Brief Report

Three-Month-Old Infants' Sensitivity to Horizontal Information Within Faces

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ABSTRACT: *Horizontal information is crucial to face processing in adults. Yet the ontogeny of this preferential type of processing remains unknown. To clarify this issue, we tested 3-month-old infants' sensitivity to horizontal information within faces. Specifically, infants were exposed to the simultaneous presentation of a face and a car presented in upright or inverted orientation while their looking behavior was recorded. Face and car images were either broadband (UNF) or filtered to only reveal horizontal (H), vertical (V) or this combined information (HV). As expected, infants looked longer at upright faces than at upright cars, but critically, only when horizontal information was preserved in the stimulus (UNF, HV, H). These results first indicate that horizontal information already drives upright face processing at 3 months of age. They also recall the importance, for infants, of some facial features, arranged in a top-heavy configuration, particularly revealed by this band of information.* Dev Psychobiol 9999: 1–7, 2016.

Keywords: *infant; early experience; vision*

INTRODUCTION

Faces are salient and biologically significant visual stimuli that provide critical cognitive and social information. Right after birth, newborns already prefer to orient towards so-called top-heavy patterns which, like faces, contain more elements in the upper than the lower part of their configurations (Goren, Sarty, & Wu, 1975; Johnson & Morton, 1991; Simion, Macchi Cassia, Turati, & Valenza, 2001; Simion, Valenza, Macchi Cassia, Turati, & Umiltà, 2002). They are also capable of discriminating their mother's face from a female unfamiliar face (e.g., Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995) and of recognizing unknown faces to which they have previously been habituated (Pascalis & de Schonen, 1994; Turati, Macchi Cassia, Simion, & Leo, 2006). Later in their development, faces remain of critical interest for infants who process their upright versions differently than their inverted versions (Turati, Sangrigoli, Ruel, & de Schonen, 2004) and differently than other meaningless (Halit, Csibra, Volein, & Johnson, 2004; Kouider et al., 2013) and meaningful patterns such as toys, strollers, or cars (de Haan & Nelson, 1999; de Heering & Rossion, 2015; Dobkins & Harms, 2014; Durand, Baudouin, Lewkowicz, Goubet & Schaal, 2013; Gliga & Dehaene-Lambertz, 2007; Peykarjou & Hoehl, 2013).

These early face-processing skills are remarkable especially if one considers the immaturity of the visual system in the first months of human life (Banks & Bennett, 1988; Candy & Banks, 1999). Newborns' sensitivity to grating contrast is about 30 times worse than that of adults (Slater & Sykes, 1977) and it is restricted to spatial frequencies below one cycle per degree (Acerra, Burnod, & de Schonen, 2002; Banks & Bennett, 1991). At this age, they tune to even lower

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spatial frequencies (below 0.5 cpd) when they have to recognize faces (de Heering et al., 2008). That is, it appears that a number of non-specific perceptual constraints filter the information the developing brain has access to, and this strongly influences the establishment of the face processing system in the first months of life (de Heering et al., 2008; de Schonen & Mathivet, 1989; Ginsburg, 1986; Sergent, 1986).

Adult face processing abilities are also influenced by the spatial frequency content of stimuli they are exposed to (Goffaux et al., 2011; Morrisson & Schyns, 2001; Näsänen, 1999). Recent work further showed that face processing in adults is also tuned to specific orientations (e.g., Dakin & Watt, 2009; Goffaux & Dakin, 2010; Pachai, Sekuler & Bennett, 2013). In line with the latter statement, adults have been described to identify naturalistic pictures of celebrities substantially best when images have been filtered to only contain horizontal information compared to other orientation bands (Dakin & Watt, 2009; but see also Goffaux & Dakin, 2010; Pachai et al., 2013). According to Dakin and Watt (2009), horizontal information may indeed conveys richer face identity information than vertical information because it better preserves the top-heavy configuration of internal facial features (see also Goffaux & Rossion, 2007; Keil, 2009). Conversely, vertical filters may preserve the lateral edges of the facial outline, the bridge of the nose and the pupils (for similar observations by means of an ideal observer; see Pachai et al., 2013), which are of lesser relevance for face identification, as also evidenced by the observation that adult face discrimination is deteriorated in a same/different task in the absence of horizontal information (Goffaux & Dakin, 2010). Importantly, the fact that face images convey more energy in the horizontal compared to other orientation ranges cannot simply explain adults' horizontal advantage of face identity processing given that Goffaux and Dakin (2010) observed that adults' face discrimination of unfamiliar faces is the best in the horizontal range only when face stimuli are upright. This however suggests that adult horizontal advantage takes place at higher levels of visual processing where upright face information is processed in a specialized way (see Goffaux, Duecker, Hausfeld, Schiltz, & Goebel, 2016 for neuroimaging evidence; Rossion & Gauthier, 2002).

The ontogeny of the horizontal tuning of face processing has recently been investigated in two distinct developmental studies targeting different levels of face categorization. On the one hand, Goffaux, Poncin, and Schiltz (2015) used the face inversion effect as a marker of the engagement of face-specialized processing (for a review, see Rossion, 2008) and explored its development from 6 to 74 years of age through a face identity *discrimination* task. They found that the size of the face inversion effect increased from 6 years of age onwards but only for upright horizontal facial cues. On the other hand, Balas, Schmidt, and Saville (2015) showed that the basic-level *categorization* of faces (against houses) is already better at horizontal than vertical angles at 5 years of age and that this horizontal bias further develops at least until 10 years of age. In sum, these developmental results indicate that: (1) the specialization of the face processing system from childhood to young adulthood roots into the refined encoding of horizontal ranges of upright face information and that (2) the coarse categorization of a face as a face attunes to horizontal orientation earlier than the fine discrimination of individual identities.

These findings, however, do not preclude that such bias may already exist earlier in development. Newborns have indeed been shown to preferentially look at horizontal than vertical gratings (Farroni, Valenza, Simion, & Umilta, 2000; Slater, Earle, Morison, & Rose, 1985; Slater & Sykes, 1977). They also look more and longer towards top-heavy configurations than towards configurations of similar complexity but presented upside-down (Simion et al., 2001, 2002) suggesting an early affinity for patterns, resembling faces, with more horizontally aligned elements in the upper than the lower part of their configuration. To address the question of whether a horizontal bias is present in infancy and, in the case it is present, whether it is already specific to the viewing of upright faces, or whether it generalizes to any visual pattern, we tested 3-month-old infants' preference on trials composed of a full-front female face and of a full-front car, either unfiltered (UNF) or filtered in order to selectively reveal horizontal (H), vertical (V), or both orientation bands (HV). At this age, infants have indeed only a few months of experience with faces but that might be sufficient for the face processing system to selectively respond to horizontal orientation range within upright faces. The same stimuli were also presented upside-down to another group of 3-month-old infants given that inversion preserves image orientation content while disrupting the visual mechanisms that are selectively specialized for the processing of upright faces (Yin, 1969; see also Goffaux & Dakin, 2010).

Regarding this study, our hypotheses were the following. First, visual processing in 3-month-old infants may not tune to any orientation. If so, infants would, according to the literature (e.g., Durand et al., 2013), prefer upright faces to upright cars no matter the orientation band they are exposed to. A second option may be that infants would show a preference for stimuli integrating several orientation bands. If so, they would look longer at unfiltered (UNF) and horizontal-vertical (HV) stimuli than at horizontal (H) and vertical (V) stimuli no matter if the stimuli are presented upright or inverted. Alternatively, infants may tune to the horizontal range irrespective of the stimulus category (face/car) and/or the picture-plane orientation (upright/inverted). Finally, they could show a horizontal tuning selectively for the processing of upright faces, as do children and adults. This is the most likely hypothesis given the combined preference for horizontal gratings (Farroni et al., 2000; Simion et al., 2001, 2002; Slater et al., 1985; Slater & Sykes, 1977) and top-heavy patterns early in life.

METHODS

Participants

This study was conducted according to the principles stated in the Declaration of Helsinki. Infants were all recruited through the local birth registry of the city of Dijon (France). The lab research assistant contacted the parents whose infant would soon celebrate his/her 3-month anniversary to tell them about the general aim of the study and invite them to participate. On the day of testing, parents were first informed about the experimental procedure and then gave their written consent.

Eighty-two 3-month-old infants were tested for the study. Forty-two infants were excluded from the sample. The inattentiveness (12 INV/6 UP) and cries (17 INV/4 UP) in the inverted group mainly explained the attrition rate. Three more infants were excluded from the sample because of fussiness (1 UP/1 INV) and discomfort due to hiccough (1 UP). This data were not considered in the analyses. Thus the final sample consisted of 20 3-month-old infants (7 males; mean age = 92 days; SE = .8) and 20 3-month-old infants (10 males; mean age = 92 days; SE = .6) exposed to upright or inverted stimuli, respectively.

Stimuli

In line with a study performed by the same group (Durand et al., 2013), we used 16 unfamiliar gray-scaled full-front pictures of female faces posing with a neutral expression and 16 gray-scaled full-front pictures of cars. Face models were alumni Psychology female students (aged between 18 and 25 years) of the Catholic University of Louvain (Belgium). Female faces were chosen because of their greater attractiveness to infants compared to male faces (Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002). These full-spectrum face and car images were placed on a white 750×750 pixel canvas and constituted the unfiltered (UNF) condition (Fig. 1). We created the inverted set by rotating the stimuli by 180 degrees. At a distance of 66 cm, they subtended approximately 23×23 degrees of visual angle.

All images were first normalized to obtain a mean (luminance) of 0 and a root-mean square (RMS) contrast of 1. Next, images were Fast Fourier transformed and multiplied with wrapped Gaussian filters (20° FWHM) centered either on horizontal (H) or vertical (V) angle. Horizontal-vertical (HV) images were constructed by summing the horizontal and vertical Fourier energy of each image, as in Dakin and Watt (2009) and Goffaux and Dakin (2010) (Fig. 1). They were introduced in the experiment because they resemble the broadband stimuli encountered in infants' visual environment while being, at the same time, not as complex as unfiltered stimuli (i.e., oblique information are preserved in unfiltered stimuli). After the inverse Fourier transformation, the luminance and RMS contrast of each image exemplar was adjusted to match the average luminance and RMS contrast of its category (i.e., faces or cars) so that all images were equalized in term of these low-level properties.

Procedure

All infants were brought to the Baby Lab of the Center for Smell, Taste and Food Science of Dijon (France). They were securely and comfortably seated in a car seat in semi-reclining position. Parents were specifically instructed not to intervene during the experiment (in speaking or coming close to the infant) but, if they were willing to, they could stay in visual contact with their infant by sitting right behind them.

Infants were tested in a dimly lit room and randomly assigned to the upright or the inverted group. They were exposed to eight trials (four filter types (UNF—HV—V—H) × left/right position of the face alternated across two consecutive trials), in total, counterbalanced across infants in a Latin square design. On each trial, infants were shown one face and one car stimulus side-by-side and their looking behavior was recorded. The experiment was built so that each face identity was always associated to the same car exemplar throughout the different filtering conditions.

Infants looking behavior was monitored by means of a camera (Handycam, Sony) positioned centrally above the screen and located at 66 cm from the infants' eyes. The experimenter manually launched the first trial as soon as the infant looked at the screen. The experiment started with a 1 s blue screen. Next, a pair of stimuli appeared for 15 s and was replaced by another 1 s blue screen before the next trial started again when the experimenter judged the infant looked at the screen.

All testing sessions were videotaped. Videotapes of eye movements were codified off-line frame by frame. The mean estimate on reliability between the two blind and independent observers calculated on 20% of the testing sessions was large and of 82.5% (Pearson correlation, $p < .0001$).

RESULTS

We first conducted an ANOVA on infants' total fixation times (seconds) with group (UP, INV) as the between-subject factor and filter type (UNF, HV, V, H) and stimulus category (face, car) as within-subject factors.

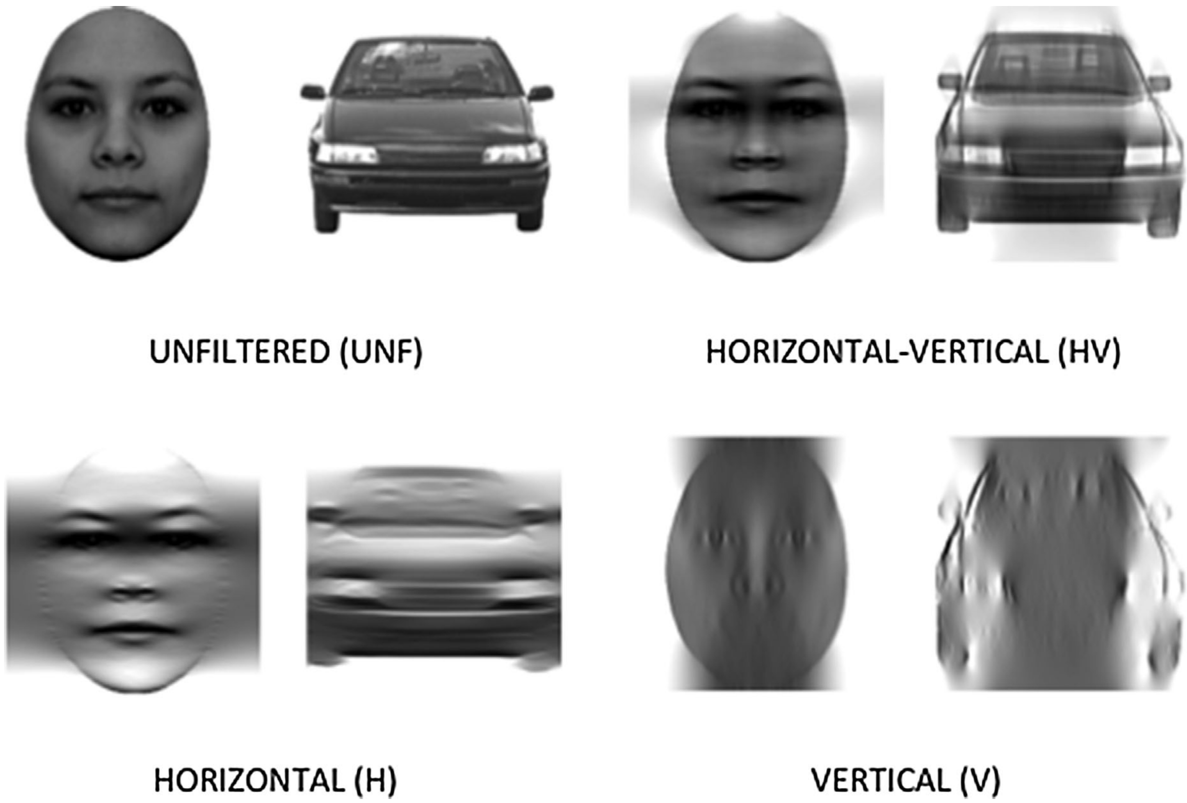

FIGURE 1 Example of stimuli 3-month-old infants were exposed to in the experiment. Stimuli were either unfiltered (UNF) or filtered to reveal horizontal (H), vertical (V) or both orientation bands (HV). The position of the face (left/right) was reversed in half of the trials.

Main effects of group (UP > INV: $F(1,38) = 7.555$, $p = .009$), filter type (UNF > HV > H > V: $F(3,114) = 8.784$, $p < .0001$) and stimulus category (face > car: $F(1,38) = 4.976$, $p = .032$) were significant. Overall, infants looked longer at upright than inverted stimuli and at faces than cars (Fig. 2). There were also significant interactions between filter type and stimulus category ($F(3,114) = 6.361$, $p = .001$), stimulus category and group ($F(1,38) = 4.827$, $p = .034$) and a triple interaction between filter type, stimulus category and group ($F(3,114) = 5.352$, $p = .002$). The filter type by group interaction did not reach significance ($p > .05$). We further explored the triple interaction by splitting the ANOVA according to the group factor (UP, INV).

When stimuli were viewed upright, the ANOVA indicated a main effect of stimulus category (face (5.73 s) > car (3.79 s): $F(1,19) = 8.696$, $p = .008$) and a significant interaction between filter type and stimulus category ($F(3,57) = 7.964$, $p < .0001$) suggesting that infants' preferential looking patterns differed according to filter type. There was however no main effect of filter type ($p > .05$). We ran multiple t-tests and controlled for the multiplicity of the tests performed by using the False Discovery Rate (FDR) procedure (Benjamini & Hochberg, 1995). Infants looked longer at the face than at the car in all conditions composed of horizontal information (UNF, HV, H) (UNF: faces: 6.65 s vs. cars: 3.90 s, $t(19) = 2.641$, q(FDR) = .02; HV: faces: 6.20 s vs. cars: 3.37 s, $t(19) = 2.977$, q(FDR) = .016; H: faces: 6.59 s vs. cars: 2.72 s, $t(19) = 3.301$, q(FDR) = .016) but infants' differential looking time (face *minus* car) did not vary across these filter types ($F(2,59) = .349$, $p = .707$). When horizontal information was excluded from the stimuli (V condition), infants tended to look less at faces than at cars although these stimuli were strictly equalized in terms of luminance and contrast both within this filtering condition and across filtering conditions (V: faces: 3.48 s vs. cars: 5.09 s, $t(19) = -2.065$, q(FDR) = .053) (Fig. 2A).

When stimuli were viewed inverted, the ANOVA only showed a main effect of filter type ($F(3,57) = 7.157$, $p < .0001$). There was no main effect of stimulus category (face (3.70 s) = car (3.55 s): $F(1,19) = .001$, $p = .980$) and no interaction between

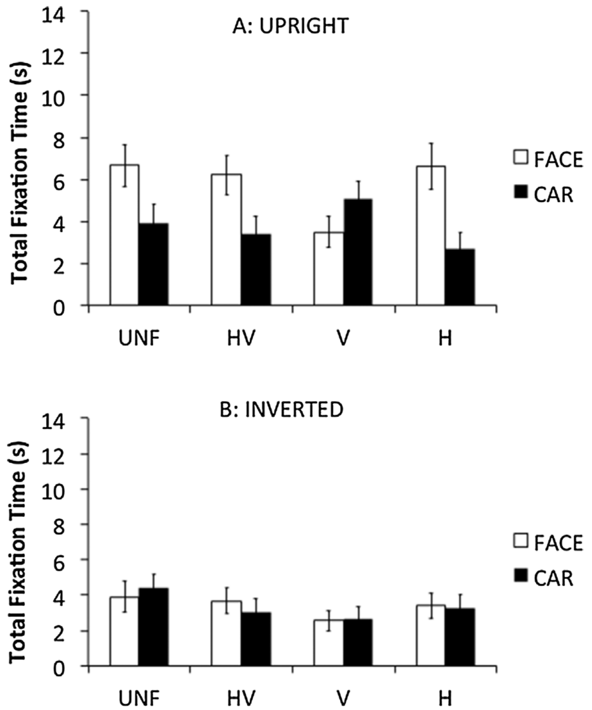

FIGURE 2 Three-month-old infants' total fixation time (s) on upright (A) and inverted (B) stimuli displayed according to the four filter types (UNF, HV, V, and H).

filter type and stimulus category ($F(3,57) = .739$, $p = .533$), suggesting that infants did not manifest any preference for either the face or the car across the four filtering conditions. This result was confirmed by multiple *t*-tests with FDR correction (UNF: faces: 3.90 s vs. cars: 4.42 s, $t(19) = -.474$, q(FDR) > .05; HV: faces: 3.67 s vs. cars: 3.05 s, $t(19) = .911$, q(FDR) > .05; H: faces: 3.39 s vs. cars: 3.28 s, $t(19) = .185$, q(FDR) > .05; V: faces: 2.55 s vs. cars: 2.69 s, $t(19) = -.229$, q(FDR) > .05) (Fig. 2B).

We finally explored the triple interaction between filter type, stimulus category and group by splitting the overall ANOVA according to the filter type (UNF, HV, V, H) in order to determine whether the relative preference for faces over cars was also specifically greater at upright than inverted orientation in the conditions preserving horizontal information (UNF, HV, H). To do so, separate ANOVAs on infants' total fixation times (seconds) with group (UP, INV) as the between-subject factor and stimulus category (face, car) as the within-subject factor were performed for each filter type separately. According to our predictions, the stimulus category by group interaction was significant in both the unfiltered and the horizontal conditions (UNF: $F(1,38) = 4.675$, $p = .037$; H ($F(1,38) = 8.495$, $p = .006$) and was marginally significant in the HV condition ($F(1,38) = 3.591$, $p = .066$). In contrast, it was not significant in the vertical condition ($F(1,38) = 2.263$, $p = .141$). These results suggest that infants' increased preference for faces at upright orientation was greater in the conditions preserving horizontal information within faces.

DISCUSSION

In this study we tested whether horizontal information is of particular importance to 3-month-old infants and whether this sensitivity is restricted to upright faces (i.e., upright face-specific tuning). To do so, we tested 3-month-old infants' preference on stimuli whose content was either non-restricted (UNF) or restricted to the horizontal (H), the vertical (V), or both (HV) orientation band(s). By equalizing the low-level properties (i.e., luminance and contrast) of our stimulus set with the exception of the orientation content, we could determine the orientation band which drives young observers to prefer upright faces to inverted faces and to non-face stimuli such as cars within their first months of life (e.g., Durand et al., 2013).

Our results unequivocally revealed a horizontal tuning selective for the processing of upright faces at 3 months of age. Indeed infants looked longer at upright faces than at upright cars only when horizontal information was preserved in the stimuli (UNF, HV, H). This upright face-specific horizontal tuning suggests that infants' horizontal advantage does not simply inherit from low-level visual biases driven by the facial image but rather that it originates from high-level visual mechanisms specialized for the processing of upright faces (for similar results on children and adults; see Goffaux & Dakin, 2010; Goffaux et al., 2015, 2016; Jacques, Schiltz, & Goffaux, 2014). Infants' preference for upright horizontal face information was also not influenced by the presence of other orientation ranges in the stimulus given that it was comparable across horizontal (H), unfiltered (UNF), and combined (HV) filtering conditions.

Inspired by other studies on the topic (Dakin & Watt, 2009; Goffaux & Rossion, 2007; Keil, 2009), we would suggest that several elements could participate to infants' particular sensitivity to the horizontal range of upright face information. In particular, this orientation band is known to preserve as follows: (1) the top-heavy configuration of facial features that newborns are particularly sensitive to (Simion et al., 2001, 2002; but for contradictory findings in infants, see Chien, 2011; Mondloch et al., 1999), (2) the key facial features, such as the eyes, that are crucial to infant face preference and recognition (e.g., Dupierrix et al., 2014; Farroni, Massaccesi, Menon, & Johnson, 2007), and (3) the combination of the two, namely the top-heavy configuration of horizontally oriented facial features (e.g., eyes and mouth) thought to offer the optimal and most stable cues to face identity in adults (Dakin & Watt, 2009; Goffaux & Dakin, 2010; Goffaux & Rossion, 2007).

Overall the present results show sensitivity to horizontal information within upright faces in 3-month-old infants. We suggest that the early tuning of the face processing system to this narrow orientation range offers an ideal basis for the progressive refinement of face processing skills during development. In the future, one could test newborns in a similar experiment in order to investigate the very early stages of horizontal tuning and disentangle whether the horizontal advantage of upright face perception reported here results from a prewired processing bias, present at birth, or from infants' exposure to faces for 3 consecutive months.

NOTES

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