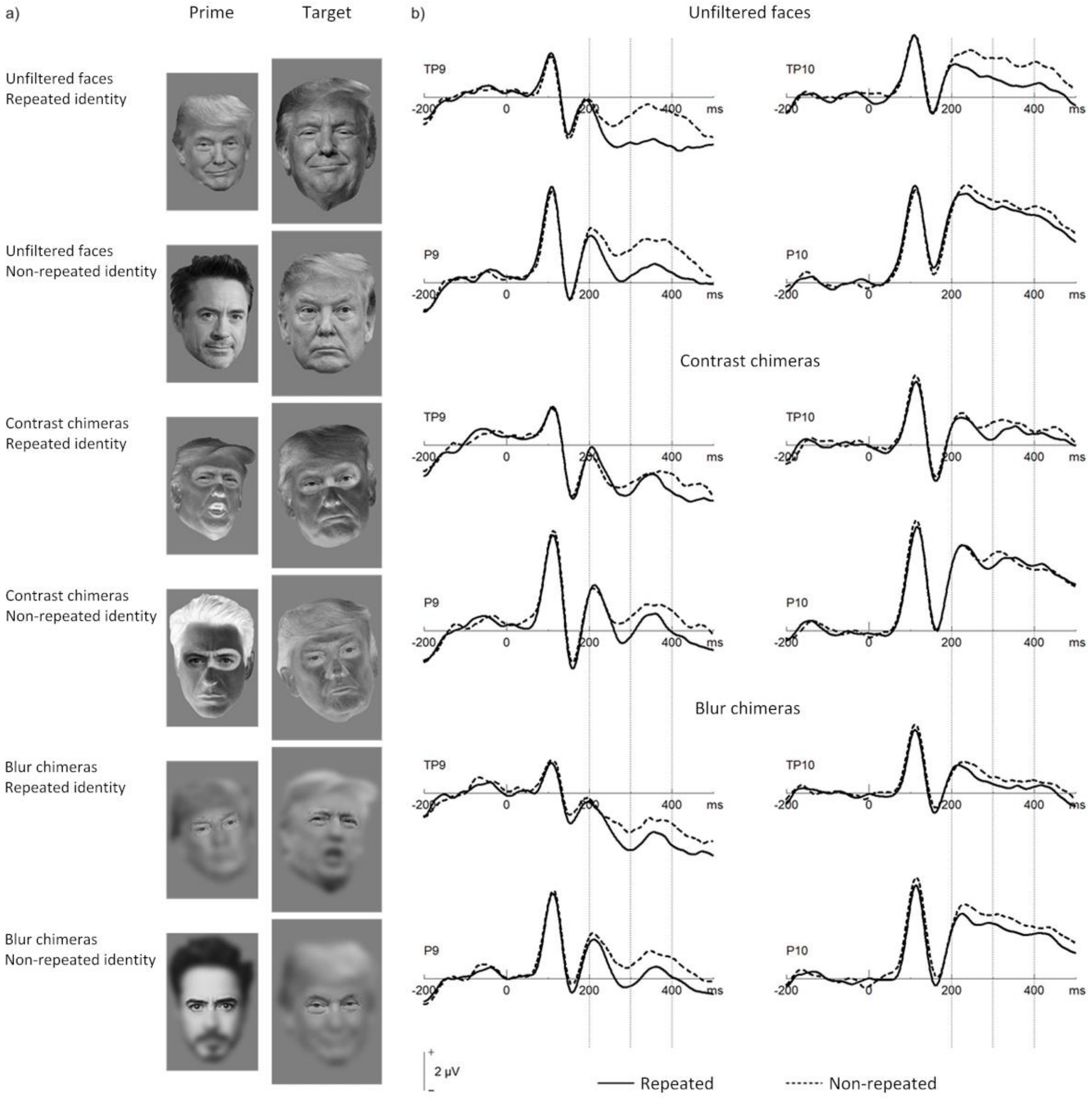

Figure 12. The effects of identity repetition priming across three image filtering conditions. (a) Illustration of the prime and target conditions with sample stimuli. (b) Grand average ERPs of target stimuli at electrodes P9/P10 and TP9/TP10. Vertical dotted lines indicate the 200ms-300ms and 300ms-400ms N250r time windows respectively.

A repeated-measures ANOVA in the 200ms-300ms time window with the within-subjects factors hemisphere, site, image filtering condition and repetition revealed a significant main effect of repetition, $F(1,23) = 15.17$, $p = .001$, $\eta^2p = .40$ (see Figure 12). Repeated targets ($M = 0.98$, $SD = 3.39$) generated significantly more negative amplitudes than non-repeated targets ($M = 1.46$, $SD = 3.54$). The ANOVA also revealed a significant main effect of image filtering, $F(2,46) = 4.46$, $p = .017$, $\eta^2p =$

.16. Post hoc paired-samples *t*-tests (see Table 7) revealed that unfiltered faces (*M* = 1.57 , *SD* = 3.82) generated significantly more positive amplitudes than both contrast chimeras (*M* = 1.09 , *SD* = 3.63) and blur chimeras (*M* = 0.99, *SD* = 3.01). There was no significant difference in amplitude between contrast chimeras and blur chimeras.

Table 7

Paired-samples comparisons of N250r in the 200ms-300ms and 300ms-400ms time windows

ERP	Effect	M_{diff}	95% CI	*t*(23)	*p*	d_{unb}	95% CI
N250r (200ms-300ms)							
	Unfiltered faces vs. Contrast chimeras	0.48 µV	[0.12, 0.84]	2.77	.011	.12	[0.07, 0.28]
	Unfiltered faces vs. Blur chimeras	0.58 µV	[0.09, 1.08]	2.43	.023	.13	[0.04, 0.23]
	Blur chimeras vs. Contrast chimeras	0.10 µV	[-0.32, 0.53]	0.50	.621	.03	[-0.07, 0.13]
N250r (300ms-400ms)							
	Unfiltered faces vs. Contrast chimeras	0.36 µV	[-0.04, 0.76]	1.86	.076	.32	[0.20, 0.47]
	Unfiltered faces vs. Blur chimeras	0.79 µV	[0.47, 1.11]	5.12	<.001	.14	[-0.00, 0.31]
	Blur chimeras vs. Contrast chimeras	0.43 µV	[0.06, 0.80]	2.40	.025	.19	[0.03, 0.36]

Although we did not observe a significant interaction effect between repetition and image filtering condition, *F*(2,46) = 2.65, *p* = .081, $\eta^2 p$ = .10, paired-samples *t*-tests were conducted to test the effects of repetition on the different image filtering conditions separately, in accordance with the study's a priori hypotheses (see Table 8 and Figure 13). For unfiltered faces, repeated targets (*M* = 1.18, *SD* = 3.87) elicited a significantly more negative amplitude than non-repeated targets (*M* = 1.96, *SD* = 3.83). For contrast chimeras, however, repeated (*M* = 1.01, *SD* = 3.61) and non-repeated targets (*M* = 1.18, *SD* = 3.70) did not elicit significantly different amplitudes. Critically, for blur chimeras, repeated targets (*M* = 0.74, *SD* = 2.82) elicited significantly more negative amplitudes than non-repeated targets (*M* = 1.24, *SD* = 3.28).

Table 8

Paired-samples comparisons of the N250r in the 200ms-300ms and 300ms-400ms time windows

ERP	Effect	M_{diff}	95% CI	*t*(23)	*p*	d_{unb}	95% CI
N250r (200ms-300ms)							
	Repetition effect, Unfiltered faces	-0.78 µV	[-1.17, -0.38]	-4.08	<.001	-.20	[-0.32, -0.10]
	Repetition effect, Contrast chimeras	-0.17 µV	[-0.53, 0.19]	-0.99	.332	-.05	[-0.14, 0.05]
	Repetition effect, Blur chimeras	-0.50 µV	[-0.96, -0.04]	-2.26	.033	-.16	[-0.31, -0.03]
N250r (300ms-400ms)							
	Repetition effect, Unfiltered faces	-1.15 µV	[-1.76, -0.55]	-3.93	.001	-.42	[-0.68, -0.21]
	Repetition effect, Contrast chimeras	-0.39 µV	[-0.75, -0.03]	-2.24	.035	-.17	[-0.33, -0.02]
	Repetition effect, Blur chimeras	-0.67 µV	[-1.12, -0.23]	-3.11	.005	-.29	[-0.50, -0.10]

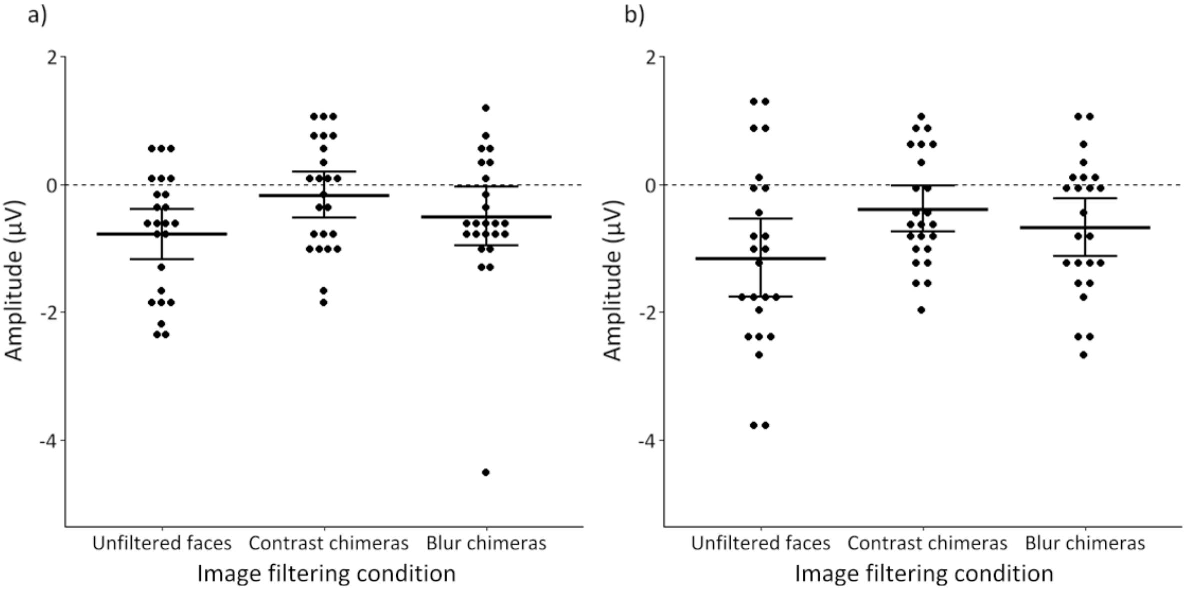

Figure 13. Mean and individual participants' priming effects (repeated - non-repeated) in the (a) 200ms-300ms time window and (b) 300ms-400ms time window, at electrodes P9/P10/TP9/TP10. Error bars reflect 95% Confidence Intervals.

A corresponding repeated-measures ANOVA in the 300ms-400ms time window revealed a significant main effect of repetition, *F*(1,23) = 32.72, *p* < .001, η^2p = .59. Repeated targets (*M* = 0.53, *SD* = 2.32) generated a significantly more negative amplitude than non-repeated targets (*M* = 1.27, *SD* = 2.35). The repeated-measures ANOVA also revealed a significant main effect of image filtering, *F*(2,46) = 10.04, *p* < .001, η^2p = .30. Post hoc paired-samples *t*-tests (see Table 7) revealed that both unfiltered faces (*M* = 1.28, *SD* = 2.58) and contrast chimeras (*M* = 0.92, *SD* = 2.28) generated significantly more positive amplitudes than blur chimeras (*M* = 0.50 , *SD* = 2.22). There was no significant difference in amplitude between unfiltered faces and contrast chimeras. No significant interaction effect between repetition and image filtering condition was observed, *F*(2,46) = 2.63, *p* = .083, $\eta^2 p$ = .10. As before, due to the study's a priori hypothesis, paired-samples *t*-tests were conducted to test the effects of repetition on the different image filtering conditions separately (see Table 8 and Figure 13). For unfiltered faces, repeated targets (*M* = 0.71, *SD* = 2.70) elicited significantly more negative amplitudes than non-repeated targets (*M* = 1.86, *SD* = 2.65). Similarly, both contrast chimeras (repeated targets: *M* = 0.73, *SD* = 2.29; non-repeated targets: *M* = 1.12, *SD* = 2.34) and blur chimeras (repeated targets: *M* = 0.16, *SD* = 2.25; non repeated-targets: *M* = 0.83, *SD* = 2.33) yielded significant repetition effects.

3.4.3 Correlations

To examine the possibility that chimeras' delayed elicitation of N170 ERPs was responsible for less potent N250r ERPs, a post-hoc examination of correlations between these two measures was conducted. The relationship between chimeras' respective N170 latency delay compared with unfiltered faces, and the size of their early (200ms-300ms) and late (300ms-400ms) N250r ERPs (non-repeated – repeated) was assessed for both chimeras. Based on the assumption that higher N170 latency delay would cause reduced N250r potency, a negative correlation was predicted between the two.

Pearson correlation tests showed that, for both blur and contrast chimeras, latency delay was not significantly correlated with N250r potency in either time window (*p* > .05 in all conditions; see Table 9).

Table 9

Correlations between N170 latency delay and N250r potency for contrast and blur chimeras.

Stimulus	ERP	N	95% CI	Pearson's *r*	*p*
Contrast Chimeras					
	Early N250r (200ms-300ms)	24	[-1.00, 0.43]	.10	.69
	Early N250r (300ms-400ms)	24	[-1.00, 0.44]	.11	.69
Blur Chimeras					
	Early N250r (200ms-300ms)	24	[-1.00, 0.51]	.21	.83
	Early N250r (300ms-400ms)	24	[-1.00, 0.42]	.08	.64

Note. All tests are one-tailed, predicting a negative correlation.

3.4.4 Exploratory Statistics

While the effects of hemisphere (left vs. right) and site (P vs. TP) were not considered as relevant to this study's a priori hypotheses, a table of their respective main effects and interaction effects with hypothesis-relevant variables are listed in Appendix G.

3.5 Discussion

The present study aimed to establish if chimeras – unfiltered eye-regions in otherwise manipulated faces – elicited similar event-related potentials (ERPs) to typical, unfiltered faces. Such results from chimeras would suggest that the robust cognitive representations of familiar faces – face recognition units (FRUs) – can be efficiently activated by unobstructed access to the eye-region, while cues in the surrounding face were limited. This aim was derived from previous studies, which demonstrated the differing ERP results of two different chimera varieties. Wiese et al. (2019a)'s contrast chimeras – featuring a negative contrast face-region – produced only a small, delayed N250r ERP, demonstrating reduced identity repetition priming relative to unfiltered faces (Schweinberger et al., 1995). This reduced repetition priming was concluded to indicate inefficient FRU pre-activation by contrast chimeras, not reflective of typical recognition processing. Quinn et al. (2021)'s blur chimeras – featuring a blurred face-region – indirectly appeared to elicit a more efficient, potent N250r ERP than contrast chimeras, despite lacking detailed HSF/MSF information in the filtered face-region, which should be important to recognition. We suggested that differences in earlier processes of face detection and structural encoding, as represented by the N170 ERP (Bentin et al., 1996), may underly the disparity between chimeras' N250r production. Without a within-study comparison of blur and contrast chimeras, however, this suggestion remained speculative.

This study aimed to address this lack of direct evidence through comparison of contrast and blur chimera ERPs in a within-subjects design. Based on prior results, it was hypothesized that blur and contrast chimeras would differ in the amplitude and latency of their N170 ERPs, with contrast chimeras eliciting significantly more enhanced and delayed peaks. Based on this inefficient processing, chimeras were also predicted to differ in their N250r ERPs, with contrast chimeras reduced N250r either delayed, or absent from the examined time windows. For both the N170 and N250r, blur chimeras were hypothesized to elicit ERPs representative of typical or close-to-typical recognition. The N170 and N250r ERP results produced here largely aligned with these hypotheses, determining the reliability of the findings produced by Wiese et al. (2019a) and Quinn et al. (2021).

Performance results suggested a recognition accuracy advantage of repeated-identities over non-repeated-identities, and unfiltered faces over blur chimeras, which in turn were recognized better than contrast chimeras. While differences between manipulations appeared to align with the N250r potency results discussed below, with larger N250r effect sizes equating with better recognition, we did not consider the priming paradigm used in the present experiment to effectively reflect recognition accuracy (see p. 17 of this dissertation for a similar discussion regarding Quinn et al.'s (2021) priming paradigm, replicated here; and the results of Experiments 1-3 for a more accurate indication of chimera recognition accuracy).

Unfiltered faces produced clear N250r ERPs, with a significantly more negative amplitude for targets which repeated the identity of primes in both the early (200ms-300ms) and late (300ms-400ms) time windows. Based on previous research (see Schweinberger & Neumann, 2016), this was assumed to reflect the initial efficient pre-activation of an identity-specific FRU facilitating subsequent reactivation of the same FRU, given the exclusion of pictorial priming by the present experiments multiple face-per-identity stimuli. As predicted, a significant N250r repetition effect was found for blur chimeras in both time windows, suggesting that blur chimeras activated FRUs with enough efficiency to allow facilitation through repetition. Contrast chimeras only elicited N250r repetition effects in the late time window, and with a smaller effect size than other conditions. Evidence of repetition priming indicated that contrast chimeras can activate FRUs, however the delay and smaller effect size suggested that FRU activation was inefficient when compared to unfiltered faces and blur chimeras.

This finding matched the results of Wiese et al. (2019a) in their comparable experiment 3, who found a similarly smaller, reduced N250r for contrast chimeras. Given previous studies' indications that fully blurred or negative contrast faces do not produce an N250r (Wiese et al., 2019a; Quinn et al., 2021), the present study's chimeras provided evidence that unobstructed access to the eyes in an otherwise manipulated face is sufficient to activate FRUs with enough efficiency for repetition priming. An efficiency disadvantage is evident for contrast chimeras, however, and it is therefore critical to assess the reason for this before a convincing case for efficient chimera FRU activation can be established. The identical eye-region used across both chimeras clearly demonstrates that differences in utilizing manipulated information underlie this processing disparity. The critical question, therefore, is whether this difference between blurred and negative contrast information negatively influences FRU activation directly, or if this detriment is resultant from inefficiency at an earlier processing stage.

Given the serial nature of face recognition, from structural encoding to name recall (Bruce and Young, 1986), inefficient processing at an earlier stage can have knock-on disruptive effects onto subsequent stages (e.g. Nakashima et al., 2008a). Based on the results of previous blur and contrast chimera studies, the present study hypothesized that inefficiencies in detection of the face in the visual field or structural encoding may have knocked-on to cause inefficient FRU matching for contrast chimeras. Comparison of prime N170 ERPs – associated with face detection and the initiation of structural encoding prior to recognition (Eimer, 2000; 2011) – in the present study supported this hypothesis. Contrast chimeras elicited significantly larger and delayed prime N170 ERPs than other conditions, even when amplitude was corrected for low-level image property differences at P1. Enhanced and delayed N170 ERPs have been associated with inefficient processing, with increased amplitude assumed to reflect the additional neuronal recruitment required to process a facial stimulus which deviates from a typical template (Sadeh & Yovel, 2010), such as when a face is depicted upside down (e.g. Jemel et al., 1999).

Issues in detecting a face-like pattern within a contrast chimera provide a potential explanation for this inefficient processing. The N170 responds to patterns resembling the alignment of internal facial features (first-order configurations; Maurer et al., 2002), rather than requiring detailed facial representations, evident from responses to simplified faces such as emoticons (Churches, Nicholls, Thiessen, Kohler, & Keage, 2014). However, a study by Paras & Webster (2013) has indicated that the N170 is not elicited by simplified patches of dark contrast corresponding to the eye-region alone. Given contrast negation's established effect on inhibiting recognition-relevant cues (Johnston et al., 1992; Russell et al., 2006), contrast chimeras' inverted nose and mouth impairs the utility of two typically stable dark contrast cues by which first-order configurations remain detectable across multiple lighting, angle and distance conditions (Sinha, 2002). Contrast chimeras may therefore be initially detected as isolated eyes rather than full faces. Isolated eyes have also been shown to elicit an enhanced, delayed N170 (e.g. Bentin et al., 1996), suggested to be due to lack of inhibition of eye detection neurons by face detection neurons which normally work in tandem (Itier & Batty, 2009). As chimeras are known to undergo subsequent recognition processing as holistic faces (Sormaz et al., 2013), if initially detected as eyes, the delay and inefficiency in processing likely reflects the additional effort required to decrypt the atypical cues necessary to integrate and encode contrast negated information into a holistic whole (Rossion et al., 1999; Fisher et al., 2016a).

Reinforcing this hypothesis, blur chimeras, featuring typically shaded first-order configurations, generated less delayed, typical amplitude N170s, suggesting full-face detection. Unexpectedly, however, despite the N170 peaking significantly earlier relative to contrast chimeras, this peak was significantly delayed compared to unfiltered faces. This delay may have been due to the averaging of luminance and contrast information causing low-level image differences, reflected in an abnormal P1 ERP (Tanskanen, Näsänen, Montex, Päällysaho, & Hari, 2005; Tobimatsu & Celesia, 2006). Knock-on effects have been evidenced to occur from as early as P1 (e.g. Kendall et al., 2016), and their control has been cautioned in other studies examining spatial frequency in face recognition for this reason (e.g. Nakashima et al., 2008a). While differences in P1 amplitude were controlled for in the present study, differences in latency were not considered. Given that an N250r within the early time window was produced for blur chimeras, this small delay in early processing stages can be assumed not to have affected subsequent ERPs to a noticeable degree. Furthermore, examination of correlations between blur chimera N170 latency and N250r potency indicated no notable relationship between the two, further suggesting that this latency increase above unfiltered faces did not substantially affect subsequent FRU activation.

While the contrast chimera N170 of this study successfully indicates the reliability of the results found by Wiese et al. (2019a), it is noteworthy that other studies have indicated a comparable N170 amplitude between contrast chimeras and unfiltered faces (e.g. Fisher et al., 2016b; Gandhi et al., 2012) . An explanation for this disparity is deducible from a study by Fisher et al. (2016b) which investigated the role of gaze location on the N170 produced by negative contrast faces. They noted that if gaze was fixated on the eye-region, typical N170 ERPs were produced by contrast chimeras. If gaze was fixated on the lower face, contrast chimera N170 ERPs were enhanced and delayed. As hypothesized here, this was taken to reflect disruption in the eye-region's integration with cues from the filtered face-region. Critically, based on a replication of Wiese et al.'s (2019a) methodology, the present study used face-centralized fixation crosses. Given the ambient faces used, the positioning of these relative to the eyes was variable, however, can be estimated to have fixated gaze on the centre-point of the face – typically below the eyes. While several differences exist between Fisher et al.'s (2016b) study and the chimeras used in the current experiment – most notably their exclusion of external features (e.g. ears, hair) and non-ambient faces – this offers a potential explanation of the differences in N170 amplitudes found for contrast chimeras between our own and previous studies. More importantly, the accuracy of this explanation is verifiable in future research via replication of the present experiment with eye-centred fixation crosses. If Fisher et al.'s (2016b) claim can be validated, then this also offers a means to address the present study's hypothesis that a contrast chimera, free from knock-on effects, should produce a typical N250r, demonstrating efficient FRU priming.

Contrary to Wiese et al.'s (2019a) conclusions, the evidence presented here suggests a unique importance of the eye-region to activating FRUs. The inefficient, effortful prime N170 elicited by contrast chimeras provides evidence of a potential knock-on inefficiency, that we suggest is responsible for delaying and reducing FRU priming effects, reflected in a delayed, smaller effect size N250r. Comparing these with blur chimera's efficient prime N170 and timely N250r, there is solid grounds for reasoning that contrast chimeras would also produce similarly efficient FRU activation if the N170 were controlled to a typical level. While the present study does not offer direct evidence to support this supposition, fixating gaze on the eyes potentially provides a means to validate this hypothesis. It is currently unclear, however, if the effect demonstrated by Fisher et al.'s (2016b) highly controlled stimuli are replicable in more naturalistic, ambient faces, as used in the present study, which is of critical importance in relating this finding to relating findings drawn from chimeras to real-world processing.

While blur chimeras (and theoretically contrast chimeras) are therefore indicated to activate FRUs with sufficient efficiency to meet the threshold needed to elicit significant repetition priming ERP correlate, it would be incorrect to assume that this reflects typical processing potency and efficiency. For both chimeras, the effect size of repetition priming was smaller than for typical faces, clearly indicating that access to the typically observable range of luminance and/or HSF/MSF information in a face contributes substantially to the potency of FRU pre- and re-activation. This appears to suggest that while the eyes may be the predominantly salient feature for FRU activation, the face outside of the eye-region also contributes to the pre- and re-activation of FRUs. Results from a Pearson correlation test indicated that N170 latency delay was not significantly correlated with the reduction in size of N250r production for either chimera. As this experiment was not designed to effectively assess correlations, this may simply be the result of the small sample size obscuring a small but significant correlation. However, this result can be considered to indicate that a delay in initially detecting a face (or – in the case of contrast chimeras, we propose, detecting the eyes) is not the predominant factor in either chimeras' reduction of FRU activation potency. Based on this lack of correlation, it seems more likely that inefficiency with subsequent structural encoding (i.e. overcoming initial eye detection and encoding contrast negated information into a holistic whole) for contrast chimeras is responsible for their priming strength detriment, rather than a delay in initial face detection. For blur chimeras, our results suggest that lack of potency in FRU activation was not related to processes correlated with the N170, but arose from the increased cognitive effort required to match a blur chimera to an FRU.

Despite demonstrating significant repetition priming effects across both time windows, the target N250 for blur chimeras was elicited at a significantly more negative amplitude than the target N250 for typical faces. As such, this is likely to also reflect the recruitment of additional neurons, and therefore suggests increased effort in matching a blur chimera to an FRU (Sadeh & Yovel, 2010).This effortful processing may be seen to reflect to the artificiality of blur chimeras as a stimulus, rendering them unlikely to be encountered in real life. Research into other-race faces (e.g. Wiese, Kaufmann, & Schweinberger, 2014), has suggested that limitations in perceptual expertise increases the neural demands for identity-specific processing (Herzmann, 2016). This seems unlikely, however, given that a target N250 with a comparable amplitude to unfiltered faces was produced by contrast chimeras in the later time window, despite being an equally (if not more) artificial stimulus. Alternately, while amplitude and latency are assumed to represent different elements of inefficient processing (Fisher et al., 2016a), there is also the possibility that high amplitude FRU activation resulted from delayed face detection, which was evident across both chimeric conditions. This possibility was also considered somewhat dubious, as FRU activation for blur chimeras did not appear to be delayed, although we acknowledge that the use of time-windows rather than comparison of target N250 peak latency was not an accurate means to assess differences in this measure. Furthermore, no significant correlations were found between N170 latency and N250r potency for blur chimeras, making this possibility increasingly unlikely. We therefore suggest that the decreased potency is more likely to simply reflect that the more limited information available in chimeras requires higher-effort processing to activate an FRU. If so, it appears that MSF/HSF information from the region of the face external to the eyes does contribute to overall FRU activation, and should not be considered irrelevant. This suggestion appears to be supported by the present study's contrast chimeras, which produced an (albeit delayed) target N250 with comparable amplitude to typical faces. Notably, contrast negation does not eliminate the same detailed recognition cues from an image as blur chimeras (Gilad et al., 2009), instead impairing their usage. Given that the addition of a positive eye-region has been suggested to restore utility to these impaired cues in the filtered face-region (Sormaz et al., 2013), this suggests that the majority of fully detailed cues can be used, thereby allowing lower-effort FRU matching than blur chimeras.

In addition to the aforementioned means to examine the effects of a controlled N170 on contrast chimera N250 ERPs, further research should seek to specify the reason for this effortful FRU matching for blur chimeras. Chimera-based learning experiments to increase perceptual expertise and examination of intermediate ERPs (such as the P200) for progressive knock-on effects should rule-out if this enhanced amplitude is due to the limited recognition-relevant information available in chimeras, or has other influencing factors. Based on the results of the present study, we suggest that that while information from the eye-region is sufficient to activate FRUs with enough efficiency to allow repetition priming, detailed information from the surrounding face facilitates the efficiency of FRU activation. As such, reduced information present in the filtered face-region of blur chimeras requires additional cognitive effort to compensate. However, without evidence negating alternate possibilities, this conclusion remains speculative for the time being.

To conclude, the present findings demonstrate that both blur and contrast chimeras produce the typical ERP correlates indicative of sufficiently efficient FRU activation to elicit identity repetition priming. While this was delayed for contrast chimeras, comparison of earlier ERPs between chimeras provided solid grounds to assume that this was due to a knock-on effect from disrupted face detection. The results presented suggested that FRUs can be activated from efficient access to the eyes, however the potency of this activation is reduced when cues reliant on accurate luminance and/or HSF/MSF information in the surrounding face are obscured. In addition, the increased amplitude required to activate FRUs from otherwise efficiently processed blur chimeras suggests that HSF/MSF facial details, obscured within the filtered face-region, facilitate this process.

Findings from this study highlighted the necessity of two lines of further research: first, controlling contrast chimera’s disrupted face detection to examine uninterrupted FRU activation processing, and establish similarity therein between chimeras. Second, isolating and identifying the cause of blur chimeras’ effortful FRU activation. Results from this and subsequent studies should assist in clarifying how chimeras are processed, and inform larger questions about the relative contribution and integration of the eyes and their surrounding features in familiar face recognition.

Chapter 4

4. General Discussion

What information do humans need to recognize a face effectively? Research has suggested a particular salience of the eye-region to two quintessential processes: (i) the initiation of structural encoding or face detection (e.g. Rousselet, et al., 2014); and (ii) the matching of holistically encoded facial stimuli to representations of familiar faces in memory (e.g. Gilad et al., 2009). Despite this, surprisingly little is known about what precise visual information is necessary to allow these representations, so-called face recognition units (FRUs; Bruce & Young, 1986), to be effectively built and matched. The importance of the eye-region to recognition has led to the claim that FRUs are built around the eyes and have a unique salience to activating them, when compared to other features (see Bruce & Young, 2012, p. 269). This hypothesis has largely been informed by contrast chimeras – contrast positive eyes in a contrast negative face – which are recognized significantly better than contrast negative faces (Gilad et al., 2009; Sormaz et al., 2013). However, ERP evidence demonstrating that contrast chimeras are not processed in the same manner as typical faces (Wiese et al., 2019a) has caused questioning of claims regarding the unique importance of the eyes in the FRU activation process. More efficient ERP correlates of face recognition elicited by newly introduced blur chimeras – unfiltered eyes in an otherwise blurred face – seem to suggest that this conclusion may be pre-emptive. However, due to the novelty of blur chimeras, this claim is limited by a lack of empirical evidence indicating its reliability.

The present studies provided the first direct behavioural and electroencephalographic comparisons between contrast chimeras and blur chimeras. In doing so, we aimed to resolve several unclear issues from previous literature. First, we wanted to establish whether ERPs indicative of efficient FRU activation are paralleled by a behavioural recognition advantage in blur chimeras, similar to contrast chimeras. Second, we aimed to resolve the apparent disparity between blur and contrast chimeras in efficiently activating FRUs, as indexed by the N250r ERP. By accomplishing these two tasks, this dissertation would provide stable groundwork to assess the claim that the eye-region has a special significance to activating FRUs. Furthermore, direct comparison of the behavioural and electrophysiological similarities and differences between chimeras would elucidate some of the required visual information for effective detection and recognition, which would be challenging to infer from examination of individual chimeras alone.

4.1 Evidence of a chimera advantage for blurred faces

Results from Experiments 1 & 2 revealed a chimera recognition advantage for the addition of un-blurred eyes to an otherwise blurred face. This finding showed that the efficient FRU matching by 7cpi blur chimeras established by Quinn et al. (2021) and in Experiment 4 translated into a high level of recognition accuracy. Novel evidence was also presented by Experiment 2, indicating that the chimera advantage was preserved for more strongly degraded faces with a 5cpi spatial frequency cut-off, considerably below optimal recognition (Parker & Costen, 1999; Näsänen, 1999). In addition, the recognition afforded to blur chimeras appeared restricted to the same conditions as those previously demonstrated for contrast chimeras (Gilad et al., 2009; Sormaz et al., 2013). First, Experiment 2 demonstrated that the chimera advantage was not produced by leaving an identically-sized mouth region unfiltered, and was therefore assumed to be unique to the eyes. This finding aligned with evidence from contrast chimeras, which showed that no advantage was produced by an unmanipulated mouth, nose, or forehead (Sormaz et al., 2013, Experiment 1). While a detailed examination of other features was not conducted in this dissertation, evidence suggests that the mouth is the second-most informative feature for recognition (Tanaka & Farah, 1993; Fraser, Craig, & Parker, 1990). We therefore assumed that leaving less salient features unfiltered would produce a similar lack of advantage in blur chimeras.

Second, akin to contrast chimeras (Sormaz et al., 2013, Experiment 1), despite the substantial contribution of cues within the eye-region to recognition (e.g. McKelvie, 1976; Royer et al., 2018), blur chimeras were not recognized due to restored detailed cues in the eye-region alone. This much was evident from Experiment 2, which revealed a significantly greater recognition accuracy for blur and contrast chimeras than intact eye-regions in silhouettes. Rather than featural processing of the eye-region (Mohr et al., 2018), this result suggested that chimeras' recognition advantage relies on integration of the eye-region with its surrounding features, aligning with theories of holistic integration in typical face processing (Rossion 2013; Farah et al., 1998; Richler & Gauthier, 2014). Given that fully blurred faces with obscured eyes were recognized poorly, our findings are also in line with the hypothesis that the initiation of holistic integration relies upon detection of the eyes via sufficiently detailed HSF/MSF information (e.g. Rousselet et al., 2014; Ohayon et al., 2012).

Based on these similarities, it was assumed that the recognition advantage afforded to both blur and contrast chimeras operated via the same process. However, indications that combined blur+contrast chimeras were only recognized from cues in the eye-region from Experiment 3 suggested that blur and contrast chimeras did not integrate the same information from the manipulated face area to produce a recognition advantage. This appeared logical, given the different means by which blurring and contrast negation impair recognition of a face (i.e. luminance inversion of pigmentation cues (Russell et al., 2006; Liu et al., 2000) vs. elimination of HSF/MSF cues; (Vuilleumier et al., 2003; Loftus & Harley, 2005)). It was therefore concluded that the chimera advantage was flexible in the integrated information that could be used. Based on the conclusions of Sormaz et al., (2013), for contrast chimeras, we suggested that this information consisted of restored access to recognition cues which were inhibited by contrast negation – most likely benefiting primarily from restored use of pigmentation information (Liu et al., 2000; Russell et al., 2006). Contrastingly, we suggested that blur chimeras integrated coarse 3D shape information, unrefined shading indicators of which have been shown to remain spared despite blurring (Hayes, 1988; Hayes et al., 1986), and are used across other facets of face perception (e.g. detection Goffaux & Rossion, 2006; Goffaux et al., 2005; and emotional recognition; Vuilleumier et al., 2003, Liddell et al., 2005). While previous research has largely suggested the dominant use of pigmentation cues for recognition (Hancock et al., 1996; Bruce & Langton, 1994; Russell & Sinha, 2007), the present behavioural studies' findings align with contemporary indications of flexible cue use, depending on task and individual ability (Kaufmann et al., 2013; Itz et al., 2017; Kaufmann and Schweinberger, 2008; 2012). We therefore suggested that detection of an intact eye-region allows for the integration of a variety of cues from the surrounding face, dependent on their availability and presumably prioritized by their typical reliance. As such, we concluded that the chimera advantage is elicited by the same integrational mechanism, despite differences in integrated information.

4.2 Processing differences between blur and contrast chimeras

The notion of a shared chimera advantage created from contrast negative and blurred faces was at odds with previous studies which have demonstrated differences in their respective efficiency in producing ERPs associated with face recognition. The elicitation of an N250r (Schweinberger, Pfütze, and Sommer, 1995) from two different images of the same familiar individual is assumed to index the efficient activation of an FRU (Schweinberger & Neumann, 2016). While evident for unfiltered faces, the N250r was unreliably produced by contrast chimeras, and was considerably delayed and elicited with a reduced effect size (Wiese et al., 2019a). While blur chimeras also produced a delayed N250r, evidence of significant trend of higher amplitude N250 ERPs for identity-repeated targets in an earlier time window, combined with larger effect sizes than contrast chimeras suggested that these were processed more similarly to unfiltered faces, despite the considerable degradation of detailed information in the filtered face area (Quinn et al., 2021). How could this apparent disparity between behavioural and electrophysiological results be resolved? Evidence of significant differences between ERPs produced by the two types of chimeras was demonstrated in Experiment 4 of this dissertation. However, this novel direct comparison also provided a rationale with which to resolve this question.

Results of Experiment 4 were comparable to those produced by Wiese et al. (2019a, Experiment 3), with the observation of significant N250r repetition priming for contrast chimeras appearing in a later time-window than unfiltered faces. As expected from behavioural evidence indicating that contrast chimeras were well recognized (e.g. Gilad et al., 2009) this result suggested that their FRU activation was occurrent but delayed. Comparatively, unfiltered faces and blur chimeras both showed evidence of N250r repetition priming across the earlier and later time windows. Notably, this result differed from that of Quinn et al. (2021), with their significant trend in amplitude increase for identity repeated targets in the earlier 200ms-300ms time window evident here as a significant effect, verifying the speculation of their more efficient FRU activation when compared to contrast chimeras. Moreover, the effect size of the repetition priming amplitude increase was more comparable between unfiltered faces and blur chimeras than unfiltered faces and contrast chimeras across both time windows, suggesting that contrast chimera targets received more limited FRU pre-activation from same identity primes.

Based on the assumption that the delayed N250r effect for contrast chimeras was due to earlier issues with face detection and the initiation of structural encoding (see Wiese et al., 2019a, pp. 12-13), Experiment 4 also examined the N170 ERP, assumed to correlate with these processes (Eimer, 2011; Rossion & Jacques 2011), which revealed significant differences between stimuli. Compared to both unfiltered faces and blur chimeras, the N170 for contrast chimeras was generated with a significantly delayed peak and more negative amplitude, aligning with previous studies indicating a similarly enhanced contrast chimera N170 (Wiese et al., 2019a; see also Fisher et al., 2016b). Enhanced and delayed N170 peaks have been evident across image manipulations which deviate facial appearance from a typical template, rendering recognition challenging, such as full-face contrast negation (e.g. Itier & Taylor, 2002), and displaying a face upside down (e.g. Jemel et al., 1999). As such, enhanced and delayed N170s have been taken to indicate increased effort and inefficiency during the face detection and structural encoding stage of processing (Fisher et al., 2016a; Bentin et al., 1996; Eimer, 2000; Rossion et al. 1999; Zion-Golumbic & Bentin, 2007). Critically, blur chimeras elicited a similar N170 to unfiltered faces, suggestive of typical-effort processing. This difference supported the hypothesis that contrast chimeras' delayed N250r was a result of inefficient processing at the N170 stage, rather than an inability to efficiently activate FRUs from accessible information in the eyes alone.

A plausible explanation for this finding comes from a similarly delayed and enhanced N170 in response to isolated eyes (Itier, Alain, Sedore, & McIntosh, 2007; 2006; Bentin et al., 1996). This result has aligned with intracranial recordings in humans (e.g. Puce, Allison, & McCarthy, 1999; McCarthy, Puce, Belger, & Allison, 1999) and primate single-neuron recordings (e.g. Perrett, Rolls, &

Caan, 1982) to suggest coexisting eye-selective and face-selective neurons in the human brain, the interaction of their respective activations causing modulation of the N170 (Itier, Alain, Sedore, & McIntosh, 2007; Itier & Batty, 2009; Nemrodov & Itier, 2011). Specifically, these models posit that, when eyes are presented within a face, eye-selective neurons are inhibited by face-selective neurons (resulting in the N170 amplitude for an unfiltered face), however, in eyes in isolation activate both eye- and face-selective neurons in tandem (thereby explaining the more negative N170 for isolated eyes). Face-sensitive neurons automatically interpret minimal schematic face-like patterns as faces. This is evident from pareidolia – seeing faces in non-face objects with sufficiently face-like layouts. The potentially innate automaticity of this behaviour is evident from orienting towards simplistic face-structures by neonates (Macchi Cassia, Simion, & Umiltaà, 2001; Johnson, Dziurawiec, Ellis, & Morton, 1991). This is also reflected in the N170, which similarly responds to simplified representations of faces such as cartoons (Kendall et al., 2014), emoticons (Churches et al., 2014), or even face-like objects (Hadjikhani, Kveraga, Naik, & Ahlfors., 2009). As such, the N170 is also assumed to index the detection of a simplified face-like pattern composed of the alignment of internal features (eyes above a centred nose above a mouth - so-called first-order configurations; Maurer et al., 2002). Given the evident importance of ordinal contrast relationships to face processing (Gilad et al., 2009; Sormaz et al., 2013) it is interesting to note that the most stable regions of darker contrast in the face: the eyes, nostrils, and mouth (Sinha, 2002) compose this first-order configuration pattern. These are preserved in the aforementioned simplified representations of faces, and are also notably a common element across the face-like objects used by Hadjikhani et al. (2009). As such, it seems likely that these stable ordinal contrast regions are used to detect faces even when in low visual acuity or at distance (see Loftus and Harley, 2005). Furthermore, LSF information which preserves little information beyond these broad contrast relationships (Hayes, 1988; Hayes et al., 1986), and has been suggested to play a primary role in the rapid detection of faces in the visual scene (Crouzet et al., 2010; Halit et al., 2006), as demonstrated by effective face detection and the elicitation of N170s despite substantial low-pass filtering (Goffaux, Gauthier, & Rossion, 2003; Flevaris, et al., 2008; Hanso et al., 2010).

It therefore seems likely that face-selective neurons rely on ordinal contrast cues towards first-order configurations to effectively be activated. Critically, while eye-sensitive neurons only rely on the detection of the eyes, face-sensitive neurons are activated by detection of this specific darkly shaded pattern indicative of internal features in their normal alignment. A recent study by Paras and Webster (2013) has demonstrated that regions of darkness arranged to replicate the ordinal contrast relationship of the eyes alone is insufficient to trigger a comparable N170 to one elicited by a typical face, instead resembling the N170 elicited by non-face objects. This suggests that not only do eye-sensitive neurons rely on some degree of detailed information to indicate the presence of eyes within this region, but face sensitive neurons are also presumably reliant on detection of the full pattern of first-order configurations. A contrast chimera also does not retain this pattern, despite the positivity of the eye-region, as inversion the mouth and nostrils removes the typically dark indicators of first-order configurations' lower half, thereby not activating face-selective neurons. As such, we suggest that the enhanced N170 generated by contrast chimeras is likely to represent their detection in the same manner as isolated eyes, thereby causing the activation of eye- and face-sensitive neurons in tandem, without inhibition. If initially detected as eyes, rather than faces, then the evident latency delay may reflect additional processing time needed to overcome this initial automated detection, and decode and integrate cues from the contrast negated region with the contrast positive eyes into a holistic whole (Rossion et al., 1999; Fisher et al., 2016a).

The presence of detailed eyes and clearly contrasted first-order configurations in blur chimeras allows for the inhibition of eye-selective neurons by face selective neurons, as found for unfiltered faces, thus eliciting a similar amplitude N170. While a delay was noted between unfiltered faces and blur chimeras, this was considered resultant from low-level image differences of LSF information causing a knock on delay from early processing, which was not taken into account in the examination of latency in Experiment 4 (see Nakashima et al., 2008; Tanskanen, et al., 2005; Tobimatsu & Celesia, 2006). While this was not statistically analysed in the current study, and is therefore speculative, examination of the ERP (Figure 11) does appear suggestive of a slightly delayed early waveform for blur chimeras when compared to unfiltered faces, particularly evident at P9 and TP9. An examination of potential correlations between blur chimeras' N170 latency and 250r potency indicated no significant relationship. Combined with the production of N250rs within the same time windows as unfiltered faces, this appears to suggest that any knock-on effects from delayed P1 or N170 production for blur chimeras did not noticeably delay or reduce the elicitation of N250, and we conclude that blur chimera FRU activation can be examined in relative isolation from knock-on effects.

Contrastingly, we suggest that the inefficiency of face detection reflected in the atypical prime N170 produced by contrast chimeras created knock-on inefficiency in prime FRU pre-activation. Although we did not examine target N170 ERPs in the present study, we assume that additional inefficiently here, compounded with the inefficient pre-activation, subsequently affected re-activation by the target, delaying the N250r. It is noteworthy that contrast chimeras' absence of significant N250r production in the earlier 200ms-300ms time window is unlikely to be due simply to the delayed production of the N170. Firstly, it seems highly unlikely that (even compounded with a presumably similar delay for a target N170) the 5.94ms average delay noted for contrast chimera primes knocked-on to create the potentially 100ms delay in N250r production. Moreover, there was no indication of a correlation between N170 delay (compared to unfiltered faces) and N250r potency. As such, while the delayed production of the N170 is likely to have delayed the subsequent processing stream by a minor degree, we suggest that the more significant contributor to contrast chimeras' delayed N250r repetition priming was due to difficulty in detecting/structurally encoding a face representation from the stimulus. As aforementioned, this may have been due to erroneous initial detection of contrast chimeras as eyes, necessitating additional time and effort to overcome this initial detection issue, and decipher the surrounding contrast negated cues into a holistic face whole. Without similar inefficiencies in earlier processing, blur chimeras were able to undergo more efficient FRU pre- and re-activation, resulting in an N250r ERP in the earlier time window.

4.3 Recognition relevant information revealed by chimera comparisons

A direct comparison between contrast and blur chimeras thereby indicates that, despite apparent differences in their ability to produce a timely N250r, this is likely due to differences in earlier face detection, rather than FRU activation. Of relevance to the present dissertation, behavioural and electrophysiological differences and similarities elicited between stimuli informed understanding of the information required to detect a face in the visual field, and effectively match this to an FRUs.

Based on behavioural evidence from the present studies, it appeared that while restoration of the broad ordinal contrast relationship surrounding the eyes was not necessary to initiate the chimera advantage as previously assumed (Gilad et al., 2009; Sormaz et al., 2013), the presence of this relationship is critical to the effective functioning of face detection and structural encoding processing. Based on the aforementioned relationship between eye-sensitive and face-sensitive neurons (Itier et al., 2007; Itier & Batty, 2009) responsible for these processes, it seems likely that the presence of this ordinal contrast relationship is relevant to the activation of face-sensitive neurons, given that it provides a stable indicator of the upper portion of first-order configurations (Sinha, 2002). This is supported by previous studies' indication of an N170 for LSF faces which is significantly greater than that of non-face objects (Goffaux et al., 2003; Rossion et al., 2000; Flevaris, et al., 2008). With the restoration of these eye-region fine-contrast relationships in a blur chimera, combined with the already-intact broader ordinal contrast relationship retained through blurring, we posit that blur chimeras activate face selective neurons, inhibiting eye selective neurons in the same manner as an unfiltered face, reflected in a typical amplitude N170 (Experiment 4) and high recognition accuracy (Experiments 1&2).

As such, the results led us to conclude that efficient face detection and structural encoding initiation, as indexed by the N170 (Bentin et al., 1996; Eimer, 2000; Bruce and Young, 1986), is reliant on both the presence of detailed contrast relationships within the eye-region, and ordinal contrast relationships, indicative of first order configurations. (see Johnson, 2005; Jeffreys, 1996, for further discussion). Contrast chimeras are detected as isolated eyes, eliciting an atypically negative N170, failing to activate the inhibitive component of face-specific neurons due to the inability to detect intact first-order configurations in the stimulus. Contrastingly, this inhibitive relationship between face- and eye- selective neurons is evident in a typical amplitude N170 for blur chimeras and unfiltered faces. Given the potential for knock-on effects due to the serial nature of recognition processing (Bruce and Young, 1986) the present findings suggest caution in any investigation of any ERP correlates of subsequent stages of processing (such as the N250r), as inefficiency relating to a stimulus failing to activate the inhibitory relationship between eye-selective and face-selective neurons in the same manner as an unfiltered face may delay subsequent processing beyond the normal time windows.

Based on this conclusion, we suggest that contrast chimeras, unless isolated from this earlier inefficiency, are not an adequate tool to investigate the N250r effectively (e.g. Wiese et al. 2019a), and therefore do not provide conclusive evidence about FRU activation from efficient access to cues in the eyes alone. Means to investigate contrast chimeras FRU activation in isolation from N170 knock-on effects are suggested in the discussion of Experiment 4, however were not examined in the current dissertation (see p. 60). Blur chimeras, which do not appear to suffer from significant knock-on effects were demonstrated in Experiment 4 to elicit sufficiently efficient FRU (pre)activation to exhibit clear N250r repetition priming within the same time windows as typical faces. Despite efficiency for blur chimeras, the effect size for repetition priming across both chimeras was smaller than for typical faces. While their ability to elicit priming effects without detailed information in the rest of the face does suggest a special role for the eyes in FRU activation (see Bruce and Young, 2012, p. 269), this smaller effect size, combined with evidence of integration of the filtered face-region in Experiment 2, clearly demonstrates that FRU activation is facilitated by the use of information from the region external to the eyes. In further evidence of this, Experiment 4 reliably reproduced a result initially noted by Quinn et al. (2021), that the target N250 generated by blur chimeras was significantly more negative relative to unfiltered faces. While research on the identity-selective N250r has rendered less specificity as to what a more negative target N250 reflects than in the N170, this can also be assumed to represent the recruitment of additional neuronal populations, indicative of using more effort to accomplish the processing task at hand (Rosburg et al., 2010; Rossion et al. 2000; Sadeh & Yovel, 2010). As such, it seems evident that despite being able to activate FRUs with sufficient efficiency to allow for repetition priming, blur chimeras appear to require more effort to match with FRUs than unfiltered faces.

While this was not investigated further by the present studies, we suggest a potential explanation. However, it is first important to rule out an alternative based on previous research. An increment in N250(r) amplitude has been reliably found for other-race faces (Wiese et al., 2014; Stahl, Wiese, & Schweinberger, 2008; 2010; Herzmann, Willenbockel, Tanaka, & Curran, 2011; Herzmann, 2016). Research has theorized that less perceptual experience of other-race than own-race faces (Valentine, 1991; Rossion & Michel, 2011) leads to greater difficulty in recognizing other-race faces (see Meissner & Brigham, 2001; Hugenberg, Young, Bernstein, & Sacco, 2010; for reviews). Moreover, this difficulty has been suggested to stem from increased featural and less holistic processing of other-race faces (Mondloch et al., 2010; Bukach, Cottle, Ubiwa, & Miller., 2012), resulting in the more effortful processing indexed by an enhanced N250. The artificial nature of chimera stimuli renders participants as unlikely to have much (if any) perceptual experience of such a stimulus prior to experimentation. As such, this enhanced N250 could reflect a similar process as for less experienced other-race faces. We consider that the evidence presented in the present studies makes this explanation unlikely. First, previous evidence from contrast chimeras has clearly indicated that these are processed holistically (Sormaz et al., Experiments 3 & 4), appearing consistent with the integration of eyes with other features in blur chimeras in Experiment 2. In addition, empirical evidence has indicated that neither blurring (Richler et al., 2009) nor contrast negation (Hole, George, & Dunsmore, 1999; Taubert & Alais, 2011) disrupt holistic processing to a significant degree. This appears at odds with the more featural processing of other-race faces which has been proposed as causing this increased effort. Second, contrast negated stimuli are more artificial than blurred stimuli (which can result from naturalistic occurrences such as distance, lowered visual acuity, movement; Leat, Legge and Bullimore, 1999), presumably resulting in lower perceptual experience. Despite this, contrast chimeras' target N250 was produced at a statistically similar amplitude to unfiltered faces, significantly less negative than blur chimeras. As such, evidence of holistic processing, combined with a more artificial stimulus producing a less enhanced target N250 does not align with this increased effort resulting from lack of perceptual expertise.

We instead suggest that a more likely explanation is simply the result the removal of detailed recognition cues reliant on MSF and HSF information. For an unfiltered face, these would normally facilitate the process of matching a perceived face with an FRU, and their absence makes this a more difficult and thereby more resource-intensive process. This suggestion appears to be supported by behavioural evidence from Experiments 1 & 2, which demonstrated limiting information by lowering the spatial frequency cut-off in the filtered face area of blur chimeras from 7cpi to 5cpi produced a substantial decline in recognition accuracy (92%; 79%). As such, despite un-filtering of the eyes providing a chimera advantage in both instances, recognizing a face with less information is more difficult, and therefore more effortful. While 5cpi blur chimeras were not examined in the ERP component of this dissertation, we hypothesize that these would have elicited an even more enhanced target N250 amplitude than the 7cpi faces featured. Supporting this further, while the N250r for contrast chimeras was delayed, which we suggested was due to earlier detection inefficiency (see pp. 58-61, 67-69), it was elicited at a similar amplitude to typical faces. Based on the suggestion by Sormaz et al. (2013) that positive eyes restore utility to contrast negated recognition cues in the surrounding face area, this should render the preserved information of the contrast negated region of the face usable for FRU matching. As such, the full range of spectral and geometric details preserved in a contrast chimera should require little effort to successfully match an FRU, reflected in a typical amplitude N250. Comparison of results between chimeras and unfiltered faces therefore suggests that while detailed information in the eyes alone is sufficient to activate FRUs with enough efficiency to create a significant priming effect, the use of detailed HSF/MSF recognition cues in the filtered face-region (indicative of detailed geometry, fine-contrast and pigmentation) facilitates this process in unfiltered faces. Comparing the present study's evidence of blur chimera N250r ERPs with those demonstrating a lack of FRU identity repetition priming from fully blurred faces (Quinn et al., 2021), it appears that FRU activation is more reliant on HSF/MSF within the eye-region than HSF/MSF in the surrounding face. However, HSF/MSF information external to the eye-region does still contribute to this process, as evident from lower amplitude target N250 ERPs for unfiltered faces (and potentially contrast chimeras) which preserve this information.

Behavioural and ERP results in the present studies align to indicate that chimeras pre-activate FRUs with enough efficiency and potency to facilitate re-activation, albeit with less efficiency and potency than unfiltered faces (Experiment 4). In addition, based on the high level of recognition accuracy across both chimera varieties (Experiment 1 & 2), FRU activation is sufficient to advance the majority of processing through the later stages of recognition (Experiment 1 & 2): activating personal identity nodes to access semantic information and name recall (see Bruce & Young, 1986; Burton, Bruce, & Johnston, 1990). Based on the knock-on effect observed for contrast chimeras here, it seems probable that a similar knock on effect would be observed for processes governing recall of semantic information and names due to the less efficient and reduced potency FRU activation by chimeras. While not examined in the current study, this reduced FRU activation (especially for less robust FRUs) knocking-on to limit semantic information recall below the threshold needed to recall salient information about an individual may partially explain the lower recognition accuracy for chimeras, when compared to unfiltered faces (e.g. 76% - Sormaz et al., 2013).

While the present studies indicate that chimeras are recognized using the same processing stream as typical faces, both contrast and blur chimeras do not appear to undergo recognition with typical efficiency. Differences in image properties between chimera stimuli appear to impair different stages of recognition processing, with contrast chimeras primarily creating a knock-on detriment from impaired face detection due to affected first-order configuration cues, whereas blur chimeras require additional effort to effectively activate an FRU. While Wiese et al., (2019a) correctly caution drawing conclusions from chimeras due to the artificiality of the stimulus, as demonstrated here, the differences between the processing efficiency of chimeras and unfiltered faces provide a vital tool to identify the relevant information to efficiently complete the respective stages of recognition processing, undefinable from unfiltered face or singular chimera examination alone.

4.4 Experimental Limitations

While direct comparison of chimeras has largely affirmed speculations drawn from experiments on single chimeras, several experimental limitations should be taken into consideration in assessing the credibility of the present studies' conclusions.

Due to COVID-19 restrictions, the behavioural component of the present studies (Experiments 1-3) was conducted online, and participants used personal devices to participate in the experiment. While guidelines were provided in the experimental introduction, it was impossible to monitor if participants used external resources (e.g. consulting friends, the internet) in identifying faces, and it was impossible to establish a controlled experimental environment across participants. While this could be considered as reflective of real-world recognition, this was of particular concern when assessing the effects of spatial frequency. The effects of spatial frequency on recognition are highly dependent on image size and viewing distance (Mousavi & Oruc, 2020; Loftus and Harley 2005; Noyes and Jenkins, 2017). For this reason, the degree of visual angle taken up by face images was strictly controlled in Experiment 4 in accordance with the conditions previously established in an in an influential study by Näsänen (1999; see p. 47 of this dissertation). For behavioural experiments, participants were likely to use differing screen sizes, brightnesses, angles and distances, potentially also even moving between stimuli or blocks. All of the above may have affected the consistency of spatial frequency between and even within individual participants. As such, it cannot be said that the 7cpi and 5cpi filters used within these studies accurately reflected an accurate cut-off point of spatial frequency in visual information. For this reason, we suggest that further examinations of spatial frequency should utilize consistent and controlled conditions.

With regards to the electroencephalographic component of the present studies (Experiment 4), it is noteworthy that in replication of previous methodology, the task used to assess faces which were recognized may not have been valid in reflecting genuine recognition. While behavioural tasks in the present studies (Experiments 1-3) used a written component and comparison with recognition of unfiltered faces to assess genuine recognition, this was not included in Experiment 4 to minimize extraneous movement that may have affected the encephalographic recording. Responses of participants in the behavioural tasks indicated an element of guesswork in identifying individuals, often incorrectly assuming an identity, or writing a vague or unsure response (e.g. 'maybe was in James Bond movie?') despite being otherwise instructed. While these were easy to identify and code for accordingly due to the written component of the behavioural studies, Experiment 4's use of a 4-button keypad to assess recognition could not be controlled in a similar way. Only trials in which participants indicated recognition (indicated by a button 3 or 4 keypress) were selected for analysis, however it is unclear to what extent these button presses reflected assumptions/guesswork, or genuine recognition based on FRU activation. While this was partially compensated for by the number of trials, the significant difference between the N250 produced by a familiar and unfamiliar face (Gosling & Eimer, 2011) may have affected the validity the trials assumed to reflect recognition which were selected for analysis. As such, finding a task which can accurately assess which faces were accurately recognized, while limiting extraneous movements (such as a multiple-choice naming task) should be considered in future assessments of FRU activation.

4.5 Further research

In addition to addressing these limitations, and the within-experiment suggestions for future research (see pp. 60 & 62) we suggest two further necessities for future research to explore, which were not covered by this dissertation.

First, despite the chimera advantage providing very high recognition rates for chimeras in both the present and previous studies (Gilad et al., 2009; Sormaz et al., 2013), it is notable that in all instances, these are substantially lower than recognition rates for typical faces. While we suggest that this may be due to further knock-on inefficiencies due to smaller FRU activation potency into the subsequent serial processes of semantic and name recall (see p. 73), this has yet to be empirically established. As this dissertation did not examine any ERPs after the N250, it is also unclear if disparity also exists between blur and contrast chimeras in semantic and name recall processing efficiency. As such, it is uncertain if the additional neuronal activation needed for blur chimeras to activate FRUs (evident from an enhanced target N250) knocked-on to create more inefficient semantic recall than contrast chimeras. Examination of latency and potency of ERPs such as the N400, assumed to index the distribution of activation throughout semantic networks (Kiefer, 2002), and known to be elicited by faces (Barrett, Rugg and Perrett, 1988), may provide a means to answer this question. As such, correlation of N250r latency and potency with similar measures for the N400 should provide a means to evidence further knock-on effects into later recognition processing.

Second, further research is needed on electrophysiological responses to chimeras. While Experiment 4 largely reproduces the results from blur chimeras initially found by Quinn et al. (2021), it is unclear if this effect is partially resultant from pictorial-repetition priming, which has also been shown to elicit an N250r if matching images are used for prime and target (Schweinberger et al., 2002; 2004). While different ambient images of identities were selected to reduce the effects of pictorial priming in Experiment 4, the averaging of HSF/MSF by blurring is likely to have created pictorial similarities across images in the blur chimera condition, especially for already similar images of identity-repeated faces. As such, if a blur chimera can elicit a significant N250r by FRU pre-activation alone, this should be reflected in its ability to prime unfiltered faces of the same identity, which share less pictorial commonality with blur chimera faces. While this may result in some processing issues due to changes in low-level image properties between primes and targets (see Wiese et al., 2019a for a related discussion regarding contrast chimeras), suitable controls could be put in place to address these, via examination of and compensation for differences in the amplitude and latency of relevant ERP correlates (e.g. P1; see Itier & Taylor, 2004 for a relevant discussion).

4.6 Conclusions

To conclude, this dissertation provides behavioural and electroencephalographic comparisons between contrast chimeras and the recently introduced blur chimeras, both to assess the reliability of previous results and the validity of hypotheses based on them, and to infer the information relevant to encoding and recognizing a face from this first time comparison.

In doing so, we discovered that leaving the eye-region unfiltered in an otherwise blurred face produces a comparable recognition advantage to that of contrast chimeras. As such, we propose that in both instances, the chimera advantage relies on access to cues within the eye-region, which allow flexible integration of available recognition-relevant information from the remainder of the face. Despite behavioural similarities between chimeras and evidence of undergoing the same sequence of serial processing as typical faces, examination of their respective ERPs indicated unique differences in efficiency for blur and contrast chimeras, when compared to typical recognition processing. Specifically, contrast chimeras undergo inefficient face detection, likely due to disrupted contrast relationships indicative of first order configurations. Contrastingly, blur chimeras are efficiently detected, but undergo effortful FRU matching, likely compensating for the loss of detailed recognition cues which are reliant on HSF/MSF information to be effectively used. Moreover, neither chimera re-activated target FRUs with as much potency as unfiltered faces.

It therefore appears that while FRUs can be activated from efficient access to detailed cues in the eye-region alone, suggesting a special salience of the eyes to FRU matching, information from other facial areas facilitates and enhances this process in typical recognition. While differences in efficiency and potency suggest caution in applying conclusions from chimeras to typical face processing, this comparison provided new understanding of the stages of processing in which these differences manifest in chimeras, as well as where they elicit typical processing. Comparison between chimeras therefore provides a valuable tool to investigate the requisite information from both within and around the eye-region to efficiently conduct the serial stages of recognition. As such, the present experiments demonstrated that chimeras provide corroborative evidence for theoretical accounts of face- and eye-sensitive neurons for face detection, holistic structural encoding, and a special significance of the eye-region to FRUs activation.

More information is needed to fully understand the applicability of chimeras to typical face recognition processing. However, with the discovery of a chimera advantage for a second manipulation, this dissertation provides a preliminary example of how comparisons between chimeras can be used, not only in explaining the requisite elements to produce the chimera advantage, but also in moving towards a more complete picture of the information necessary to effectively and efficiently recognize a face.

Appendices

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Appendix A

Participant demographics from Experiments 1, 2, & 3 of the behavioural study, divided by nine image filtering condition groups.

Group	Participant *N*	Female Participant *N*	Age Mean	Age SD
Experiment 1				
7cpi Blur faces	88	77	19.4 years	1.0
7cpi Blur chimeras	88	76	19.5 years	1.4
Experiment 2				
5cpi Blur faces	26	23	19.7 years	1.1
5cpi Blur chimeras (eyes)	26	25	19.5 years	0.9
5cpi Blur chimeras (mouth)	26	24	19.4 years	1.1
Contrast chimeras	26	21	19.7 years	1.2
Silhouette chimeras	26	23	19.9 years	1.3
Experiment 3				
5cpi Blur+contrast faces	26	21	20.2 years	1.5
5cpi Blur+contrast chimeras	26	22	20.3 years	1.2

Appendix B

Example sheet of coded participant responses from Experiment 1.

Part. Info	Name	Response Unfiltered	Code	Response 7cpi Blur Chimera	Code			
F	Benedict Cumberbatch	benedict cumberbatch	1	benedict cumberbatch	1	Known Manipulation		
20	Billie Eilish	billie eilish	1	billie eilish	1	17	=	Target ID
6754	Britney Spears		0		0	Known Unfiltered		0.77273
	Cardi B		0	nicki minaj	0	22		
	Chris Evans		0	christopher lee	0			
	Chris Hemsworth	chris hemsworth	1	chris hemsworth	1			
	Danny Devito	dani devito	1	dani devito	1			
	David Mitchell		0		0			
	David Tennant	david tennant	1		0			
	Dec Donnelly	dec	1		0			
	Demi Lovato	demi levato	1	demi levato	1			
	Dua Lipa		0		0			
	Dwayne Johnson	the rock	1	dwayne the rock	0			
	Ellen Degeneres	elen	1	elen	1			
	Elon Musk		0		0			
	Hillary Clinton		0	theresa may	0			
	Iggy Azelea		0		0			
	Jake Gyllenhaal		0		0			
	Jennifer Lopez		0	lady gaga	0			
	Jeremy Clarkson	jeremy clarkson	1	jeremy clarkson	1			
	Joe Biden	prince philip	0		0			
	Judy Dench	judy dench	1	judy dench	1			
	Kanye West	kanye west	1	kanye west	1			
	Kate Middleton	kate middleton	1		0			
	Kate Winslet	rose dawson	0		0			
	Katy Perry	katie perry	1	katie perry	1			
	Keanu Reeves		0		0			
	Kylie Jenner	ariana grande	0	ariana grande	0			
	Lady Gaga	lady gaga	1	lady gaga	1			
	Mariah Carey		0		0			
	Meryl Streep	meryl streep	1		0			
	Oprah Winfrey		0		0			
	Peter Dinklage	dwarf from game of trhones	1	dwarf in game of thrones	1			
	Queen Elizabeth	the queen	1	the queen	1			
	Samuel L. Jackson		0		0			
	Steven Fry		0	jeremy clarkson	0			
	Terry Crews	terry from brooklyn 99	1	terry from brooklyn 99	1			
	Theresa May	theresa may	1	margaret thatcher	0			
	Tom Hanks	tom hanks	1	tom hanks	1			
	Will Smith	will smith	1	will smith	1			

Appendix C

Full participant responses dataset for Experiment 1, coded to indicate target identification accuracy.

P Number	P Code	Gender	Age	Condition	Known	Known 7cpi Blurred Face	Familiarity
1	3658	F	20	1	32	27	0.84375
2	3688	M	20	1	36	31	0.86111
3	3712	F	20	1	32	27	0.84375
4	3724	F	21	1	36	32	0.88889
5	3739	F	19	1	36	27	0.75000
6	3748	F	20	1	36	32	0.88889
7	3760	F	20	1	30	22	0.73333
8	3808	F	20	1	28	27	0.96429
9	3820	F	19	1	37	26	0.70270
10	3844	F	19	1	31	24	0.77419
11	3871	F	20	1	38	38	1.00000
12	3874	F	20	1	39	34	0.87179
13	3877	F	19	1	32	24	0.75000
14	3883	F	21	1	37	28	0.75676
15	3910	F	20	1	38	36	0.94737
16	3961	M	19	1	40	39	0.97500
17	3964	F	19	1	39	39	1.00000
18	4000	F	20	1	32	26	0.81250
19	4024	F	20	1	33	29	0.87879
20	4036	F	21	1	25	20	0.80000
21	4042	F	20	1	24	19	0.79167
22	4081	F	20	1	24	15	0.62500
23	4093	F	20	1	37	33	0.89189
24	4111	F	19	1	35	27	0.77143
25	4150	F	20	1	38	30	0.78947
26	4171	F	21	1	31	29	0.93548
27	4198	M	20	1	36	31	0.86111
28	4234	F	20	1	40	32	0.80000
29	4249	F	19	1	39	37	0.94872
30	4279	F	20	1	40	38	0.95000
31	4306	F	19	1	39	34	0.87179
32	4315	F	19	1	31	26	0.83871
33	4372	F	21	1	37	36	0.97297
34	4405	F	20	1	37	30	0.81081
35	4420	F	23	1	28	19	0.67857
36	4441	F	21	1	34	27	0.79412
37	4477	F	20	1	27	21	0.77778
38	4498	F	21	1	22	14	0.63636
39	4501	F	19	1	31	12	0.38710
40	6304	F	19	1	32	26	0.81250
41	6328	F	18	1	21	20	0.95238
42	6349	F	19	1	26	16	0.61538
43	6361	F	19	1	21	16	0.76190
44	6409	F	18	1	34	27	0.79412
45	6445	M	19	1	33	26	0.78788
46	6523	M	20	1	36	27	0.75000
47	6550	F	19	1	30	25	0.83333
48	6556	F	20	1	40	38	0.95000
49	6562	F	21	1	29	24	0.82759
50	6643	M	20	1	31	28	0.90323
51	6649	F	20	1	40	38	0.95000
52	6694	F	20	1	27	24	0.88889
53	6703	F	20	1	28	20	0.71429
54	6751	M	20	1	21	16	0.76190
55	6754	F	20	1	22	17	0.77273
56	6760	F	19	1	28	20	0.71429
57	6814	F	18	1	39	38	0.97436
58	6820	F	19	1	38	33	0.86842
59	6826	F	19	1	37	34	0.91892

60	6829	F	19	1	40	34	0.85000
61	6844	F	20	1	34	31	0.91176
62	6847	M	19	1	36	33	0.91667
63	6865	F	19	1	32	28	0.87500
64	6886	F	19	1	39	38	0.97436
65	7015	F	21	1	37	35	0.94595
66	7024	M	18	1	34	32	0.94118
67	7033	F	18	1	40	37	0.92500
68	7054	F	18	1	32	30	0.93750
69	7060	F	19	1	35	30	0.85714
70	7066	F	19	1	38	36	0.94737
71	7078	F	18	1	37	34	0.91892
72	7144	F	19	1	20	18	0.90000
73	7165	F	18	1	33	28	0.84848
74	7177	F	19	1	27	21	0.77778
75	7213	F	19	1	27	16	0.59259
76	7228	M	18	1	40	39	0.97500
77	7231	F	19	1	33	25	0.75758
78	7243	F	19	1	40	38	0.95000
79	7246	F	18	1	40	39	0.97500
80	7276	F	20	1	23	20	0.86957
81	7291	F	18	1	32	23	0.71875
82	7294	F	19	1	26	19	0.73077
83	7303	F	18	1	39	36	0.92308
84	7330	F	18	1	33	31	0.93939
85	7408	F	18	1	31	29	0.93548
86	7420	F	18	1	37	30	0.81081
87	7423	F	20	1	39	33	0.84615
88	7431	M	20	1	37	29	0.78378

P Number	P Code	Gender	Age	Condition	Known	Known 7cpi Blur Chimera	Familiarity
1	3640	F	20	2	34	30	0.88235
2	3646	F	20	2	39	39	1.00000
3	3670	F	20	2	38	37	0.97368
4	3694	F	19	2	32	24	0.75000
5	3703	F	20	2	38	35	0.92105
6	3736	F	20	2	38	35	0.92105
7	3769	F	20	2	30	26	0.86667
8	3802	F	19	2	32	28	0.87500
9	3829	F	19	2	34	30	0.88235
10	3862	F	21	2	32	26	0.81250
11	3880	F	20	2	39	36	0.92308
12	3901	F	20	2	33	26	0.78788
13	3919	F	20	2	33	31	0.93939
14	3979	F	20	2	35	32	0.91429
15	3997	F	20	2	26	25	0.96154
16	4048	F	20	2	31	27	0.87097
17	4051	F	19	2	40	39	0.97500
18	4072	F	19	2	32	27	0.84375
19	4102	M	19	2	40	40	1.00000
20	4153	M	20	2	37	35	0.94595
21	4165	F	20	2	38	36	0.94737
22	4189	M	19	2	20	20	1.00000
23	4201	F	19	2	30	28	0.93333
24	4219	F	20	2	39	32	0.82051
25	4243	F	21	2	37	33	0.89189
26	4276	M	19	2	39	38	0.97436
27	4300	N	25	2	35	33	0.94286
28	4339	F	20	2	37	31	0.83784
29	4360	F	20	2	34	30	0.88235
30	4495	F	21	2	27	25	0.92593
31	6091	F	21	2	36	33	0.91667
32	6298	F	19	2	40	38	0.95000

33	6346	F	18	2	29	27	0.93103
34	6352	M	21	2	37	37	1.00000
35	6403	F	19	2	35	29	0.82857
36	6457	F	19	2	31	29	0.93548
37	6460	F	19	2	33	31	0.93939
38	6490	F	19	2	34	34	1.00000
39	6496	F	19	2	39	39	1.00000
40	6511	F	18	2	33	33	1.00000
41	6514	F	18	2	26	22	0.84615
42	6580	M	18	2	34	33	0.97059
43	6589	F	22	2	37	35	0.94595
44	6598	F	19	2	39	39	1.00000
45	6613	F	19	2	35	34	0.97143
46	6622	F	18	2	39	33	0.84615
47	6655	M	18	2	27	25	0.92593
48	6658	F	19	2	36	31	0.86111
49	6673	F	18	2	33	29	0.87879
50	6682	F	19	2	29	29	1.00000
51	6688	F	18	2	37	34	0.91892
52	6715	F	19	2	32	26	0.81250
53	6724	F	18	2	25	25	1.00000
54	6778	F	19	2	32	30	0.93750
55	6793	F	19	2	22	21	0.95455
56	6805	F	19	2	37	32	0.86486
57	6919	F	19	2	38	37	0.97368
58	6928	M	18	2	20	19	0.95000
59	6934	F	19	2	27	18	0.66667
60	6946	F	19	2	35	32	0.91429
61	6961	F	19	2	28	27	0.96429
62	6970	F	18	2	39	39	1.00000
63	6985	N	18	2	27	26	0.96296
64	6994	F	18	2	29	26	0.89655
65	7009	F	18	2	37	35	0.94595
66	7012	F	19	2	34	29	0.85294
67	7015	F	21	2	38	38	1.00000
68	7027	F	19	2	35	33	0.94286
69	7048	F	24	2	30	24	0.80000
70	7069	F	19	2	39	37	0.94872
71	7087	F	20	2	30	27	0.90000
72	7111	F	19	2	40	40	1.00000
73	7114	F	27	2	40	40	1.00000
74	7132	F	19	2	39	34	0.87179
75	7195	F	19	2	20	20	1.00000
76	7234	F	19	2	39	36	0.92308
77	7237	F	18	2	32	32	1.00000
78	7327	M	19	2	30	25	0.83333
79	7378	F	18	2	29	29	1.00000
80	7390	F	20	2	33	27	0.81818
81	7411	F	18	2	29	27	0.93103
82	7510	F	19	2	36	36	1.00000
83	7513	F	19	2	29	18	0.62069
84	7831	M	19	2	34	28	0.82353
85	8026	F	20	2	38	37	0.97368
86	8044	F	20	2	20	16	0.80000
87	8053	F	19	2	31	29	0.93548
88	8055	F	21	2	39	36	0.92308

Appendix D

Full participant responses dataset for Experiment 2, coded to indicate target identification accuracy.

P Number	P Code	Gender	Age	Condition	Known	Known 5cpi Blurred Face	Blur R. Rate
1	3694	F	19	1	29	11	0.37931
2	3706	F	20	1	34	21	0.61765
3	3712	F	20	1	29	16	0.55172
4	3760	F	20	1	28	9	0.32143
5	3844	F	19	1	20	10	0.50000
6	3874	F	20	1	35	24	0.68571
7	3883	F	21	1	26	19	0.73077
8	3910	F	20	1	26	19	0.73077
9	4078	F	20	1	38	27	0.71053
10	4093	F	21	1	33	22	0.66667
11	4291	F	20	1	39	26	0.66667
12	4438	F	20	1	29	13	0.44828
13	4456	F	22	1	32	19	0.59375
14	4498	F	21	1	14	6	0.42857
15	6325	F	18	1	32	22	0.68750
16	6352	M	21	1	35	20	0.57143
17	6445	M	19	1	31	16	0.51613
18	6547	F	20	1	37	32	0.86486
19	6817	F	18	1	32	24	0.75000
20	6865	F	19	1	29	19	0.65517
21	6985	N	18	1	21	10	0.47619
22	7132	F	19	1	39	29	0.74359
23	7153	F	19	1	33	24	0.72727
24	7207	F	18	1	32	18	0.56250
25	4228	F	20	1	34	20	0.58824
26	3802	F	19	1	21	13	0.61905

P Number	P Code	Gender	Age	Condition	Known	Known 5cpi Blur Chimera (eyes)	Chim R. Rate
1	3637	F	19	2	32	25	0.78125
2	3646	F	20	2	38	34	0.89474
3	3736	F	20	2	36	32	0.88889
4	3832	F	21	2	37	27	0.72973
5	3982	F	20	2	22	17	0.77273
6	3997	F	20	2	22	15	0.68182
7	4072	F	19	2	26	20	0.76923
8	4306	F	19	2	36	27	0.75000
9	4339	F	20	2	34	18	0.52941
10	4375	F	19	2	39	33	0.84615
11	6358	F	19	2	34	23	0.67647
12	6538	F	19	2	30	24	0.80000
13	6607	F	19	2	32	30	0.93750
14	6727	F	19	2	27	21	0.77778
15	6757	F	18	2	31	23	0.74194
16	6814	F	18	2	34	29	0.85294
17	7015	F	21	2	33	24	0.72727
18	7051	F	19	2	40	38	0.95000
19	7066	F	20	2	34	30	0.88235
20	7087	F	20	2	21	14	0.66667
21	7171	F	19	2	23	14	0.60870
22	7282	M	19	2	28	25	0.89286
23	7369	F	18	2	31	29	0.93548
24	8026	F	20	2	38	29	0.76316
25	4057	F	20	2	27	21	0.77778
26	3985	F	21	2	24	20	0.83333

P Number	P Code	Gender	Age	Condition	Known	Known 5cpi Blur Chimera (mouth)	Mouth R. Rate
1	3670	F	20	3	40	33	0.82500

2	3739	F	20	3	33	19	0.57576
3	4000	F	21	3	25	15	0.60000
4	3919	F	20	3	24	15	0.62500
5	3925	F	22	3	33	23	0.69697
6	4102	M	19	3	38	27	0.71053
7	4105	F	19	3	28	22	0.78571
8	4204	F	19	3	24	15	0.62500
9	6775	F	19	3	40	33	0.82500
10	6535	F	21	3	33	20	0.60606
11	6616	M	19	3	27	14	0.51852
12	6637	F	19	3	40	33	0.82500
13	6688	F	18	3	31	8	0.25806
14	4333	F	22	3	20	14	0.7
15	6790	F	19	3	31	7	0.22581
16	6823	F	20	3	30	15	0.50000
17	7000	F	18	3	29	11	0.37931
18	7009	F	18	3	37	23	0.62162
19	7060	F	19	3	25	6	0.24000
20	7123	F	19	3	32	21	0.65625
21	7165	F	18	3	32	19	0.59375
22	7204	F	19	3	37	19	0.51351
23	8047	F	20	3	22	15	0.68182
24	4165	F	20	3	37	18	0.48649
25	3820	F	19	3	34	21	0.61765
26	7168	F	18	3	23	10	0.43478

P Number	P Code	Gender	Age	Condition	Known	Known Contrast Chimera	Contrast R. Rate
1	3763	F	22	4	24	17	0.70833
2	3799	F	19	4	29	26	0.89655
3	3973	M	23	4	21	9	0.42857
4	4048	F	20	4	28	21	0.75000
5	4171	F	21	4	26	19	0.73077
6	4234	F	21	4	39	30	0.76923
7	4249	F	20	4	36	33	0.91667
8	4294	F	20	4	36	31	0.86111
9	6598	F	19	4	38	38	1.00000
10	6604	F	18	4	34	30	0.88235
11	6625	F	19	4	39	38	0.97436
12	6658	F	19	4	37	27	0.72973
13	6676	M	19	4	40	35	0.87500
14	6811	F	19	4	29	25	0.86207
15	6958	M	19	4	35	29	0.82857
16	7018	F	18	4	40	38	0.95000
17	7150	F	20	4	39	33	0.84615
18	7267	M	18	4	40	36	0.90000
19	7294	F	19	4	21	13	0.61905
20	7342	M	19	4	26	20	0.76923
21	8050	F	21	4	34	26	0.76471
22	3769	F	21	4	22	15	0.68182
23	3892	F	19	4	21	16	0.76190
24	4024	F	20	4	24	20	0.83333
25	6970	F	19	4	39	39	1.00000
26	7315	F	19	4	25	16	0.64000

P Number	P Code	Gender	Age	Condition	Known	Known Silhouette Chimera	Sil R. Rate
1	3877	F	19	5	29	14	0.48276
2	3934	F	21	5	28	21	0.75000
3	4114	F	20	5	25	11	0.44000
4	6367	F	21	5	26	14	0.53846
5	6487	F	20	5	32	25	0.78125
6	6490	F	19	5	22	12	0.54545
7	6502	F	19	5	35	20	0.57143
8	6553	F	20	5	29	12	0.41379

9	6808	F	20	5	34	22	0.64706
10	6922	F	19	5	37	28	0.75676
11	6928	M	18	5	20	13	0.65000
12	6943	F	18	5	36	23	0.63889
13	7216	F	19	5	28	21	0.75000
14	7300	M	19	5	20	12	0.60000
15	7402	F	21	5	20	14	0.70000
16	3754	F	20	5	35	26	0.74286
17	3796	F	24	5	33	28	0.84848
18	3952	F	20	5	40	26	0.65000
19	4420	F	23	5	20	9	0.45000
20	8041	M	19	5	31	22	0.70968
21	4219	F	20	5	30	15	0.50000
22	4363	F	20	5	20	9	0.45000
23	4405	F	20	5	35	29	0.82857
24	3577	F	20	5	28	13	0.46429
25	3721	F	20	5	33	25	0.75758
26	4186	F	19	5	35	19	0.54286

Appendix E

Full participant responses dataset for Experiment 3, coded to indicate target identification accuracy.

P Number	P Code	Gender	Age	Condition	Known	Known B+C Face	B+C Face R. Rate
1	3823	F	20	6	40	17	0.42500
2	3829	F	20	6	24	6	0.25000
3	3922	F	23	6	34	6	0.17647
4	4243	F	21	6	33	8	0.24242
5	4381	M	20	6	31	3	0.09677
6	4501	F	20	6	21	1	0.04762
7	6988	M	18	6	26	4	0.15385
8	4117	F	20	6	20	4	0.20000
9	4177	F	19	6	27	6	0.22222
10	4315	F	19	6	23	2	0.08696
11	6091	F	21	6	23	2	0.08696
12	6826	F	19	6	35	7	0.20000
13	7048	F	25	6	23	0	0.00000
14	3730	F	19	6	22	2	0.09091
15	3787	F	22	6	21	1	0.04762
16	4090	F	20	6	37	8	0.21622
17	4252	M	20	6	37	18	0.48649
18	4384	M	20	6	26	2	0.07692
19	6331	F	19	6	27	7	0.25926
20	6751	M	20	6	20	1	0.05000
21	7368	F	19	6	33	6	0.18182
22	8027	F	19	6	34	4	0.11765
23	4059	F	21	6	26	3	0.11538
24	7217	F	19	6	21	2	0.09524
25	7101	F	22	6	26	6	0.23077
26	4014	F	19	6	37	11	0.29730

P Number	P Code	Gender	Age	Condition	Known	Known B+C Chim	B+C Chim Sil R. Rate
1	3883	F	21	7	28	16	0.57143
2	4255	F	20	7	20	9	0.45000
3	4441	F	22	7	22	13	0.59091
4	7465	F	19	7	20	8	0.40000
5	3961	M	20	7	38	30	0.78947
6	6301	F	19	7	38	38	1.00000
7	3982	F	20	7	22	16	0.72727
8	6727	F	19	7	23	16	0.69565
9	7015	F	21	7	34	22	0.64706
10	3760	F	20	7	26	22	0.84615
11	6745	F	19	7	22	5	0.22727
12	7480	F	20	7	21	13	0.61905
13	6084	F	22	7	25	14	0.56000
14	7211	F	21	7	30	14	0.46667
15	4119	M	20	7	22	13	0.59091
16	4135	F	20	7	36	15	0.41667
17	7017	F	21	7	33	23	0.69697
18	7052	F	19	7	25	21	0.84000
19	7065	F	20	7	22	14	0.63636
20	4296	M	24	7	29	18	0.62069
21	6588	F	19	7	20	7	0.35000
22	6606	F	21	7	26	21	0.80769
23	4292	F	20	7	30	19	0.63333
24	4238	F	20	7	33	25	0.75758
25	4459	M	19	7	25	15	0.60000
26	7129	F	21	7	37	31	0.83784

Note: Experiment 3 analysed these datasets along with 2 datasets from Experiment 2 (5cpi blur chimeras (eyes) and silhouette chimeras) listed in Appendix D.

Appendix F

Participant demographics and handedness quotient for Experiment 4

P Number	P Code	Gender	Age	LH Dominance	RH Dominance	Laterality Quotient	Handedness
1	AS14	F	18	1	15	87.50	R
2	MA03	F	18	0	12	100.00	R
3	VE07	F	19	2	15	76.47	R
4	FM01	F	18	1	11	83.33	R
5	SA23	F	18	0	17	100.00	R
6	EL28	F	20	5	14	47.37	R
7	WE01	M	18	3	17	70.00	R
8	WE09	F	18	0	20	100.00	R
9	LZ24	F	18	3	13	62.50	R
10	ST12	F	19	0	14	100.00	R
11	MA17	M	22	0	19	100.00	R
12	SH15	F	22	2	15	76.47	R
13	EV03	F	20	5	14	47.37	R
14	RA14	F	20	6	16	45.45	R
15	SO01	F	21	2	17	78.95	R
16	MA14	F	21	0	16	100.00	R
17	RI12	F	21	3	15	66.67	R
18	AN09	F	21	8	10	11.11	R
19	SA22	F	21	0	19	100.00	R
20	IN10	F	20	0	24	100.00	R
21	NI22	F	20	11	8	-15.79	L
22	AM13	M	20	2	13	73.33	R
23	VA23	M	21	0	17	100.00	R
24	CA19	M	22	1	17	88.89	R

Appendix G

Repeated-measures ANOVA main and interaction effects for exploratory statistics for Experiment 4.

ERP	Effect	df	*F*	*p*	η^2p
N170 amplitude primes (140-180ms)					
	Hemisphere	(1,23)	5.80	.024†	.20
	Site	(1,23)	9.30	.006†	.29
	Hemisphere*Site	(1,23)	0.24	.692	.01
	Hemisphere*Manipulation	(2,46)	0.95	.394	.04
	Site*Manipulation	(2,46)	6.71	.003†	.23
	Hemisphere*Site*Manipulation	(2,46)	0.82	.449	.03
Peak Analysis, N170 amplitude primes (140-180ms) – P1 amplitude primes (80ms -129ms)					
	Hemisphere	(1,23)	1.97	.174	.08
	Site	(1,23)	0.98	.332	.04
	Hemisphere*Site	(1,23)	2.23	.149	.09
	Hemisphere*Manipulation	(1.41,32.53)*	1.30	.277	.05
	Site*Manipulation	(2,46)	0.57	.572	.02
	Hemisphere*Site*Manipulation	(2,46)	2.97	.061	.11
N170 latency primes (TP9/TP10)					
	Hemisphere	(1,23)	1.48	.236	.22
	Hemisphere*Manipulation	(2,46)	1.37	.264	.28
N250r amplitude (300-400ms)					
	Hemisphere	(1,23)	19.37	<.001†	.46
	Site	(1,23)	31.83	<.001†	.58
	Hemisphere*Site	(1,23)	0.09	.766	.00
	Hemisphere*Manipulation	(2,46)	2.86	.067	.11
	Hemisphere*Repetition	(1,23)	0.99	.331	.04
	Site*Manipulation	(2,46)	5.58	.007†	.20
	Site*Repetition	(1,23)	0.20	.657	.01
	Hemisphere*Site*Repetition	(1,23)	7.08	.014†	.24
	Hemisphere*Site*Manipulation	(2,46)	4.64	.015†	.17
	Hemisphere*Manipulation*Repetition	(2,46)	0.28	.757	.01
	Site*Manipulation*Repetition	(2,46)	1.56	.221	.06
	Hemisphere*Site*Manipulation*Repetition	(2,46)	1.54	.225	.06
N250r amplitude (300-400ms)					
	Hemisphere	(1,23)	20.21	<.001†	.47
	Site	(1,23)	29.97	<.001†	.57
	Hemisphere*Site	(1,23)	0.12	.732	.01
	Hemisphere*Manipulation	(2,46)	1.44	.248	.06
	Hemisphere*Repetition	(1,23)	5.64	.026†	.20
	Site*Manipulation	(2,46)	1.21	.307	.05
	Site*Repetition	(1,23)	1.08	.311	.05
	Hemisphere*Site*Repetition	(1,23)	4.58	.043†	.17
	Hemisphere*Site*Manipulation	(2,46)	2.90	.065	.11
	Hemisphere*Manipulation*Repetition	(2,46)	0.69	.505	.03
	Site*Manipulation*Repetition	(2,46)	4.83	.012†	.17
	Hemisphere*Site*Manipulation*Repetition	(2,46)	1.60	.213	.07

Note: Asterisks in the df column indicate Greenhouse-Geisser corrections, where Mauchly's Test indicated that sphericity could not be assumed.

Daggers in the *p* column denote a significant effect ($p < .05$).

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