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Categorizing facial identities, emotions, and genders: Attention to high- and low-spatial frequencies by children and adults

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Abstract

Three age groups of participants (5–6 years, 7–8 years, adults) matched faces on the basis of facial identity. The procedure involved either low- or high-pass filtered faces or hybrid faces composed from two faces associated with different spatial bandwidths. The comparison stimuli were unfiltered faces. In the three age groups, the data indicated a significant bias for processing of low-pass information in priority. In a second task, participants were asked to identify the emotion (smiling or grimacing) or gender (male or female) of hybrid high-pass/low-pass faces. Opposite results emerged in the two tasks irrespective of the age group; the gender discrimination task indicated a bias for low-pass information, and the emotion task indicated a bias for high-pass information. These differences suggest independent processing routes for functionally different types of information such as emotion, gender, and identity. These routes are already established by 5 years of age.

Keywords: Face perception; Identity; Emotion; Gender; Spatial frequency

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Introduction

Faces are polymorphous stimuli conveying various kinds of information such as gender, emotion, and identity. Most models of face processing posit that these different types of information are processed by functionally different neural/cognitive systems (e.g., Bruce & Young, 1986). The hypothesis that different systems process gender, emotion, and identity information (hereafter referred to as the hypothesis of functional separability) is supported in the literature by the following five lines of converging evidence. First, gender and identity are processed at different speeds than are emotions in judgmental tasks (e.g., Le Gal & Bruce, 2002). Second, variations of emotional expressions have little effect on facial identity judgments, but reaction times for emotion judgments are influenced by identity variations (e.g., Schweinberger & Soukup, 1998). Third, distinct patterns of cerebral activation emerge for the recognition of identity, expression, and gender (from event-related potentials [ERP] studies: e.g., Boles, Martin, Olivares, & Valdés-Sosa, 2000; from functional magnetic resonance imaging [fMRI] studies: e.g., McCarthy, Puce, Gore, & Allison, 1997; from positron emission tomography [PET] studies: e.g., Sergent, Otha, MacDonald, & Zuck, 1994). Fourth, brain lesions selectively affect adults' recognition of facial identity and emotion (e.g., Humphreys, Donnelly, & Riddoch, 1993). Fifth, in fMRI studies, presentation of low- and high-pass filtered faces results in distinct patterns of processing of face and emotional expressions (e.g., Vuillemier, Armony, Driver, & Dolan, 2003). Interestingly, all of these findings supporting the hypothesis of functional separability are based on studies of normal adults or patients. There is surprisingly little developmental research on this topic.

In one of the few relevant studies, Bruce et al. (2000) studied the development of expression, lipreading, gaze, and identity processing in 4- to 10-year-olds. There were no significant correlations among matching-to-sample tasks in the different test conditions, suggesting that these various aspects of faces are already processed independently in children of that age. In another study (Bormann-Kischkel, 1986), 5-year-olds and adults were asked to sort cards that varied in terms of identity and emotion expressions. Adults and children showed a bias for sorting on an emotion basis rather than on an identity basis, suggesting that emotion and identity can be tapped independently. Finally, De Sonneville et al. (2002) tested children (7–10 years of age) and adults in face identity and face emotion discrimination tasks. Regardless of age, face recognition was faster than emotion recognition. These three studies tend to support the hypothesis of separability in children, and this would confirm as well as expand what is known about adults. Conclusions cannot be guaranteed, however, due to the reduced number of available developmental studies. These studies, moreover, convey no detailed information on the stimulus dimensions to which children paid attention when categorizing facial emotion and identity.

In that context, the current research was aimed at better documenting the relative development during childhood of perception of identity, gender, and emotion. To better characterize the processing of emotion, gender, and identity, participants at three ages (5–6 years, 7–8 years, and adults) were tested in the current research using spatial frequency filtered facial stimuli. Our reasoning was that controlling the frequency band available on faces should indicate whether different spatial frequency channels are used by children when processing identity, emotion, and gender facial information.

The two experiments reported here focus on the processing of identity (Experiment 1) and on the processing of both gender and emotion (Experiment 2). Although presented in succession, these two experiments were actually run in a balanced order, with half of the participants being tested at first in Experiment 1 and the other half being tested at first in Experiment 2.

Experiment 1: Facial identity

Experiment 1 focused on the processing of facial identity using a procedure largely inspired by Schyns and Oliva (1999, Experiment 3). These authors showed adults hybrid stimuli that were composed by systematically overlapping the low-spatial frequency components of one individual face with the high-spatial frequency components of another individual face. After being taught to identify the pictures of six different faces, participants were asked to name the face shown in the hybrid stimulus. Response choices indicated that participants primarily relied on low spatial frequencies when processing identity of the hybrid faces. One possible account of this result is that low-pass filtering, in contrast to high-pass filtering, preserves the configural structure of the faces that is necessary for accessing identity information (Costen, Parker, & Craw, 1994; Tanaka & Farah, 1993).

Using spatial frequency filtered face stimuli, Deruelle, Rondan, Tardif, and Gepner (2004) compared perception of identity in a group of autistic children with that in normally developing children matched on chronological or mental age. The procedure involved presentation of high- or low-pass filtered faces and then asking participants to match the high- or low-pass filtered faces with their corresponding unfiltered original faces. Autistic children processed the faces differently from normal children, with the former showing a bias for high-spatial frequency components and the latter showing a bias for low-spatial frequency components. The reliability of these findings, however, is limited by small sample sizes (11 children in each group) and by age variations (participants ranged from 4.4 to 12.0 years).

In the current study, three types of stimuli were presented to children. In line with Deruelle et al. (2004), the first two types involved faces from which only the high- or low-pass spatial frequency components were retained. Following Schyns and Oliva (1999), the third type consisted of hybrid faces composed from the low-pass component of the face of one individual pasted atop the high-pass component of the face of another individual. In hybrid trials, children and adults had to match the hybrid face with one of the two original faces that composed the hybrid. In the other trials involving the filtered faces, participants had to match the high- or low-pass filtered face with the unfiltered original face to which it corresponded. To our knowledge, this research is the first attempt to qualify face processing in children using spatially filtered hybrid stimuli. We predicted that adults' response choices and error rates would indicate a bias for low spatial frequencies reflecting a configural advantage. Predictions were more uncertain for children because the developmental time course of configural processing remains a debated issue (e.g., Mondloch, Le Grand, & Maurer, 2002).

Method

Experiment 1 involved 54 participants from three age groups. The first group consisted of 18 children (10 boys and 8 girls) ranging in age from 5.0 to 6.5 years. Hereafter, this group is referred to as 5- and 6-year-olds (mean age = 5.4 years). The second group, referred to as 7- and 8-year-olds, consisted of 18 children (8 boys and 10 girls) ranging in age from 7 to 8.5 years (mean = 7.7 years). The third group consisted of 18 adults (9 men and 9 women) ranging in age from 20 to 30 years (mean = 24.1 years). Children were recruited in the kindergarten of the CNRS in Marseille, France, or by advertisement in local primary schools. Adults were student volunteers. All participants had normal or corrected-to-normal vision.

Apparatus

Participants were tested in a quiet and dimmed experimental chamber. Each participant was seated in front of a 17-in. monitor controlled by a Macintosh PC computer and placed his or her chin on a chin rest, thereby keeping the viewing distance equal to 60 cm.

Stimuli

The stimulus set was constructed from original faces of 11 females and 11 males. Original faces were black and white. They were normalized in size and luminance before being pasted on a 256×256-pixel gray background corresponding to 6° of visual angle at the viewing distance. Three types of stimuli were created from the original faces: low-pass filtered faces, high-pass filtered faces, and high-pass/low-pass hybrids. The low-pass filtered faces contained only spatial frequencies less than 2 cycles per degree of visual angle. The high-pass faces contained only spatial frequencies greater than 6 cycles per degree of visual angle. The low- and high-pass cutoffs corresponded to spatial frequencies less than 12 and greater than 36 cycles per image, respectively. The high-pass/low-pass hybrid faces were created from the superposition of one high-pass and one low-pass filtered face different from, but of the same gender as, the high-pass face. A Gaussian filter was used for the cutoffs. The overall stimulus set contained 86 stimuli corresponding to 22 stimuli for each of the original, low-pass, and high-pass types and 20 high-pass/low-pass hybrid stimuli[1] (Fig. 1). All stimuli were created using the software Scion Image (version 1.62, Scion Corporation, Frederick, MD, USA).

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[1] The number of hybrids was restricted to 20 to completely balance the gender and emotion factors (5 hybrids were created per gender per emotion condition).

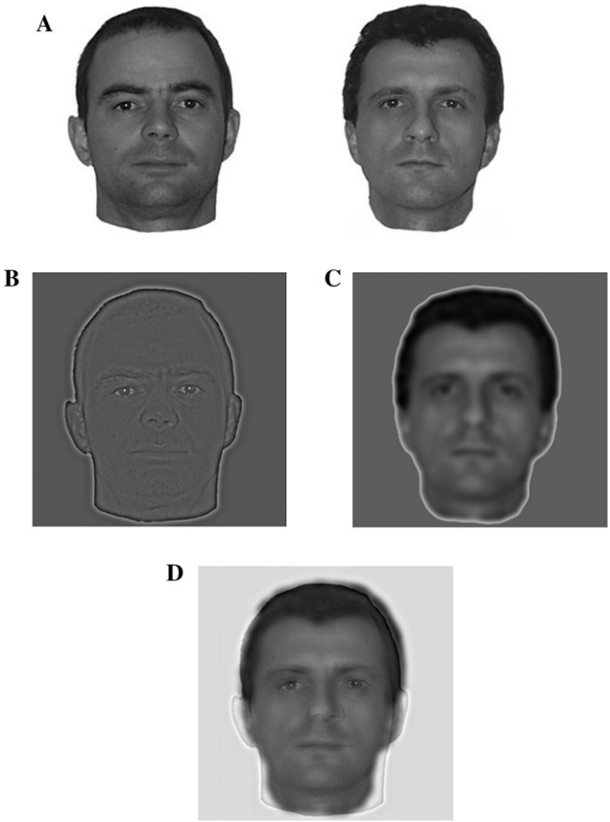

Fig. 1. Illustration of the original (A), low-pass (B), high-pass (C), and hybrid stimuli (D). In this example, the hybrid stimulus resulted from the superposition of the high- and low-pass stimuli.

Procedure

A face identity matching procedure was used. After a first press on the bar space key, a 1 × 1° of visual angle red square appeared for 500 ms in the center of the screen. This square served as the fixation point. The fixation point was immediately replaced by the sample stimulus displayed during either 400 ms (for the children) or 100 ms (for the adults) in the center of the screen. Two comparison stimuli appeared left and right of the screen, immediately after the offset of the sample stimulus. Participants were asked to judge which of the two comparison stimuli matched the sample on the basis of facial identity. Responses were given by pressing either the "A" or "P" key of an Azerty keyboard, with these keys being rendered distinctive by color patches. Key presses aborted the trials. Participants received no feedback regarding the accuracy of their choices but were regularly encouraged to pursue the task by positive verbal reinforcements. For adults and children, presentation durations were determined from a preliminary sample of observations using several exposure durations. These observations revealed that children were at chance level if the sample duration was set to 100 ms, whereas adults made virtually no errors with 400 ms.

Each participant underwent a total of 64 test trials consisting of 20 trials with the hybrid faces, 22 low-pass trials, and 22 high-pass trials. During each trial, the high-pass, low-pass, or hybrid stimuli served as the sample and the original faces served as the comparison stimuli. In the case of a high-pass or low-pass trial, the positive comparison stimulus systematically corresponded to the original face from which the high- or low-pass sample face had been derived. The negative comparison stimulus was systematically the original face of an individual different from the sample model but the same gender as the sample. In the case of a hybrid trial, the comparison stimuli were the two original faces from which high- and low-pass versions were used to create the hybrid sample.

Training trials were conducted prior to the test phase. During training, participants were verbally instructed to match the faces based on the identity of the sample. There were 4–12 training trials, depending on the participant's comprehension of the task.

Statistical analyses

For the analysis of the high- and low-pass trials, the number of errors served as the dependent variable in a 3 (age: 5–6 years, 7–8 years, or adults) × 2 (spatial frequency: low-pass or high-pass) analysis of variance (ANOVA) with repeated measures on the final factor. For the hybrid trials, a one-way ANOVA in which the age group was the unique factor was carried out on the number of low-pass choices, considering that there was no correct response for these trials. When necessary, Tukey honestly significant differences (HSD, $p < .05$) post hoc tests were carried out for pairwise comparisons.

Results

The number of errors in high- and low-pass trials was low on average, corresponding to 12.4% of all trials. Application of the age by spatial frequency ANOVA revealed a significant effect of age, $F(2,51) = 11.06$, $p < .01$. Post hoc analyses of this effect (Tukey HSD, $p < .05$) provided the following pattern of results: 5- and 6-year-olds (mean = 18.9% of errors) > 7- and 8-year-olds (mean = 10.9%) = adults (mean = 7.4%). The effect of spatial frequency also emerged as significant, $F(1,51) = 11.3$, $p < .01$. Errors were less on low-pass trials (9.3%) than on high-pass trials (15.6%). The age by spatial frequency interaction was not significant, suggesting that the advantage for low-pass trials was independent of the age of the participants.

For the hybrid trials, participants matched the faces on the basis of the low spatial frequencies rather than the high ones. In all groups, the average number of low-pass choices reliably exceeded chance level, as revealed by two-tailed t tests: 5- and 6-year-olds, mean = 12.7, $t(17) = 4.18$, $p < .001$; 7- and 8-year-olds, mean = 13.5, $t(17) = 4.18$, $p < .001$; adults, mean = 13.94, $t(17) = 5.9$, $p < .001$. There was no reliable difference across age groups regarding the number of low-pass choices, $F(2,51) =$

0.90, $p > .05$, suggesting that the advantage for low-pass information is independent of the age of the participants.

Discussion

The basic conclusion from this first experiment is straightforward: Participants tended to rely primarily on low spatial frequencies (i.e., information representing less than 12 cycles/image) in processing the identity of faces. Noticeably, that effect emerged from the comparison of error rates for the high- and low-pass filtered faces as well as from the analysis of response choices in hybrid trials. Importantly, this effect emerged consistently in all three age groups, suggesting that this propensity to code identity through the analysis of low spatial frequencies was already established in our younger participants. Before discussing these results, we present the results of a second experiment focusing on the processing of gender and emotion.

Experiment 2: Gender and emotion

Method

The participants and apparatus were the same as in Experiment 1

Stimuli

This experiment used 24 hybrid high-pass/low-pass faces, all constructed from a novel set of 12 male and 12 female faces showing either a smiling expression (6 faces per gender) or a grimacing expression (for the other 6 faces). High- and low-pass faces composing each hybrid stimulus systematically differed based on (a) the gender of the model and (b) the model's emotional expression, either smiling or grimacing. For instance, if the high-pass face showed a grimacing man, the low-pass face systematically showed a smiling woman (Fig. 2). To homogenize haircut styles, only men with short hair were retained and women were requested to tie their hair. The other aspects of the faces, such as their size and the spatial frequencies retained in high- and low-pass filtered images, were identical to those in Experiment 1.

Procedure

Participants underwent two successive sessions of 24 trials in which they were asked to identify the facial emotion of the hybrid faces in one session and to identify the gender of the hybrid faces in the other session. The order of the two sessions was counterbalanced across participants.

Before the experimental trials, participants received 4–12 practice trials depending on their levels of comprehension. The procedures for the practice and training trials were identical. A press on the bar space key triggered a 500-ms presentation of the fixation stimulus in the center of the screen. The fixation point was then replaced by

Fig. 2. Illustration of a hybrid stimulus resulting from the superposition of a low-pass face of a smiling woman and a high-pass face of a grimacing man.

a central hybrid face, which was displayed for either 400 ms (for children) or 100 ms (for adults). Therefore, stimulus durations were identical to those in Experiment 1. The screen turned white after the offset of the hybrid stimulus. In the "gender sessions," participants were asked to indicate after the target offset whether the hybrid face represented a man or a woman. The A or P keys of the Azerty keyboard were used for responding, with key assignments to the man and woman categories varying across participants in a fully balanced design. In the "emotion sessions," participants had to indicate whether the person was smiling or grimacing. The key assignments to the smiling and grimacing categories were similarly balanced across participants. The key presses aborted the trials, and the participants received no feedback regarding the accuracy of their responses. Response choices were recorded in each trial.

Participants received verbal instructions prior to each session. Verbal instructions indicated whether the responses were to be based on the gender or the emotion of the hybrid faces and emphasized the need for fast responses. Participants received 4–12 training trials prior to each session, using hybrid faces different from the test faces.

Results and discussion

Statistical analyses first verified whether a bias for either the low or high spatial information emerged in the three age groups (Fig. 3). For that purpose, the average number of low-pass choices was compared with chance level independently for each group and task (gender or emotion) by way of two-tailed t tests. For the gender categorization session, findings showed a reliable low-spatial frequency bias in all three age groups: 5- and 6-year-olds, mean = 13.8, $t(17) = 2.5$, $p < .05$; 7- and 8-year-olds, mean = 15.9, $t(17) = 4.8$, $p < .01$; adults, mean = 17.3, $t(17) = 8.3$, $p < .001$. For the

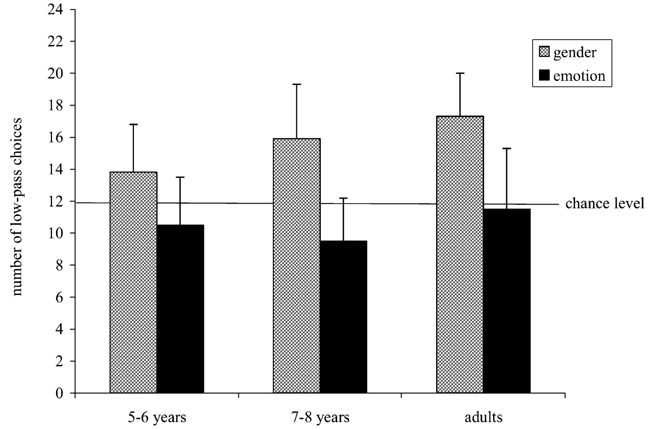

Fig. 3. Number of low-pass choices for the gender and emotion categorization tasks as a function of age.

emotion categorization session, data showed a significant high-spatial frequency bias in the two groups of children, as revealed by a number of low-pass choices significantly lower than chance: 5- and 6-year-olds, mean = 10.05, $t(17) = 2.5$, $p < .05$; 7- and 8-year-olds, mean = 9.5, $t(17) = 3.7$, $p < .01$. Preference for high-pass spatial frequencies did not emerge in the adult group, mean = 12.5, $p > .05$.

The number of low-pass choices obtained in the two test sessions was analyzed by means of a 3 (age: 5–6 years, 7–8 years, or adults) × 2 (task: gender or emotion) ANOVA with repeated measures on the final factor. There was a reliable effect of task, $F(1, 51) = 103.8$, $p < .001$; the number of low-pass choices was higher in the gender categorization task than in the emotion categorization task. The age group effect was also significant, $F(2, 51) = 5.6$, $p < .01$. Pairwise comparisons indicated a greater number of low-pass choices in the adults than in the 5- and 6-year-olds, $F(1, 34) = 13.12$, $p < .05$. The 7- and 8-year-olds did not differ significantly from the younger or older participants. Interestingly, there was no significant task by age interaction, $F(2, 51) = 2.39$, $p > .05$, suggesting that the biases for low spatial frequencies (gender categorization task) and high spatial frequencies (emotion categorization) were not significantly related to the age of the participants.

In brief, in support of the hypothesis of functional separability, Experiment 2 showed that participants of all ages relied on different frequency bands depending on the type of facial information being processed. Participants relied preferentially on high spatial frequencies in the emotion categorization task and on low spatial frequencies in the gender categorization task. Experiment 2 also showed a greater propensity to pay attention to the low-spatial frequency component of the images for older participants than for younger participants, but that bias did not differentially affect emotion and gender processing, suggesting that separability demonstrated by the main effect of task was independent of the age group. One important characteristic of our procedure is that the two test conditions used identical stimuli and response modalities but differed only in terms of instructions to participants. Therefore, the dissociation emerging from this experiment cannot be accounted for by procedural differences between the test conditions in emotion and gender categorization sessions but more likely indicates that gender and emotion processing selectively biased the participants for attending to different spatial frequency bands.

General discussion

Experiment 1 revealed that participants of the three age groups preferentially paid attention to low spatial frequencies when processing facial identity. Experiment 2 extended this finding. It revealed that different spatial frequency biases also emerged in the processing of gender and emotion, with gender processing being associated with a low-spatial frequency bias and emotion processing being associated with a high-spatial frequency bias. Taken together, Experiments 1 and 2 consistently suggest that the processing of identity and the processing of gender are qualitatively different from the processing of emotion and, consequently, support the hypothesis of functional separability. More important, our results point to the fact that functional separability is already present in 5- and 6-year-olds and is not subject to drastic changes from 5 years to adulthood.

It has already been proposed that a single route may convey the processing of identity and gender of faces. For instance, using principal components analyses of face pixel intensities, Calder, Burton, Miller, Young, and Akamatsu (2001) reported that gender and facial identity are coded from the same components of the faces. In the field of cognitive neurosciences, Dubois et al. (1999) observed that gender and identity judgments primarily recruited the same cerebral structure—the fusiform area. Our results agree with these findings by demonstrating that low spatial frequencies are critical for the processing of both face gender and face identity. These convergent findings most likely indicate that both gender and identity involve consideration of the configural properties of the faces (e.g., Rhodes, 1993; Tanaka & Farah, 1993), which are known to be processed by the fusiform area and better represented by the low-spatial frequency components of the faces than by the high-spatial frequency components of the faces (e.g., Costen et al., 1994).

The processing of emotion was associated with a high-spatial frequency bias in our research and contrasted with the low-spatial frequency bias observed for emotion and gender. A tempting hypothesis is to propose that the high-spatial frequency bias obtained for emotion processing reflects some general propensities to pay attention to the local features of the faces whenever emotion must be considered. Caution is advised, however, due to a largely incongruent literature on emotion processing.

Several studies have already reported that recognition of facial expressions is mediated in priority by the high-spatial frequency components of the faces (e.g., Schyns & Oliva, 1999; Vuillemier et al., 2003) and, therefore, presumably by the local details of the stimuli. Inspection of the stimuli suggests that this hypothesis might also apply in our research. For instance, if the orientation of the corner of the mouth is analyzed, it can potentially afford sufficient information for an accurate categorization of the emotional content of the faces. This hypothesis is contradicted, however, by another set of reports indicating that emotion processing might also be conveyed by low-spatial frequency components (e.g., Schyns & Oliva, 1999; Vuillemier et al., 2003; Winston, Vuillemier, & Dolan, 2003) and by an analysis of the faces at a more global level (e.g., Calder, Young, Keane, & Dean, 2000).

Consideration of the procedure involved in these different reports might clarify these apparent contradictions. First, the high-spatial frequency bias obtained in the current study might reflect the need for participants to decide whether the face was smiling or not rather than categorizing the faces in different classes of expressions. Consistent with this interpretation, Schyns and Oliva (1999) observed a high-spatial frequency bias in an emotion detection task but a shift in favor of a low-spatial frequency bias in an emotion categorization task. In addition, the different reports indicating a low-spatial frequency bias in emotion processing often involved a procedure in which the emotion is perceived implicitly (e.g., Vuillemier et al., 2003; Winston, O'Doherty, & Dolan, 2003), whereas reports showing a high-spatial frequency bias involved mostly explicit processing of the emotional faces. Implicit and explicit judgments about emotional faces are known to recruit different brain regions and, thus, qualitatively different modes of processes (e.g., Wicker, Deruelle, & Hubert, 2002; Winston et al., 2003). Thus, it appears that the emotional aspects of the faces can potentially be mediated by an analysis of either the global components of the faces (i.e., low-spatial frequency) or the local ones (i.e., high-spatial frequency). We presume that the participants exhibited a high-spatial frequency bias in our task due to the request for an explicit processing of the emotions.

In a different perspective, because of the likely relation between configural and low-spatial frequency processing, the fact that our three age groups indistinctively processed the low-spatial frequency information may appear to contradict published evidence that configural processing evolves during childhood. It should be noted, however, that contradictory data exist on the development of configural processing, as revealed by the development of the face inversion effect. Indeed, some researchers have observed developmental trends for the inversion effect (e.g., Schwarzer, 2000), whereas others have not (e.g., Carey & Diamond, 1994). In addition, demonstration is needed for a clear-cut relation between mechanisms involved in inversion effects and low-spatial frequency processing. Rondan and Deruelle (2004) provided recent evidence of a dissociation between the inversion effect and low-spatial frequency processing. Thus, further experiments are needed to clarify this issue.

Early developmental studies have suggested that functional separability already characterizes face processing in 7-year-olds (De Sonneville et al., 2002) and even face processing in 5- and 6-year-olds (e.g., Bormann-Kischkel, 1986; Bruce et al., 2000). They have also demonstrated that the ability to discriminate facial expressions or identities continues to develop during late childhood and adolescence (e.g., Chung & Thomson, 1995; Kolb, Wilson, & Taylor, 1992). Our study has several interesting features in this context. First, it confirms that separability is already present in 5- and 6-year-olds. Second, comparisons among the three age groups indicated that the processing of identity, emotion, and gender facial information achieved in the youngest age group is not qualitatively different from the processing of the same three kinds of information in 7- and 8-year-olds or even in adults. This finding clearly rules out the hypothesis that the developmental trends reported previously in the literature reflect qualitative changes in the face processing modes so far as the low- or high-spatial frequency processing modes are concerned. Finally, and possibly more important, the current study points out a mechanism on which separability may rely at a very early age—a differential focus on the high- or low-spatial frequency band as a function of the aspect of the face that must be processed, identity, gender, and emotion in our experiments. Further experiments using spatial frequency filtered faces with even younger children are needed to determine when separability emerges.

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