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Newborns' face recognition over changes in viewpoint

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Abstract

The study investigated the origins of the ability to recognize faces despite rotations in depth. Four experiments are reported that tested, using the habituation technique, whether 1-to-3-day-old infants are able to recognize the invariant aspects of a face over changes in viewpoint. Newborns failed to recognize facial perceptual invariances between profile and full-face poses (Experiment 1), and profile and 3/4 poses (Experiment 3). Conversely, newborns recognized the identity of a face through full-face and 3/4 poses (Experiment 2). This result cannot be explained as a consequence of newborns' inability to discriminate between the full-face and 3/4 points of view (Experiment 4). Overall, evidence was provided that newborns are able to derive a representation of an unfamiliar face that is resilient to a certain degree of rotation in depth, from full-face to 3/4 and vice versa.

Keywords: Face processing; Infant; Perceptual invariances; Infant and face recognition

Many studies demonstrated that human newborns look longer and orient more frequently toward either schematic (Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Valenza, Simion, Macchi Cassia, & Umiltà, 1996) or

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real (Macchi Cassia, Turati, & Simion, 2004) face images rather than to other equally complex visual stimuli. Given the minimal visual experience accumulated with faces soon after birth, studies on newborns' face preference were considered to have important implications in the debate on the existence of an experience-independent system for face processing, either subcortical (Johnson, 2005; Johnson & Morton, 1991) or cortical (Farah, Rabinowitz, Quinn, & Liu, 2000). Therefore, newborns' face detection – defined as the ability to identify a face among other non-face stimuli – has been the focus of an extensive body of research that investigated whether newborns' preference for faces is attributable to a content-determined built-in mechanism that specifically responds to faces (Johnson, 2005; Johnson & Morton, 1991), or to non-specific perceptual properties that faces share with other non-face visual stimuli (Simion, Macchi Cassia, Turati, & Valenza, 2003; Turati, 2004).

In contrast, newborns' face recognition – defined as the ability to identify a specific individual face – has received limited attention, even if this is paradoxically one of the predominant aspect of face processing investigated both with preschool and school age children (e.g., Carey & Diamond, 1977; Freire & Lee, 2001; Hay & Cox, 2000; Sangrigoli & de Schonen, 2004) and with adults (e.g., Diamond & Carey, 1986; Leder & Bruce, 2000; Maurer, Le Grand, & Mondloch, 2002). Besides a couple of studies on newborns' recognition of highly schematic faces (Simion, Farroni, Macchi Cassia, Turati, & Dalla Barba, 2002; Turati & Simion, 2002) and a number of studies dealing with newborns' recognition for the mother's face (e.g., Bushnell, Sai, & Mullin, 1989; Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995), only three studies specifically addressed the issue of unfamiliar real face recognition at birth (de Heering, Turati, Rossion, Bulf, Goffaux, & Simion, 2008; Pascalis & de Schonen, 1994; Turati, Macchi Cassia, Simion, & Leo, 2006). A first study showed that newborns recognize an unfamiliar face both immediately and after a 2-min retention interval (Pascalis & de Schonen, 1994). The other two studies investigated the perceptual information newborns utilize to recognize a face and demonstrated that both the inner and the outer features are sufficient cues for face recognition, although the outer part enjoys an advantage over the inner part (Turati et al., 2006). Moreover, the visual information newborns rely on to recognize a face is based on low rather than high spatial frequency bands (de Heering et al., 2008), supporting the idea of a low spatial frequency advantage in individual face recognition at birth.

A common element of all studies on newborns' face recognition is that subjects were asked to recognize faces in the same full-face pose to which they were previously habituated, thus leaving completely unsolved the question of whether newborns are able to recognize some aspects of the physiognomy of a face that remains invariant across variations in perspective. In other words, based on available literature, one may claim that the observed newborns' face recognition competences simply resides on infants' ability to match two identical patterns relying on an image-based representation (Johnson & de Haan, 2001), rather than being dependent on a robust face representation that is resilient to a variety of spatial transformations. The present study was aimed at investigating whether the ability

to recognize the invariant aspects of a face over changes in viewpoint is present a few days after birth.

How adults recognize familiar faces despite considerable variations in retinal input is a long-standing problem in vision science. Different rotations in depth of a face produce very different images. Yet, human observers have little difficulty in recognizing familiar faces from most viewpoints. Successful recognition requires that images from a variety of viewpoints all be identified as being different pictures of the same face, even though they are more different from each other than are pictures of different people seen from the same viewpoint. Effect of rotations in depth has received considerable attention in face recognition, because they shed light on the nature of the underlying representations, and reveal how faces are stored in memory (Hill, Schyns, & Akamatsu, 1997). In adults, both psychological and neurophycological data suggest that faces are stored in memory by means of view-dependent representations, that is, as a set of discrete views, instead of a view-invariant representation (Liu & Chaudhuri, 2002; Valentin, Abdi, & Edelman, 1997). However, the nature of the views stored in memory is not entirely clear (see Liu & Chaudhuri, 2002). Psychological studies suggest that unfamiliar faces are represented in memory by means of one canonical view, the three-quarter view (a 45° rotation in depth around the vertical axis from the full-face). Indeed, faces in 3/4 view are better identified and recognition of faces learned or tested in a 3/4 view may generalize better to other views in terms of both response accuracy and speed (Bruce, Valentine, & Baddeley, 1987; Logie, Baddeley, & Woodhead, 1987; O'Toole, Edelman, & Bulthoff, 1998; Valentin et al., 1997). For example, Logie et al. (1987) found that when adults were presented with a single three-quarter view, recognition accuracy in the test phase for a profile view was better than when they were presented with a single full-face view. Also, a single three-quarter view resulted in a level of performance similar to that found for presentation of both a frontal and a profile view. The advantage for 3/4 views might be due to the fact that such perspective maximizes the amount of salient information embedded in a face, thus revealing most useful features to recover the identity of a face, or to the fact that a three-dimensional view dependent representation is stored in memory (Marotta, McKeeff, & Behrmann, 2002; Valentin et al., 1997).

Evidence from neurophysiological data in monkeys seems to depict a fairly different picture, suggesting the existence of two canonical views, frontal and profile. Studies of single-cell recordings in the temporal cortex of monkeys (Perrett, Oram, & Ashbridge, 1998; Perrett et al., 1991) found view-specific cells tuned to frontal and profile views of a face. The authors theorized that intermediate views, like three-quarter views, are recognized by interpolating between these two canonical views. This conclusion is in line with the claims of other authors (Bruce, 1988; Valentin et al., 1997) which point out that the contradiction between the psychological and neurophysiological data is only apparent. According to Bruce (1988), the advantage for 3/4 views might emerge from the simultaneous activation of both sets of neurons tuned to full-face and profile views, if the 3/4 pose is within range of both these specialist detectors. Consistently, Valentin et al. (1997) demonstrated with a computational model that a 3/4 view advantage is obtained even when only frontal and profile views were used as canonical or prototypical views.

Developmental evidence on this issue is scarce, particularly in infancy literature. Sai and Bushnell (1988), testing one-month-olds, showed that infants were able to recognize their mother's face over that of a stranger's face when faces were presented in full frontal and three-quarter poses, but not in a profile pose. However, the face of the mother may have a special status for the newborn, because it is learned in association with stimuli of various kinds that might play the role of rewards, so that fixating the mother's face might be part of a conditioned operant response based on infants having associated pleasurable experiences with the presence of their mother (Pascalis & de Schonen, 1994). Indeed, in the case of the mother's face a preference for the familiar rather than for the novel stimulus is observed. Also, newborns' preference for their mother capitalizes on the extensive experience with this peculiar face that newborns acquire in their daily life within a multimodal, natural context. As a consequence, the amount and type of experience that leads to the emergence of the preference for the mother's face eludes any control. For instance, Sai (2005) showed that when neonates are prevented from hearing their mother's voice from birth through testing, the preference for the mother's face vanishes. Thus, recognition of the mother's face seems to be contingent on prior exposure to the mother's voice. This is not the case when newborns' face recognition is tested using unfamiliar faces and the habituation rather than the visual preference technique (Pascalis & de Schonen, 1994; Turati et al., 2006). Finally, studies on newborns' preference for their mother's face lack a systematic manipulation of the face poses to which newborns are exposed to in the learning phase and of the presence versus absence of inner and outer facial features, thus leaving unsolved the question of whether newborns are truly capable to generalize recognition of a face from one to a different pose and based solely on inner face features.

Evidence provided by studies with older infants (Fagan, 1976) demonstrated that 7-month-olds recognized 3/4 and profile views of faces they had previously seen only in a frontal view. Subsequently, Cohen and Strauss (1979) found that 30-week-old but not 18- and 24-week-old infants were able to recognize a full-face previously seen in a 3/4 view. More recently, Rose, Jankowski, and Feldman (2002) supplied further evidence for 7- and 12-month-old infants' ability to generalize the identity of baby full-faces to a novel pose (3/4 and profile): Younger infants recognized the 3/4 transformation but not the profile, whereas older infants were able to recognize both. However, critically the face images used in all these studies differed not only in terms of the internal facial sections but also in their hair outlines, therefore unresolving whether the infants really generalized the facial identity over different poses or whether they simply recognized faces relying on the face specific outline (Pascalis et al., 1995; Turati et al., 2006). This issue has been the focus of two recent studies that investigated the ability of 3- to 6-month-old infants to recognize unfamiliar real faces over changes in viewpoint using pictures of faces in which the hair outline was masked (Pascalis, de Haan, Nelson, & de Schonen, 1998; Turati, Sangrigoli, Ruel, & de Schonen, 2004). Multiple different poses of the same face were presented during habituation. In the test phase, a different pose of the same face was shown together with a novel face in the same pose. Results demonstrated that by 3–4 months of age infants are

able to learn a face seen through different poses and to recognize as familiar a new pose of the same face, relying only on the inner face portion.

Still, available evidence does not disentangle the question of whether some facial perspectives enjoy an advantage over others in infants' face recognition when cues related to the outer portion of the face are not available. Also, it remains unknown whether the ability to recognize a face over changes in viewpoint emerges gradually during the first 3–4 months of life, or is present early after birth. Indeed, literature reports that the ability to recognize a perceptual invariance is present from birth in the case of non-face stimuli: Newborns are able to perceive an object as invariant across the retinal changes caused by modifications in slant or distance (Slater, Mattock, & Brown, 1990; Slater & Morison, 1985). Thus, it is plausible that the same competence is available at birth also in the case of a much more complex but also biologically relevant class of stimuli, that is, faces.

The goal of the present study was to investigate whether newborns recognize the invariant aspects of a face over changes in viewpoint when images of unfamiliar real faces were shown in one of three different poses, i.e. full-face, three-quarter and profile. It is possible that, even at birth, face recognition is viewpoint-dependent in that performance might be a function of misorientation relative to the learned view. If this is the case, recognition of a face across changes in perspective could be confined to variations concerning the full-face and three-quarter views, but not profile. Full-face and 3/4 views might be easier to process than the profile because they preserve more information about each individual feature, as well as the spatial relation between features.

Four experiments were carried out to examine whether few-day-old infants, after being habituated to a certain pose of a face, are able to recognize the same face in a different pose. Successful recognition requires that the two images are identified as being different pictures of the same face. To avoid recognition based on the outer facial features, the hair outline was masked so that only the inner portion of the faces was visible. If the information provided by the inner portion of a face is sufficient to recognize the physiognomy of a face across different views, one may conclude that newborns recognize a face going beyond a simple pattern-matching strategy and are probably able to build up a robust internal representation of a face. In contrast, if newborns fail to generalize face identity from one pose to another, results will imply that at birth face recognition is confined to perceptual tasks in which infants have to match two identical visual patterns, in so doing a sort of template match.

Experiment 1

The purpose of Experiment 1 was to test whether newborns can generalize the recognition of an image of a face from a full-face pose to a profile pose (90° of rotation from the frontal view) or vice versa. Following habituation to a photograph of a full-face, newborns were presented with a photograph of the familiar face in a profile

pose paired with a photograph of a novel face in the same profile pose. Alternatively, following habituation to a profile pose, newborns were tested with the familiar and a novel face both in a full-face pose (Fig. 1). According to the novelty preference paradigm, generalization of identity was inferred when infants looked longer at the novel face than at the familiar face in a novel pose. This result would imply that newborns are able to recognize the face presented during the habituation phase overcoming the perceptual discrepancies between the full-face and the profile poses of the same face. Conversely, a simple pattern-matching strategy would not allow newborns to recognize a full-face from a profile view and vice versa.

Method

Participants

Participants were 24 healthy and full-term newborns infants. Six infants were removed from the study because they changed their state during testing. So, the final sample consisted of 18 infants aged 12–72 h (mean age = 43 h). Newborns were randomly selected at the maternity ward of the Paediatric Clinic of the University of Padova and assigned to one of two groups: One group was habituated to an image of a full-face pose (Full-face habituation group), the other was habituated to an image of a profile pose (Profile habituation group). The selection of the infants was done in a random manner, but the number of newborns assigned to each group was established and balanced by the experimenter. All infants met the screening criteria of normal delivery, a birth weight between 2015 and 4115 g, and an Apgar score

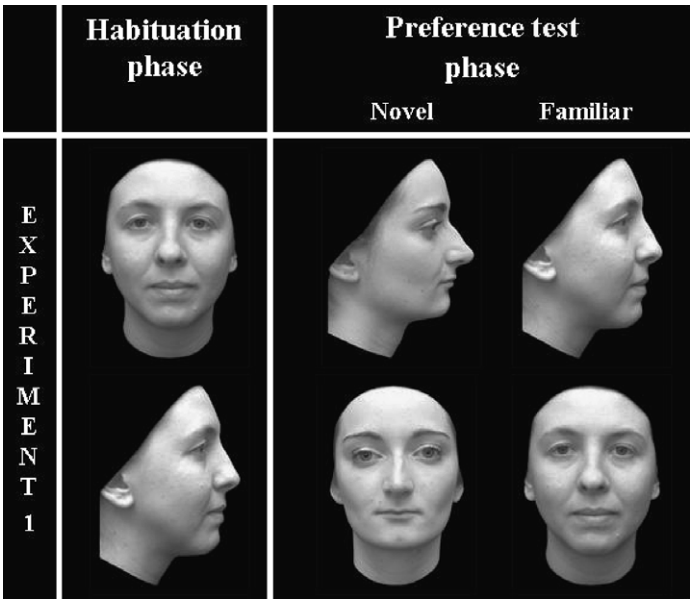


Fig. 1. Examples of face stimuli used in Experiment 1.

between 9 and 10 at 5 min. Infants were tested only if awake and in alert state, after the parents gave their informed consent.

Stimuli

Stimuli were black and white photographs of 6 Caucasian women's faces paired into three invariable pairs. Each face was photographed in a full-face pose and a profile pose (a 90° rotation in depth around the vertical axis from the full-face) under the same lighting conditions and against the same black background (Fig. 1). The hair outline of each face was removed with Adobe Photoshop so that recognition had to rely exclusively on the inner part of the face. Face images measured 18.5 cm (about 35°) in height, 12.5–13 cm (about 24°–25°) in width in the full-face pose, and 13–14 cm (about 25°–27°) in width in the profile pose. The luminance of all photographs was about 54 cd/m^2.

Apparatus

The newborn sat on one experimenter's lap, in front of a black panel, at a distance of about 30 cm. The panel had two square holes where the black screens of two computer monitors appeared. The horizontal midline of the images was aligned with a red flickering LED that was located in the centre of the panel, between the screens. The LED was used to attract the infant's gaze at the start of both the habituation and preference test phases, subtended about 2° of visual angle and, when turned on, blinked at a rate of 300 ms on and 300 ms off. Plain white curtains were drawn on both sides of the infant to prevent interference from irrelevant distractors.

Procedure

In an infant controlled habituation procedure, half newborns were habituated to an image of a face in a full-face pose (Full-face habituation group), the other half to an image of a face in a profile pose (Profile habituation group). Testing began with the central flickering LED. As soon as the infant's gaze was properly aligned with the LED, the habituation was begun by a second experimenter who watched the infant's eyes by means of a video-monitor system and pressed a key on the computer keyboard. This automatically turned off the central LED and activated the onset of the stimuli. Habituation was established by recording the duration of individual fixations. The observer recorded the duration of each fixation on the image of the face by pressing a push button that was connected to the computer. Because during the habituation phase, the same face image was presented on the left and the right side, the amount of looking time was recorded irrespective of the side. A look-away criterion of 2 s was used to determine the end of each fixation. To be sure that this criterion was strictly respected, the software automatically compacted two consecutive fixations that were not separated by a time interval of at least 2 s. The habituation phase was terminated when the habituation criterion was reached, that is, when from the fourth fixation the sum of any three consecutive fixations was 50% or less than the total of the first three (Slater, Morison, & Rose, 1985). When the habituation criterion was reached, the images were automatically turned off and the central flickering LED was turned on.

As soon as the infant's gaze was realigned to the LED, the preference test phase began. Each infant was given two paired presentations of the test stimuli. During each presentation, infants were presented with an image of the familiar face in a novel pose paired with a novel face in the same pose. The group of newborns that was habituated to an image of a full face was presented with the familiar and the novel face in a profile pose, while the group that was habituated to a profile pose was presented with full-face test images. The initial left–right order of presentation was counterbalanced across subjects. The central LED flickered between the first and the second presentation, but did not flicker when the test image was shown. A presentation lasted until each image had been fixated at least once and a total of 20 s of looking fixation had been accumulated. The experimenter recorded the duration of infant's fixations on each image by pressing two different push buttons depending on whether the infant looked at the right or left position. Testing sessions were video-recorded and subsequently codified by a different observer unaware of the stimuli presented. The mean estimate of reliability between observers, calculated on 30% of test phases, was $r(4) = 0.94$, $p = 0.017$, $N = 6$ (Pearson correlation).

Results

All newborns reached the habituation criterion. The average total fixation time to habituate in the full-face and in the profile habituation groups was, respectively, 74.94 s (SD = 30.66) and 65.47 s (SD = 21.80). A t test for independent sample revealed that the comparison between total fixation times in the two groups was not significant, $t(16) = 0.76$, $p = 0.46$, two-tailed.

To test whether newborns were able to recognize the face to which they were habituated, a novelty preference score (percentage) was calculated. Each infant's looking time at the novel face during the two test presentations was divided by the total fixation time to both test stimuli, and subsequently converted into a percentage score. Novelty preference scores were then compared to the 50% chance value by means of one-sample t test. A one-sample t test was run on the entire set of data comparing the overall amount of the novelty preference scores to the chance value ($M = 53.5\%$, SD = 12.41). The difference was not significant, $t(17) = 1.2$, $p = 0.25$. The novelty score was not significantly different from the chance level neither in the full-face habituation group ($M = 52.67\%$, SD = 12.65), $t(8) = 0.63$, $p = 0.55$, two-tailed, nor in the profile habituation group ($M = 54.33\%$, SD = 12.87), $t(8) = 1.01$, $p = 0.34$, two-tailed. A t test for independent samples indicated that the mean novelty preference scores did not differ significantly in the two groups, $t(16) = 0.28$, $p = 0.79$, two-tailed.

Discussion

Experiment 1 investigated whether newborns were able to recognize the invariant aspects of a face from a full-face view to a profile view and vice versa. Following habituation to an image of a face in a full-face pose or a profile pose, in the test phase newborns had to recognize the familiar from a novel face where faces were presented

in a novel pose. Results showed that the preference score to the novel face was not different from chance. Therefore, Experiment 1 demonstrated that there is no evidence of newborns' recognition of a face through different poses when full-face and profile views are used. Nevertheless, these results do not rule out the possibility that newborns are able to overcome the change in appearance induced by modification of viewpoint. Actually, as noted earlier, the lack of recognition may be due to the use of a specific pose, the profile pose. Probably, the amount of information about the face provided by the inner portion of a profile pose is not sufficient for newborns to perceive the invariant aspects of a face when oriented in depth. Moreover, when a full-face view and a profile view are used to test the generalization of the face's invariant structure, a large rotation is applied between the habituation and the test phase (90° of rotation). To test the possibility that the lack of newborns' recognition of a face over changes in viewpoint might be due to the use of either a pose that did not convey enough cues to support efficient recognition of a perceptual invariance – the profile pose, or a great amount of angular rotation between faces presented in the habituation and the test phase – 90° rotation, in Experiment 2 newborns were presented with a 3/4 and a full-face pose, which convey more perceptual information and subtend a smaller amount of angular rotation (45° of rotation).

Experiment 2

Experiment 1 showed that newborns were not able to recognize the invariant aspects of a face over changes in depth orientation when a full-face pose and a profile pose were used. However, such evidence does not clarify whether newborns' failure to generalize the identity of a face over changes in viewpoint is confined to the full-face/profile variation or is a reliable index of newborns incapacity to detect facial perceptual invariances. Specifically, it is possible that the use of a more informative pose, i.e., the 3/4 rather than the profile pose, and the consequent reduction of the rotation in depth (45° rather than 90° of rotation) might enhance newborns' ability to overcome the perceptual discrepancies from one pose to the other. As observed in adults, both a 3/4 view and a small amount of angular rotation are decisive factors to improve the recognition of the invariant aspects of a face through different perspectives (Liu & Chaudhuri, 2002; O'Toole et al., 1998; Valentin et al., 1997). Therefore, unlike Experiment 1, in which newborns were presented with full-face and profile poses, Experiment 2 was designed to test newborns' face recognition when images of full-face and 3/4 poses were shown during habituation and test phases (Fig. 2).

Method

Participants

Participants were 25 healthy and full-term, 1-to-3-day-old infants. They were recruited at the maternity ward of the Paediatric Clinic of the University of Padova. One infant was removed from the study because of a technical error, five because they changed their state during testing and one because he did not reach the criterion

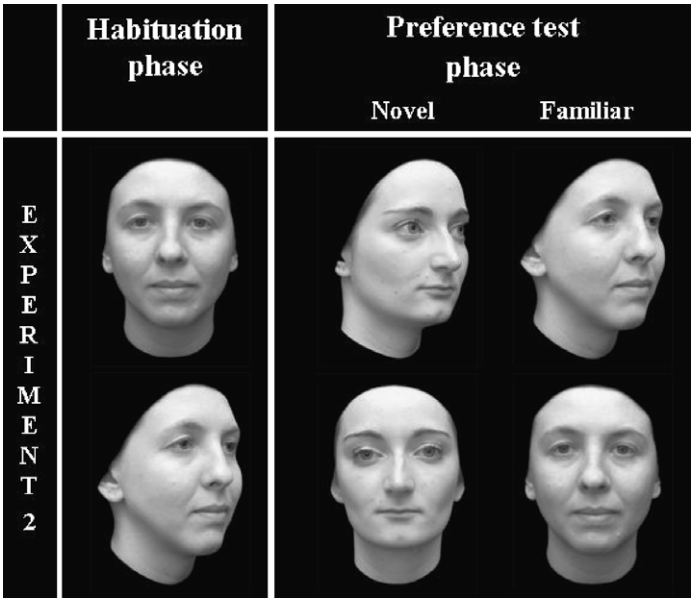


Fig. 2. Examples of face stimuli used in Experiment 2.

during the habituation phase. So, the final sample consisted of 18 infants, assigned to one of two groups (Full-face habituation group or 3/4 habituation group). The selection of the infants was done in a random manner, but the number of newborns assigned to each group was established and balanced by the experimenter. Infant age at the time of testing ranged from 12 to 96 h (mean = 40 h). All of them met the screening criteria of normal delivery, a birth weight between 2320 and 4070 g, and an Apgar score between 9 and 10 at 5 min. Infants were tested only if awake and in alert state. Informed consent was obtained from their parents.

Stimuli

The stimuli were the same used in Experiment 1, with the exception that face images were presented in full-face and 3/4 poses (45° of rotation in depth from the full-face pose) (Fig. 2). In the 3/4 pose, the images measured 18.5 cm (about 35°) in height, 12.6–14.7 cm (about 24°–28°) in width.

Apparatus and procedure

The apparatus and procedure were identical to those used in Experiment 1. In the habituation phase, newborns were presented with either an image of a full-face pose (Full-face habituation group) or an image of a face in a 3/4 pose (3/4 habituation group). In the test phase, the 3/4 habituation group was shown the familiar face in a profile pose paired with a novel face also in a profile pose, while the Profile habituation group was presented with the familiar and the novel pose both in a 3/4 pose. The mean estimate of reliability between observers was $r(4) = 0.97$, $p = 0.014$, $N = 6$ (Pearson correlation).

Results

As for the habituation phase, a *t* test for independent samples was applied to compare total fixation times to reach the habituation criterion in both the full-face habituation group (54.52 s, SD = 15.72) and the 3/4 habituation group (69.23 s, SD = 18.29). The comparison did not reach statistical significance, $t(16) = 1.83$, $p = 0.09$.

As for the test phase, a novelty preference score analogous to that calculated in Experiment 1 was computed. Each infant's looking time at the novel face during the two test presentations was divided by the total fixation time to both test stimuli, and subsequently converted into a percentage score. When computed irrespective of the group to which newborns belonged, the mean novelty preference score was 65% (SD = 6.39) and differed significantly from the chance level of 50%, one-sample $t(17) = 9.96$, $p < 0.001$. The comparison attained statistical significance both in the full-face habituation group ($M = 66.33$, SD = 6.61), $t(8) = 7.41$, $p < 0.001$, two-tailed, and in the 3/4 habituation group ($M = 63.67$, SD = 6.25), $t(8) = 6.57$, $p < 0.001$, two-tailed. A *t* test for independent samples revealed no statistical difference between the mean novelty preference scores in the two groups, $t(16) = 0.88$, $p = 0.39$, two-tailed.

Discussion

Experiment 2 provided evidence that, when full-face and 3/4 poses were used, newborns were able to generalize the invariant aspects of a face from one pose to another. After being habituated to a full-face pose or a 3/4 pose, newborns looked longer at the novel face in the novel pose than at the familiar face in the same novel pose. Indeed, novelty preference scores obtained in the present experiment ($M = 65\%$, SD = 6.38) significantly differ from those found in Experiment 1 ($M = 53.5\%$, SD = 12.4), in which newborns were requested to recognize the identity of a face from a full-face view to a profile view and vice versa, $t(34) = 3.5$, $p < 0.001$. The advantage in the recognition response revealed in the test phase using full-face and 3/4 poses might derive from the preservation of more information about the face viewed in the habituation phase and from the reduction of the size of angular rotation between the original and the rotated view (90° vs 45°). This outcome is in agreement with previous studies with young infants in which 7-month-olds' face recognition through different perspectives is greatly facilitated when the face is presented in full-face and 3/4 views, but not in a profile view (Fagan, 1976; Rose et al., 2002).

Altogether, the findings of Experiment 2 demonstrated that, at least under some conditions, newborns were able to recognize an image of a face overcoming the perceptual discrepancies induced by changes in viewpoint. Nevertheless, two different issues remain unsolved. A first issue concerns the fact that the evidence so far obtained does not clarify which kind of visual information may affect newborns' ability to recognize a face in a novel pose. Specifically, it remains unknown whether the face recognition advantage found using the full-face and 3/4 poses (Experiment 2),

but not the full-face and profile poses (Experiment 1), was due to the reduction of angular rotation or to the perceptual cues conveyed, respectively, by the 3/4 (Experiment 2) and the profile views (Experiment 1). Three-quarter and profile poses were presented in Experiment 3 to understand which kind of visual information may affect newborns' recognition and separate the effect caused by angular rotation from those potentially caused by the perceptual properties of a specific pose. Second, one might claim that in Experiment 2 newborns, rather than being able to detect a perceptual invariance across changes in viewpoint, did not differentiate the two poses of the same face. Actually, two or more stimuli are recognized as invariant in relation to a perceptual property only if evidence is provided that the stimuli have been differentiated (Quinn & Eimas, 1996). Experiment 4 was carried out to investigate whether newborns were able to discriminate a full-face view from a 3/4 view of the same face.

Experiment 3

The degree of angular rotation between the face presented during habituation and the face presented in the test phase was 90° in Experiment 1, and 45° in Experiment 2. A recent review on adults' face recognition over changes in viewpoint (Liu & Chaudhuri, 2002) showed that the advantage of the 3/4 pose almost invariably depended on the different amount of angular rotation that was present between learning and test views. The 3/4 effect vanished when the angular rotation was equalized between conditions. The amount of angular rotation, regardless of the information contained in each pose, might affect the recognition of the perceptual invariance of different perspective of a face also at birth.

Experiment 3 was designed to investigate whether newborns' recognition of a face through different views depended on the size of angular rotation between the original and the rotated view (90° or 45°) or on the perceptual cues conveyed by the different poses (3/4 and profile poses). To pursue this goal, we tested newborns' recognition performance when images of 3/4 and profile views of the face were shown (Fig. 3). The use of a 3/4 and a profile pose allowed us to pair the size of the angular rotation with the size employed in the full-face vs 3/4 condition of Experiment 2, in which newborns recognized a face through different points of view. If the size of angular rotation is critical to perceive the invariant characteristic of a face, newborns should generalize the identity of a face from one perspective to the other, even though a pose that did not convey a great amount of information, i.e. a profile pose, was used. Conversely, if the quality and quantity of perceptual information provided by each pose is a key cue for newborns' face recognition, probably the use of a profile pose would not allow newborns to generalize the identity of a face from one pose to another.

Method

Participants

Twenty-three healthy, full-term newborn infants were selected from the maternity ward of the Paediatric Clinic of the University of Padova. Five infants were removed

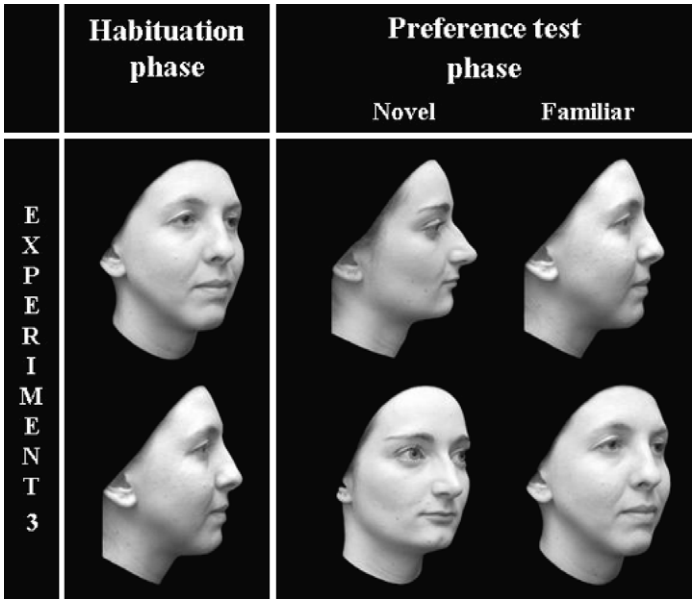


Fig. 3. Examples of face stimuli used in Experiment 3.

from the study because of position bias ($n = 2$) or because they changed their state during testing ($n = 3$). So, the final sample consisted of 18 infants aged 16–120 h (mean age = 41.28 h). All of them met the screening criteria of normal delivery, a birth weight between 2300 and 4390 g, and an Apgar score between 9 and 10 at 5 min. Infants were tested only if awake and in alert state, after the parents gave their informed consent. Infants were assigned to 3/4 habituation group or Profile habituation group.

Stimuli

The stimuli were the same as those used in the previous experiments. The images of the faces were presented in profile and 3/4 poses (Fig. 3).

Apparatus and procedure

The apparatus and procedure were identical to those used in Experiment 1. Half newborns were habituated to an image of a face in a 3/4 view (3/4 habituation group), the other half to an image of a face in a profile view (Profile habituation group). In the test phase, infants were presented with an image of the familiar face in a novel pose paired with a novel face in the same pose. The mean estimate of reliability between observers was $r(4) = 0.94$, $p = 0.017$, $N = 6$ (Pearson correlation).

Results

A *t* test for independent samples was run to compare total fixation times to habituate, respectively, in the 3/4 (71.63 s, SD = 23.59) and in the profile habituation

groups (61.93 s, SD = 29.12). The comparison was not significant, $t(16) = 0.77$, $p = 0.45$, two-tailed.

As for the test phase, a novelty preference score analogous to that calculated in the previous experiments was computed. A one-sample t test performed on the entire set of data showed that novelty preference scores were not significantly above the chance level of 50% ($M = 48.61\%$, SD = 17.39, $t(17) = 0.34$, $p = 0.74$. To determine whether newborns were able to recognize the familiarized face in each of the two tested groups, two separate one-sample t test were applied, one for each group. Preference scores did not significantly differ from the chance level neither in the 3/4 habituation group ($M = 51.11\%$, SD = 16.14), $t(8) = 0.21$, $p = 0.84$, two-tailed, nor in the profile habituation group ($M = 46.11$, SD = 19.17), $t(8) = 0.61$, $p = 0.56$, two-tailed. In order to test whether the mean novelty preference scores differed in the two groups, a t test for independent sample was run. The comparison did not reach statistical significance, $t(16) = 0.6$, $p = 0.56$, two-tailed.

Discussion

Evidence indicates that newborns' recognition of the perceptual invariance of a face over changes in viewpoint did not depend on the different amount of angular rotation that was present between learning and test views. Even though the rotation in depth from a 3/4 to a profile view subtended 45° of rotation, an angular degree that was demonstrated to allow newborns to recognize a full-face vs a 3/4 view (Experiment 2), the findings of the present experiment showed that in the test phase newborns did not recognize the face to which they were habituated. Therefore, when newborns were presented with profile and 3/4 poses, the size of angular rotation alone was not sufficient to determine infants' ability to recognize the perceptual invariance. As in Experiment 1, in which the recognition test was carried out in a full-face vs profile condition, the use of a profile pose disrupted newborns' ability to generalize a face across rotations in depth. Unlike full-face and 3/4 poses, that retains information about features embedded in a face and their spatial relations, the profile pose did not preserve enough perceptual cues to drive the recognition of a face presented in a different pose. These results, when linked to those obtained in Experiments 1 and 2, demonstrated that when newborns were asked to recognize the physiognomy of a face across different views, the identity of the face is generalized better through those poses that convey more quantity and quality of perceptual information. In other words, the perceptual information contained in each pose was crucial to allow newborns to recognize the face in a different perspective.

Experiment 4

Experiment 2 showed that newborns were able to recognize a face from a full-face to a 3/4 pose and vice versa. In order to rule out the possibility that such ability was due to a fail in differentiating one pose from the other (Quinn & Eimas, 1996), Exper-

iment 4 tested whether few-day-olds were able to discriminate a full-face and a 3/4 view of the same face. Infants were habituated to an image of a face in a full-face pose (Full-face habituation group) or a 3/4 pose (3/4 habituation group). In the test phase, an image of the familiar face in the familiar pose paired with an image of the familiar face in a novel pose was presented (Fig. 4).

Method

Participants

Participants were twenty healthy, full-term newborn infants selected from the maternity ward of the Paediatric Clinic of the University of Padova. Three infants were removed from the study because of position bias ($N = 1$) or because they changed their state during test ($N = 2$). So, the final sample consisted of 17 infants aged 12–117 h (mean = 54 h), assigned to one of two groups (Full-face habituation group or 3/4 habituation group). All of them met the screening criteria of normal delivery, a birth weight between 2606 and 3620 g, and an Apgar score between 9 and 10 at 5 min. Infants were tested only if awake and in alert state.

Stimuli

The stimuli were the same used in Experiment 2 (Fig. 4).

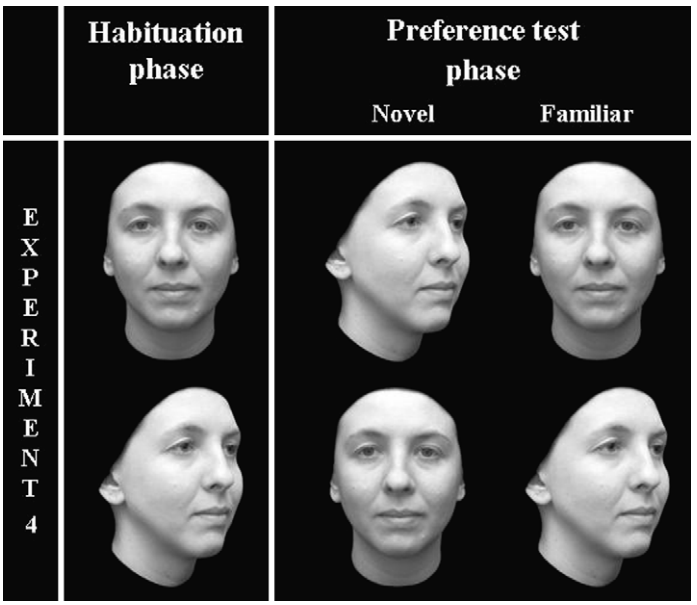


Fig. 4. Examples of face stimuli used in Experiment 4.

Apparatus and procedure

The apparatus and procedure were identical to those used in Experiment 1, except for the fact that, during the habituation phase, infants were shown either a full-face (Full-face habituation group) or a 3/4 face (3/4 habituation group), and that, during preference test phase, infants were presented with the familiar face image paired with a novel image of the same face. The mean estimate of reliability between observers was $r(4) = 0.99$, $p = 0.01$, $N = 6$.

Results

The comparison by means of a t test for independent samples between the average total fixation times to reach the habituation criterion in the two conditions (full-face and 3/4 habituation groups) did not reach statistical significance $t(15) = 1.48$, $p = 0.16$, two-tailed). The average total fixation times were 68.37 s (SD = 18.54) in the full-face habituation group and 53.80 s (SD = 22.22) in the 3/4 habituation group.

Total fixation times toward the novel face image in the test phase were transformed into percentages. To determine whether they differed from the chance level, a one-sample t test was applied. A reliable mean novelty preference score, significantly greater than the chance level, was obtained when newborns' performance was collapsed across the two habituation groups, $M = 64\%$ (SD = 11.66), one-sample $t(16) = 4.95$, $p < 0.001$, two-tailed. The novelty score was significantly different from the chance level both in the full-face habituation group ($M = 62.78$, SD = 12.84), $t(8) = 2.96$, $p = 0.02$, two-tailed, and in the 3/4 habituation group ($M = 65.38$, SD = 10.86), $t(7) = 4.00$, $p = 0.005$, two-tailed. In order to test whether the novelty preference differed significantly in the two groups, the novelty preference score in the full-face habituation group was compared with the preference score in the 3/4 habituation group. A t test for independent sample revealed no statistical difference between the mean novelty preference scores in the two groups, $t(15) = 0.45$, $p = 0.66$, two-tailed.

Discussion

Results demonstrated that newborns can discriminate a full-face pose from a 3/4 pose of the same face: Infants were able to differentiate a novel view of a face from the view to which they have been experimentally habituated. According to the assumption reported above, that two or more stimuli are recognized as invariant in relation to a perceptual property only if evidence is provided that the stimuli have been differentiated (Quinn & Eimas, 1996), the outcome of the present experiment provides a confirmation that newborns in Experiment 2 really recognized the perceptual invariance from a full-face to a 3/4 view.

General discussion and conclusions

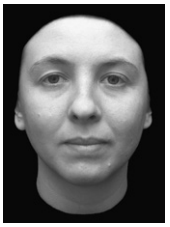
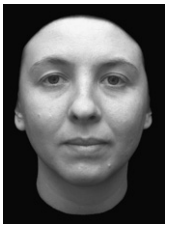
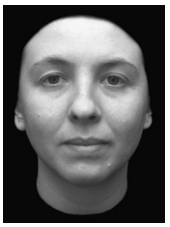
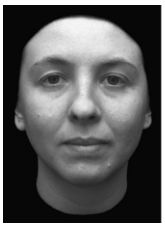
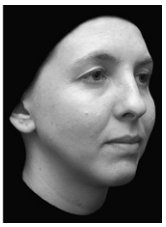
Despite convergent evidence on newborns' ability to learn and discriminate individual faces, little is known about the nature of the underlying representation new-

borns' face recognition relies on. Based on available evidence, one possibility was that the observed newborns' face recognition competences simply resides on infants' ability to match two identical patterns relying on an image-based representation, since newborns were supposed to be unable to extract facial perceptual invariances (Johnson & de Haan, 2001). In fact, all studies examining newborns' ability to recognize a stranger's face showed the same face in the same pose during both the learning and the test phase, thus leaving completely unsolved the question of whether newborns are able to detect facial invariances and treat different images of the same face as equivalent throughout perceived differences. However, faces of the adults that interact with babies are far from being always static and unchangeable, but vary continuously as a function of rotation in several different planes. Thus, in infants' natural visual environment, the ability to recognize an individual face should result from a process of detecting some perceptual invariances across time and presentations.

Here, we presented a study that explored whether newborns' face recognition ability is preserved when two different images of the same face are shown during the learning and the test phases (Table 1). Evidence demonstrated that at birth infants failed to recognize a face in the profile pose after being habituated to the same face in a frontal pose, and are unable to recognize a face learned in the profile pose when it is shown in a frontal pose (Experiment 1). In contrast, newborns' ability to detect facial perceptual invariances is sufficiently established to allow them to recognize a face learned in a frontal pose when viewed in a 3/4 pose and vice versa (Experiment 2). The advantage in newborns' recognition performance observed when the frontal and 3/4 views (Experiment 2), rather than frontal and profile views (Experiment 1), are employed does not depend on the minor size of angular rotation between the original and the rotated view (45° vs 90°), since newborns' face recognition vanished even when infants had to recognize a 3/4 from a profile pose or vice versa (Experiment 3). In this case, the amount of angular rotation is identical to that applied in Experiment 2 (45°), but newborns' performance overlaps that obtained in Experiment 1 when infants failed to recognize the familiar face. Finally, the detection of perceptual invariances between full-face and 3/4 views (Experiment 2) cannot be interpreted as due to newborns' failure to discriminate between the two different poses of the same face showed in the habituation and in the test phase, because infants were able to differentiate two images that portray the same face in a frontal and 3/4 pose (Experiment 4). Thus, based on our results (Table 1), it can be concluded that the profile pose precludes newborns' face recognition, independent of angular rotation. In other words, the profile pose does not convey sufficient perceptual cues to drive newborns' ability to recognize a face. Interestingly, this happens both when the face has to be encoded and stored in memory in the profile pose – that is, when the profile pose is shown in the habituation phase –, and when the profile pose is the base for face information retrieval – that is, when the profile pose is presented in the test phase.

Obtained evidence shed some light on the nature of the representations that mediate face recognition at birth. Our findings point to the idea that newborns' face recognition cannot be reduced to a simple pattern-matching process. If recognition in

Table 1
Summary table with the results of the four experiments

	Habituation phase	Test phase		Results
Exp. 1				$M = 53\%$ $p = 0.25$
Exp. 2				$M = 65\%$ $p < 0.001$
Exp. 3				$M = 49\%$ $p = 0.74$
Exp. 4				$M = 64\%$ $p < 0.001$

The p values refer to the novelty scores (M) compared to the chance level (50%) using a one-sample t test.

the first week of life were pictorial, a change in the point of view should prevent recognition. In contrast, newborns are able to derive a representation of an unfamiliar face that is resilient to a certain degree of rotation in depth, from full-face to three-quarter and vice versa. Importantly, this representation could be based exclusively on inner face features, since outer face features were not visible. This is further evidence that the limited resolution capacities of the visual system at birth do not prevent few-day-old infants from detecting and discriminating the information embedded in the inner portion of a face (Turati et al., 2006). We are not claiming

that the outer facial features do not play an important role in newborns' face recognition, our main point is that, soon after birth, inner facial features alone convey sufficient information to allow newborns to recognize a face, even when the pose of the face to be recognized deviates from that learned. Thus, newborns' face representation relies also on the internal facial features, rather than being based exclusively on the external facial features.

Moreover, the present study demonstrates that newborn infants' ability to recognize the invariant characteristics of a visual pattern, when a rotation in depth is applied, is not confined to very simple geometric figures, like a square or a trapezium (Slater & Morison, 1985) but extends to facial images as well. Newborns are able to extract the invariant features of a face regardless of changes in slant relative to the observer. However, this ability is limited to those poses that convey enough perceptual information. The full-face and 3/4 views of a face seem to provide enough information about each other to allow newborns to generalize recognition of an individual face from full-face to three-quarter and vice-versa, although as demonstrated in Experiment 4, there were discriminable changes between the two face images. Newborns ignored some of the perceived differences and responded in terms of similarity. In contrast, the profile and the frontal views of a face do not share sufficient perceptual information to permit newborns' recognition of the unchanging elements that identify an individual face.

Newborns' failure to generalize face identity from a profile pose parallels adults' poorer recognition performance of faces shown in a profile view (Hill et al., 1997). Several explanations have been raised in the adult literature to interpret this phenomenon. First, the profile view might be poor for identification because important information, such as the configuration of internal features, is less visible (Diamond & Carey, 1986). Second, small rotations in depth of the profile view will qualitatively change the appearance of a face, while moderate rotation of the 3/4 view will not result in qualitative perceptual changes. This implies that, while all views appear to provide sufficient information for recognition, generalization from individual views is dependent on learned viewpoint (Hill et al., 1997). A third explanation specifically deals with what is currently known about newborns' face processing. Few-day-old infants detect as faces visual stimuli that display three contrast elements in the correct positions to represent eyes and mouth (Johnson & Morton, 1991) or, according to more recent proposals (Simion et al., 2003; Turati, 2004), stimuli that display more contrast elements in the upper rather than in the lower portion of the configuration. A face profile would comply with neither of these two early face definitions, thus when newborns are asked to recognize an invariance between a 3/4 or a full-face pose and a profile, they might be required to detect a similarity between a face and what they perceive as a non-face stimulus (i.e. the profile). Finally, it is worth to point out that if neonates may have accumulated significant visual experience with full- and 3/4 faces, it is unlikely that they have comparable experience with face profiles. Thus, newborns' recognition failure with the profile view might also be dependent on the newborns' scarce visual experience with this view. Further research is needed to disentangle between these possible interpretations.

The finding that newborns can recognize some unchanging aspects of a face, across spatial rotation, also raises the issue of what kind of visual information newborns rely on when they recognize invariances related to inner face portion across rotation in depth. In adults, it has been supposed that the visual system might use view-invariant feature properties (e.g., skin tone and texture), local shape cues (e.g., size of nose and mouth), holistic information (e.g., global three-dimensional shape), and configural information (e.g., the spatial relation among the inner elements). Future research might address this issue at birth testing whether newborns' ability to extract facial perceptual invariances is preserved under inverted orientation conditions, where faces do not engage holistic or configural processes but instead are recognized piecemeal, by part-based, part-dependent processes (e.g., Moscovitch, Winocur, & Behrmann, 1997).

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