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Neural correlates of facilitations in face learning by selective caricaturing of facial shape or reflectance

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ABSTRACT

Spatially caricatured faces were recently shown to benefit face learning (Schulz et al., 2012a). Moreover, spatial information may be particularly important for encoding unfamiliar faces, but less so for recognizing familiar faces (Kaufmann et al., 2013). To directly test the possibility of a major role of reflectance information for the recognition of familiar faces, we compared effects of selective photorealistic caricaturing in either shape or reflectance on face learning and recognition. Participants learned 3D-photographed faces across different viewpoints, and different images were presented at learning and test. At test, performance benefits for both types of caricatures were modulated by familiarity: Benefits for learned faces were substantially larger for reflectance caricatures, whereas benefits for novel faces were numerically larger for shape caricatures. ERPs confirmed a consistent reduction of the occipitotemporal P200 (200–240 ms) by shape caricaturing, whereas the most prominent effect of reflectance caricaturing was seen in an enhanced posterior N250 (240–400 ms), a component that has been related to the activation of acquired face representations. Our results suggest that performance benefits for face learning caused by distinctive spatial versus reflectance information are mediated by different neural processes with different timing and support a prominent role of reflectance for the recognition of learned faces.

Introduction

Behavioral and neuropsychological evidence suggests that qualitatively different processes are involved in familiar versus unfamiliar face perception (for a review, see Johnston and Edmonds, 2009). While familiar face recognition and matching remains robust across different images that encompass variability for instance in expression, viewpoint, or lighting (Bruce and Young, 1986; Burton, 2013), performance for unfamiliar faces under such conditions is massively impaired (Bruce et al., 1999; Hancock et al., 2000). Furthermore, evidence from face-sensitive event-related potentials (ERPs) suggests that different stages of familiar and unfamiliar face processing (see the models by e.g. Bruce and Young, 1986; Haxby et al., 2000; Schweinberger and Burton, 2003) are mediated by different underlying neural processes. However, while a substantial number of studies investigated ERP correlates of familiar (i.e. famous) face recognition, behavioral and neural processes that accompany the learning of novel faces are less well-known (for a review, see Schweinberger, 2011).

It is therefore important to understand the functional and neural processes that mediate the transition from a fragile and image-dependent mental representation to a robust representation as a face becomes familiar during learning. Although initial studies of ERP correlates of these processes yielded promising results (Kaufmann et al., 2009; Tanaka et al., 2006), an important but unresolved question is which diagnostic cues are utilized for face recognition. Assessing facial diagnostic cues in terms of local features or spatial frequency bands has a particularly long tradition in psychophysics that goes back at least to the excellent seminal work by Sergent (1985); subsequent research that used spatial frequency filtering, inversion, or the "Bubbles" technique resulted in significant further progress (e.g. Gaspar et al., 2008; Schyns et al., 2003; Sekuler et al., 2004). Relative to this earlier work that focused on information in particular locations or spatial frequency bands, the purpose of our study was to determine diagnostic cues in terms of shape versus reflectance information that are utilized for face learning and recognition. In computational image analyses, the two main sources of variability between faces, sometimes briefly referred to as shape and texture (Jenkins and Burton, 2008), concern facial shape including the spatial configuration of features, and reflectance properties (i.e. luminance, hue, and saturation). These two sources of variability correspond to the "warping" and "fading" components of standard image morphing software (e.g. Beale and Keil, 1995).

While many researchers appear to believe that subtle differences in the spatial configuration of features are crucial for face recognition (e.g. Richler et al., 2009), other research suggests that familiar face

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recognition is surprisingly robust to spatial distortion (Hole et al., 2002), or to the removal of individual shape via shape normalization (Burton et al., 2005; Russell and Sinha, 2007). In studies in which the impacts of shape and reflectance information on face recognition were directly compared, early evidence from recognition performance on laser-scanned familiar faces (presented either as 3D shapes devoid of reflectance information, or as “flattened” reflectance maps) pointed to a predominance of reflectance cues for recognition (Bruce et al., 1991). For small groups of people with extremely good or poor face recognition skills however, Russell et al. (2012) found no clear differential dominance of either shape or surface reflectance information. By contrast, Kaufmann et al. (2013) reported that observers generally use distinctive (caricatured) shape when encoding *novel* faces, while people with relatively low recognition skills – in contrast to good recognizers – continued to rely more on shape even for *learned* faces. These authors therefore hypothesized that reflectance information would be particularly important for successful recognition of familiar faces, but since reflectance information was not directly manipulated, this hypothesis could not be directly assessed in that study. Here we utilized both advanced methods of digital image manipulation and analyses of event-related potentials (ERPs) to investigate behavioral and neural effects of selectively caricatured shape and reflectance information on face learning and recognition.

Caricaturing, i.e. exaggerating those characteristics of a face that deviate from a norm (Perkins, 1975), has been shown to enhance perceived distinctiveness (Schulz et al., 2012a; Stevenage, 1995). This is important because distinctive faces are easier to remember than typical ones (Brown and Lloyd-Jones, 2006; Sommer et al., 1995; Valentine, 1991; Vokey and Read, 1992). To date, many experiments using caricatures employ spatial caricaturing, which accentuates the shape of separate features as well as their metric distances from each other (second-order configuration). While earlier studies using line drawings showed higher best-likeness ratings for caricatures of familiar faces (Rhodes et al., 1987), experiments using photorealistic caricatures of familiar faces yielded mixed results, with reports including caricature advantages (Irons et al., 2014; Lee and Perrett, 2000; Lee et al., 2000), no effects, or even caricature disadvantages (Allen et al., 2009; Kaufmann and Schweinberger, 2008).

Importantly, caricaturing was later shown to modulate the face-sensitive ERP components N170, P200, N250, as well as a late positive component (LPC). Caricatures compared to veridical images of *unfamiliar* faces elicited consistently larger occipitotemporal N170 and N250 ERPs (Kaufmann and Schweinberger, 2008). The N170 is more sensitive to faces compared to other stimuli (Bentin et al., 1996) and is generally unaffected by familiarity (Bentin and Deouell, 2000; Gosling and Eimer, 2011; Tanaka et al., 2006). Several researchers have associated this component with the detection and structural encoding of faces (Eimer, 2011; Schweinberger, 2011). According to Bruce and Young (1986), structural encoding “produces a set of descriptions of the presented face, which include view-centred descriptions as well as more abstract descriptions both of the global configuration and of features.” (p. 311). In contrast, the later N250 consistently reflects the processing of facial familiarity: Initially, an N250r was found to be larger for immediate repetitions of familiar faces (Schweinberger et al., 1995, 2002). Of particular relevance, an N250 was later found to be larger for previously learned or familiar faces (Gosling and Eimer, 2011; Kaufmann et al., 2009; Tanaka et al., 2006) compared to unfamiliar ones. Therefore, Kaufmann and Schweinberger's (2008) findings of caricature effects in the N250 for unfamiliar (but not familiar) faces prompted the idea that caricaturing might be particularly helpful in the initial encoding of novel faces. In a subsequent study, the same authors found monotonically increasing performance benefits (higher accuracies and shorter reaction times) for increasing levels of shape caricaturing (0%, 35%, and 70%). Simultaneously, shape caricaturing elicited monotonically decreasing right occipitotemporal P200 amplitudes, accompanied by smaller modulations of the N170, N250, and late-positive component (LPC; Kaufmann and Schweinberger, 2012). The LPC, as well as an N400-like component, is usually more positive for learned compared to novel faces (Eimer, 2000), and is interpreted in terms of a facilitated activation of identity-specific semantic information.

Recently, performance costs were found for spatial anti-caricatures, in which faces were warped towards an average shape, i.e. reduced in idiosyncratic spatial information (Schulz et al., 2012b). Moreover, the most systematic ERP modulation of the spatial manipulations appeared in the right occipitotemporal P200, with decreased amplitudes for caricatures, but increased amplitudes for anti-caricatures. This suggests that a decrease of the P200 may specifically reflect increasing deviation of idiosyncratic shape information from the perceptual prototype.

Despite this established role of facial shape for recognition, other recent research can be taken to suggest a major role of characteristics other than idiosyncratic facial shape, and thus aspects of reflectance (including luminance, texture, and coloration): Importantly, Schulz et al. (2012a) found significantly larger recognition benefits for naturally distinctive faces, compared to benefits for spatially caricatured faces that were matched to the former in terms of perceived distinctiveness. Moreover, a left-hemispheric N250 was largest for naturally distinctive faces. We note that Lee and Perrett (2000) reported higher best-likeness ratings for images of familiar famous faces enhanced in color, a finding which is also consistent with this idea.

The first study that directly compared the ERP effects of selective manipulations of either facial shape or reflectance was conducted by Caharel et al. (2009). Using an adaptation paradigm, these authors reported that changing global 3D face shape and changing 2D reflectance evoked different ERP effects: Specifically, the onset of ERP effects was earlier for shape, affecting the N170, whereas both shape and reflectance changes modulated the later N250. While these findings provide the first direct evidence for different neural processes underlying the processing of facial shape and reflectance, Caharel et al. (2009) did not find differences between shape and reflectance manipulations in matching performance, and did not study recognition performance.

Based on the findings reviewed above, we hypothesized that facial shape is more relevant during earlier stages of processing and for encoding of initially unfamiliar faces, whereas reflectance-related cues are more important for later stages of processing and for recognition of familiar faces. To explore the relative diagnostic values of facial shape and reflectance on face recognition, we compared effects of selectively caricaturing in either shape or reflectance on the acquisition of new face representations, using different images at learning and at test. We expected performance benefits as well as modulations of face-sensitive ERPs for both types of caricatures, but with systematic differences in the precise pattern of those effects. Specifically, for shape caricatures, we expected earlier ERP modulations with an onset in the N170 time-range, and a prominent effect for the P200 and the N250. By contrast, we expected a later onset of ERP modulation for reflectance caricatures, with a larger effect on the N250. In parallel, for shape caricatures, we expected a pattern of performance benefits that would reflect a facilitation of processing already at the encoding of novel faces, i.e. the correct rejection of novel faces. By contrast, we hypothesized that the performance benefits elicited by reflectance caricatures would be particularly prominent for learned faces.

Material and methods

Participants

Data were collected from 36 participants (27 females; aged 18–33 years [$M = 23.3$, $Mdn = 22.5$] all right-handed) who verbally confirmed normal or corrected-to-normal vision. Data from two additional participants were excluded due to an insufficient number of artifact-free EEG trials. All participants gave written informed consent and were compensated with either course credit or money. A bonus of either one Euro for ≥85% correct responses or two Euros for ≥90% correct