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Proficient use of low spatial frequencies facilitates face memory but shows protracted maturation throughout adolescence

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ABSTRACT

Face perception is characterized by configural processing, which depends on visual information in the low spatial frequency (LSF) ranges. However, it is unclear whether LSF content is equally important for face memory. The present study investigated how face information in the low and high SF range plays a role in the configural encoding of faces for short-term and long-term recall. Moreover, we examined how SF-dependent face memorization develops in female adolescence, by comparing children (9–10-year-olds), adolescents (12–13-year-olds and 15–16-year-olds), and young adults (21–32-year-olds). Results show that similar to face perception, delayed face recognition was consistently facilitated by LSF content. However, only adults were able to adequately employ configural LSF cues for short-term recall, analogous to the slow maturation of LSF-driven configural face perception reported by previous studies. Moreover, the insensitivity to face inversion of early adolescents revealed their inadequate use of configural face cues regardless of SF availability, corroborating previous reports on an adolescent "dip" in face recognition. Like face perception, face recognition has a protracted maturational course. In (female) adolescence, sensitivity to configural LSF cues is developed, which aids not only configural face perception but also face memorization.

1. Introduction

Faces are perceived as an integrated configuration ('Gestalt') rather than as a collection of independent features (e.g., Sergent, 1984). This configural processing style appears to be a specific strategy for faces: When configural processing is disrupted, for example by presenting stimuli upside down, perception of faces is much stronger degraded than perception of other object classes (the so-called 'Face Inversion Effect' or FIE; Yin, 1969; see Rossion, 2008 for review). Importantly, configural information is mainly extracted from coarse information in the low spatial frequency (LSF) range (e.g., Bar, 2004; Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Sergent, 1986). In contrast, high spatial frequencies (HSF) convey information about local perceptual details, which enables the fine-grained processing of face features (Goffaux & Rossion, 2006). Whereas research suggest the importance of LSF over HSF information for configural face *perception* (face discrimination), the role of SF in face *recognition* (face memory) has not been investigated yet. The present study investigates how face information in the LSF and HSF range play a role in the encoding of faces for short-term and long-term recall.

In typical adult face perception, information carried by low, mid, and high SF bands is combined according to a coarse-to-fine sequence (Goffaux et al., 2011; see Ruiz-Soler & Beltran, 2006 for review). First, the rapidly available coarse LSF content is analyzed for configural cues. These cues are particularly important for the fast interpretation of holistic information emerging from the simultaneous processing of features, for example to establish emotional states (Vlamings, Goffaux, & Kemner, 2009). Subsequently, more fine-grained information in HSF ranges is examined for featural aspects, for example to assess facial age (see Fig. 1 for examples of faces in which only LSF or HSF information is available). Previous psychophysical findings support this differential influence of information conveyed by low versus high SF ranges: Goffaux et al. (2005) showed participants displays with low-pass or high-pass filtered face triplets for which they had to indicate

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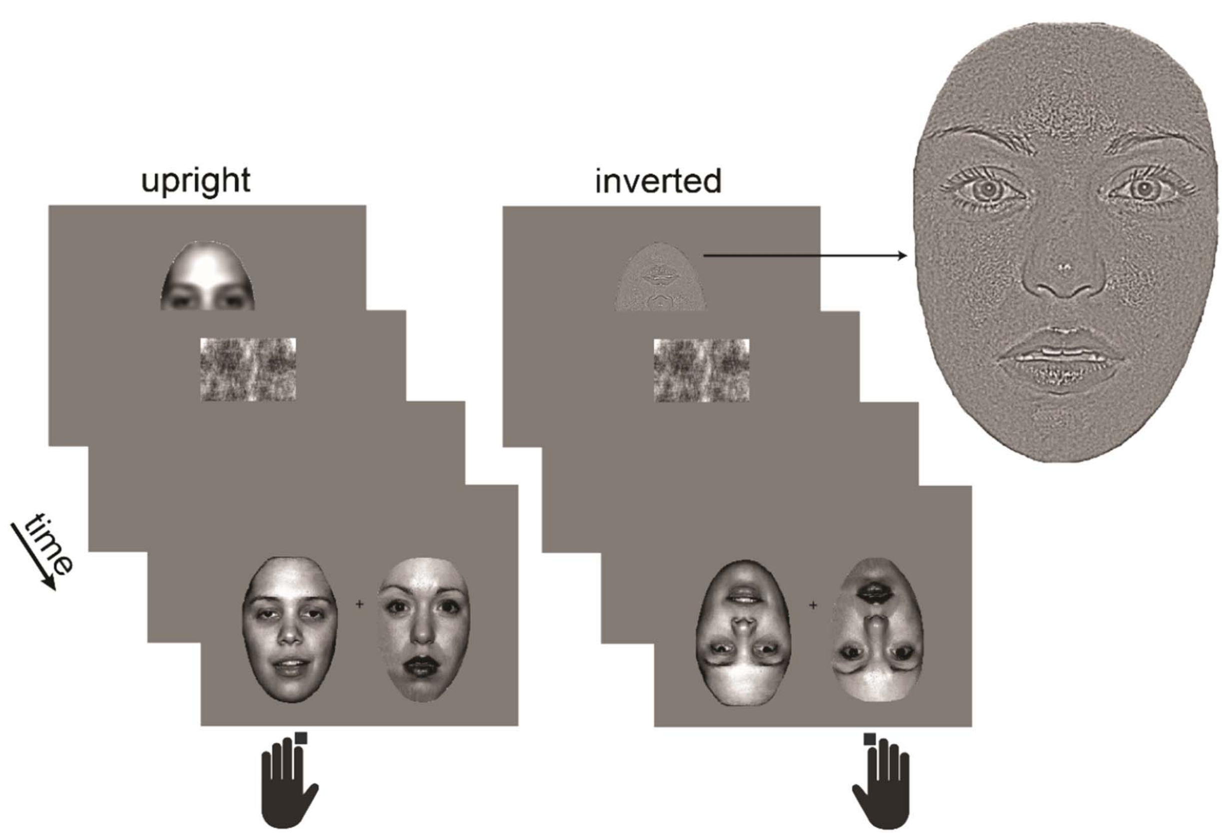

Fig. 1. Exemplars of an upright (left) and inverted (right) trial in the short-delay recognition task. Trials started with the presentation of an LSF or HSF face (sample), immediately followed by mask (scrambled version of a random full-spectrum face). After the delay (500 ms), a matching and non-matching full-spectrum probe was shown on the left and right side (random per trial, counterbalanced across orientation trials) and subjects had to press the button corresponding to the side of the match. In these examples, the probe matching the LSF sample in the upright trial was presented left so subjects pressed the left button. In the inverted trial, the HSF face (inset shows upright & enlarged version for illustrative purposes) matched the probe on the right, requiring a right button response.

which of the two probe faces matched the sample face. When the probes differed in configural aspects (spatial relations between features, such as the metric distance between eyes), subjects were faster in discriminating low-pass filtered faces than high-pass filtered faces. In contrast, high-pass filtered faces provided an advantage when probes differed on local features. Thus, the presence of LSF content facilitated configural processing, whereas the availability of HSF information supported local feature processing. However in Goffaux et al.'s study, sample and probes faces were presented simultaneously until the subject responded. Hence, subjects could compare the sample and probes solely using perceptual information without the need to rely on memory processes (other than trans-saccadic memory). Thus, although Goffaux et al. (2005) provided important insights into the differential role of LSF versus HSF cues in face perception, it remains unclear whether face memory depends on similar divergent SF contributions. Although face memory and face perception are related, underlying processes could be biased to different SF bands: Face perception relies on LSF-based configural processing, which is useful to monitor fast and global changes, such as switches between emotional states or head turns. However, memorizing a face might require an additional focus on local feature details that contain specific information on facial identity. For example, encoding identity-specific, fine details such as eye contours, lip shape, or skin texture could help to keep a memory representation of a facial identity separate from other stored representations of resembling faces, which is essential for accurate recall of the appropriate facial identity. Such specific details are conveyed by HSF rather than LSF content. Therefore, unlike face perception, HSF information in faces might be as relevant for face memory as LSF content. The present study investigates this question by employing a paradigm akin to Goffaux et al. (2005), but with (short and long) memory delays between sample and probe presentations. In addition, low-pass and high-pass filtered faces were not only presented in upright orientation, but also in inverted orientation. Face inversion disrupts configural processing more strongly than the processing of local features (e.g., Goffaux, 2009; Rossion, 2008), while preserving intrinsic input properties. Therefore, manipulation of picture-plane orientation allows a well-controlled examination of the relative involvement of configural versus local feature processes. Face perception research showed the importance of LSF for configural processing. If (potential) contributions of LSF content to face memory were likewise attributable to the configural cues conveyed by this SF range, disruption of such cues by face inversion will have a particular strong impact on LSF-driven memory processes. In contrast, given that local feature processing is less affected by face inversion, inverting high-pass filtered faces might be less disruptive for face memory.

In addition to the role of SF in adult face memory, the present study also examines how SF-driven face processing changes during development, with a particular focus on the dynamic period during early adolescence. Children adopt a different SF processing strategy than adults, which might underlie their inefficiency in configural processing. Children below 10 perform poorly on face perception tasks that require the use of configural information (Mondloch, Le Grand, & Maurer, 2002; Schwarzer, 2000). This might be related to the finding that, unlike adults, in 9–10-years-olds configural face processing is not driven by LSF content (Peters, Vlamings, & Kemner, 2013). Interestingly, the same children who perform poorly on configural face perception tasks, perform well on tasks that entail the use of face features (Mondloch et al., 2002; Schwarzer, 2000; see Maurer, Le Grand, & Mondloch, 2002 for review). This good performance, which in some cases reaches adult levels, might benefit from the preferred use of