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On the typical and atypical development of face processing and recognition during the first three months of life and in a population of school-aged children born prematurely.

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Abstract

Face stimuli challenge the infant's immature visual processing system's capacity to differentiate stimuli that differ in subtle ways.

Experiments 1 to 4 investigated infants' preference for the human face between birth and 3 months of age when contrasted with four control stimuli. A visual preference technique was used because it does not call upon the participant's ability to speak.

A spontaneous preference for a photographic representation of the human face was observed at birth for three out of four conditions. At 3 months of age, a preference for the human face was observed in two conditions. However, at 1 month of age, no preferences were observed. Findings did not support the view that the selectivity of the infant's responses to faces increases with exposure to faces and narrowing of the perceptual window (Nelson, 2001).

Experiment 5 examined infants' ability to discriminate specific exemplars of the human face category, namely the mother's face, between 1 and 9 months of age. A preference for the mother's face was observed at 1 month. A tendency to prefer the stranger's face was observed at 3 months. No preference was observed at 6 and 9 months, thus suggesting that the visual preference procedure is not suitable for measuring recognition at these ages.

Premature birth is associated with brain injury, which can lead to visual and intellectual deficits. Experiment 6 investigated general intelligence as well as face processing in school-aged children born prematurely and at term. Results indicated that premature children displayed levels within the normal range of intelligence. Furthermore, no long-term visual deficits were observed as performance levels for the discrimination of facial emotions were comparable between groups. Only premature children displayed an inversion effect, thereby demonstrating an adult-like face processing system.

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Foreword

This thesis is divided into two parts. Part one consists of five experiments and is dedicated to the study of infants' face processing and recognition abilities between birth and 9 months of age. Part two is dedicated to the comparative study of face processing and visual memory abilities of full-term and premature children aged between 7 and 10 years.

PART 1 : FACE PROCESSING IN NEONATES AND INFANTS

1. Adult-like face processing

1.1 Featural and configural processing in adulthood

Researchers typically distinguish between featural and configural facial information (e.g. Sergent, 1984; Freire, Lee and Symons, 2000; Maurer, Le Grand, Mondloch, 2002). Featural information allows the processing of isolated elements of the face and can be referred to in relative isolation (e.g. the distinctive shape of one's nose), while configural information allows the processing of spatial relationships within a face (e.g. the distance between one's nose and one's mouth).

Adult face processing is thought to rely primarily on configural processing (e.g. Maurer et al., 2002). It contrasts with featural processing, which accounts for analytical processing and is thought to play a secondary role in adult face processing.

Three types of configural processing can be distinguished: detection of *first-order relations* that define faces (e.g. Diamond and Carey, 1986; Moscovitch, Winocur and Behrmann, 1997), i.e. two eyes, a nose and a mouth; *holistic processing* (e.g. Tanaka and Farah, 1993; Young et al., 1987), i.e. putting the features together to form a gestalt; and processing of *second-order relations*, i.e. the spacing between features (e.g. Diamond and Carey, 1986; Freire et al., 2000; Leder and Bruce, 1998, 2000). Thus, configural processing refers to three types of configural information relating to spatial relationships within a face.

1.1.1 First-order relations

Researchers using event-related potentials (ERPs) and functional magnetic resonance imaging (fMRI) have uncovered the neural correlates of face detection (e.g. Bentin et al., 1996; McCarthy et al., 1997; Aguirre, Singh and D'Esposito, 1999; Rossion et al., 2000; Haxby et al., 2001). The event-related negative potential N170 is larger for faces than for many other stimuli, including hands, houses and cars (Bentin et al., 1996; Rossion et al., 2000). fMRI activation in regions of the ventral occipitotemporal cortex, the inferior occipital gyrus, and the lateral fusiform gyrus (i.e. the fusiform face area or FFA), is larger for faces than for a number of non-face stimuli, including cars, houses, hands and furniture (Aguirre et al., 1999; Haxby et al., 2001; McCarthy et al., 1997). Isolated eyes can also evoke the N170 (e.g. Bentin et al., 1996). However, the neural correlates seem to be associated with perceiving a face rather than the stimulus characteristics. For example, when viewing an ambiguous stimulus such as a visual illusion, fMRI activity in the FFA is higher when there is perception of the stimulus as a face than, for instance, as a vase (Hasson et al., 2001).

1.1.2 Holistic processing

When the first-order relations of a face are detected, adult subjects tend to process the stimulus as a gestalt, thus making it more difficult to process individual features (Maurer et al., 2002). For instance, when the top and bottom halves of two familiar face stimuli are used to create a new composite face, subjects are slower and less accurate in recognising the face when the two halves are upright and aligned than when the composite face is inverted or when the two halves are offset laterally (Young et al., 1987; Hole, 1994). This phenomenon, called the composite face effect (Young et al., 1987), occurs presumably because a novel holistic configuration emerges when the two halves are aligned. Accuracy also tends to be higher (by about 10%) when subjects have to recognise one single facial feature in the context of the entire face rather than in isolation (Tanaka and Farah, 1993; Tanaka and Sengco, 1997). This phenomenon, called the whole-part face effect (Tanaka and Farah, 1993), has not been observed with scrambled faces or houses. Holistic processing has also been observed between the internal and the external contour. Sinha and Poggio (1996) demonstrated that adult subjects find it difficult to recognise that the internal features of two faces are identical when they are presented embedded in different external contours.

1.1.3 Second-order relations

All faces share the same first-order relations, making second-order relations, i.e. the spatial distances among internal features (Diamond and Carey, 1986), essential for the recognition of individual faces. Changes in the spacing of facial features influence adults' perception of the aesthetics of faces (Searcy and Bartlett, 1996) and their distinctiveness (Leder and Bruce, 1998).

1.2 Face inversion effect

In adults, it is commonly accepted that comparing recognition abilities for upright versus inverted faces allows to establish whether configural or featural facial processing is used. Thus, the importance of configural processing has been largely demonstrated by the inversion effect (e.g. Farah et al., 1995; Rhodes, Brake and Atkinson, 1993; Yin, 1969). According to Sergent (1984), inversion disrupts configural processing of faces, which explains why inverting face stimuli has an unfavourable effect on adults' ability to recognise and process faces holistically.

In adults, ratings of distinctiveness of faces that have undergone distortions of second-order relations (e.g. spacing of the eyes) drop significantly after inversion, whereas ratings of faces that have undergone featural distortions (e.g. darker eyebrows) do not change (Leder and Bruce, 1998). These findings suggest that separate mechanisms operate in second-order relations and featural processing of individual faces. Additionally, Collishaw and Hole (2000) demonstrated that adults fail to recognise the identity of faces that have been blurred and inverted, despite being capable of discrimination when the faces are blurred and presented upright (Sergent, 1987; Hayes, 1988). Blurring is thought to remove featural information whereas inversion is thought to disrupt sensitivity to second-order relations.

The face inversion effect (FIE) is described as the greater decrease in recognition performance for inverted faces than for other mono-oriented inverted objects categories (Yin, 1969; see review by Valentine, 1991; Rossion and Gauthier, 2002). Extensive testing has shown that, in adults, the FIE has been observed through two-alternative forced-choice paradigms with or without delay (e.g. Yin, 1969; Diamond and Carey, 1986; Tanaka and Farah, 1993; Freire et al., 2000; Leder and Bruce, 2000), old-new recognition paradigms (e.g. Carey, Diamond and Woods, 1980), when orientation is manipulated in separate blocks (e.g. Valentine and Bruce, 1986) as well as in randomised presentations of upright and inverted faces (e.g. Yin, 1969; Carey and Diamond, 1977; Diamond and Carey, 1986), and that it is virtually identical for unfamiliar and familiar faces (Collishaw and Hole, 2000; Rock, 1974. No differences were reported between upright and inverted cars (Aguirre et al., 1999), between upright and inverted houses (Haxby, Ungerleider, Clark, Schouten, Hoffman and Martin, 1999), and only a small difference was observed between upright and inverted novel objects (Greebles) before any familiarisation with these novel objects (Gauthier, Tarr, Anderson, Skudlarski and Gore, 1999). As expertise was acquired with Greebles, however, there was an increase in the FFA (Gauthier et al., 1999).

The inversion effect is thought to result from the combined actions of configural processing and extensive visual experience with faces (e.g. Diamond and Carey, 1986; Farah, 1990; Bruyer and Crispeels, 1992). Configural processing focuses on disparities in the spatial relationships (distance, position and orientation) between facial features rather than on the shape of the features (e.g. Diamond and Carey, 1986; see review by Valentine, 1988). Although configural processing seems to emerge later during childhood (see Freire and

Lee, 2001; Mondloch et al., 2002), sensitivity to the configural characteristics of individual faces has been observed in 5- to 10-month-old infants using a face recognition task (Deruelle and de Schonen, 1998), and in 7-month-olds using a novelty preference task (Cohen and Cashon, 2001).

Evidence also shows that the FIE reflects extensive experience with facial stimuli. In fact, an inversion effect comparable with that obtained with faces has been observed for the recognition of dogs in adult dog experts (Diamond and Carey, 1986) and for the recognition of handwriting with experts in this field (Bruyer and Crispeels, 1992).

1.3 Expertise for faces and non-faces

Evidence from functional magnetic resonance imaging (fMRI) shows that training and development of expertise in processing a non-face category of stimuli can also lead to the activation of face processing systems. In this context, two separate studies showed that an inversion effect is observed in experts in naturally learned categories (for instance a dog expert; Diamond and Carey, 1986) or experimentally learned categories (for instance an expert in 'Greebles'; Gauthier and Tarr, 1997).

Greebles is a class of artificially created stimuli that have the configural properties of faces although they look little like them. For trained adults, i.e. experts, such stimuli show the inversion, fracturing, and isolated-part effects that usually distinguish faces from objects. Furthermore, using a fMRI procedure, Gauthier et al. (1999) demonstrated that training in Greeble recognition caused an increase in activation of regions of the face specific fusiform gyrus. This observation demonstrates that some elements of adult face processing considered unique to the recognition of faces can, in certain cases, be acquired later in life for a non-face category. Expertise in discriminating and remembering prototypes from a particular category could mean that we automatically process these exemplars at an individual (or subordinate) level (Tanaka and Taylor, 1991). For example, because we are all experts at face recognition, we encode a face more automatically as an individual person, rather than just "a face". In contrast, for non-expert categories we tend to encode at a more basic level, for instance, "a table" rather than "the table that is sitting in my aunt's living room."

In summary, the expertise hypothesis claims that faces are not special. They are, however, the most commonly encountered category of stimuli and can be recognised at a subordinate exemplar-specific level.

1.4 Prototype formation

In adult face processing, the emergence of functional occipito-temporal cortical involvement is thought to allow subjects to encode new faces in terms of how much they deviate from a prototype. This hypothesis is supported by evidence that adults find unusual faces easier to remember than typical faces (Light, Kayra-Stuart and Hollander, 1979; Valentine and Bruce, 1986).

Prototype formation is a cognitive ability common to both infants and adults and makes it possible for prototypes to be formed after viewing just a few exemplars of a class or category (e.g. Bomba and Siqueland, 1983; Quinn, 1987; Quinn, Eimas and Rosenkrantz, 1993; Eimas and Quinn, 1994). A prototype can be defined as the calculated average of the characteristic features of a category and represents the averaged members of this category (e.g. Komatsu, 1992; Posner and Keele, 1970; Rosch et al., 1976). The prototype of a class or category is typically the preferred exemplar of its class or category. For instance, the prototypes of colour categories (Martindale and Moore, 1988), object categories (Whitfield and Slatter, 1979) and musical categories (Smith and Melara, 1990) are typically looked at for longer periods of time than less prototypical exemplars.

Valentine and Bruce (1986) proposed that a face prototype is formed from the previously encountered faces and that individual faces deviate from this prototype through a number of transformations. Thus, distinctive faces are recognised faster than typical faces but would be classified more slowly. These effects encouraged Valentine (1991) to propose a theoretical framework for face recognition in which faces are encoded as points in a multidimensional face-space. This theory proposed that the centre of the space represents the average value of the population on each dimension, while the dimensions of the space serve to discriminate between faces (Valentine, 1999). Thus, typical faces would be located close to the centre, while distinctive faces would be located further from the centre of the space. Consequently, distinctive faces are easier to recognise as they are located further away from neighbouring faces in the space and less susceptible to confusion.

1.5 Developmental changes in face processing during childhood

We were interested in finding out more about face recognition abilities rather than face processing style. Evidence of improvements of face recognition abilities has been found throughout childhood (Goldstein and Chance, 1964) and a steady development in recognition performances with unfamiliar faces has been observed from 6 years of age until adulthood (Chung and Thompson, 1995 for a review). However, the age at which face recognition becomes mature and adult-like varies with the study (10 years of age in Carey, 1992; 11 years in Feinman and Entwisle, 1976; 16 years in Carey et al., 1980 and Campbell et al., 1999). For instance, Feinman and Entwisle (1976) reported no further improvement in recognition performance for faces after the age of 11, suggesting that facial recognition abilities may have reached adult levels by this age. In reality, several studies (e.g. Carey et al., 1980; Flin, 1980; Diamond, Carey and Back, 1983) report a similar developmental discontinuity after which there is a temporary decline in face recognition performance. This developmental curve has been reported to appear after the age of 10 (Carey and Diamond, cited in Carey, 1978) and 12 (Carey et al., 1980; Flin, 1980). Other researchers (Diamond and Carey, 1977; Carey et al., 1980; Benton and van Allen, 1973) reported a plateau inducing a standstill in performance. However, inconsistent results across studies challenged the reliability of such a developmental dip (Chung and Thomson, 1995).

Chung and Thomson (1995) suggested that children's manner of encoding faces is not fundamentally different from that of adults even though it is less efficient than in adults. Consistent with this pattern, Flin and Dziurawiec (1989) proposed that older participants may perform better at face processing tasks because they encode a greater amount of facial information. Several studies support this hypothesis (e.g. Blaney and Winograd, 1978; Winograd, 1981; Ellis and Flin, 1990). Similarly, there is little difference between the recognition of *familiar* faces in children and adults (Goldstein and Mackenberg, 1966; Langdell, 1978; Young and Bion, 1981) and no developmental differences have been found.

These differences may reflect changes in the processing style: Carey (1992) suggested that children are less efficient than adults because, under the age of 10, children only use featural information and present an immature neural substrate of face encoding skills. In contrast, other researchers (Flin, 1985; Baenninger, 1994; Chung and Thomson, 1995) suggested that the use of featural and configural information is similar in children and in adults, but that the amount of information used and efficiency improve with age.

1.6 Face selective electrophysiological wave : the N170

Face selective electrophysiological activity has been observed in event-related potential (ERP) studies of electrocortical activation during face processing in adults. For instance, the N170 is a negative deflection peaking at around 170 ms after stimulus onset. This potential tends to be of larger amplitude and shorter latency for faces than other objects (Bentin et al., 1996). It has been reported to be influenced by stimulus inversion, a factor which has been found to influence measures of face recognition at a strictly behavioural level. Thus, the N170 is of larger amplitude and longer latency for inverted human faces compared to upright human faces. This effect is particular to the human face stimulus and has not been observed for animal faces (de Haan, Pascalis and Johnson, 2002) or objects (Rossion et al., 2000).

Taylor et al. (1999) demonstrated that the N170 could be observed, albeit with a longer latency, in children as young as 4 years of age. However, it failed to reach adult levels by mid-adolescence, thus implying that face processing undergoes maturational changes between childhood and adulthood. Nevertheless, as visual sensory processing is thought to be mature by about 5 years of age (Taylor and McCulloch, 1992), Taylor et al. (1999) indicated that this development cannot be due to its increased efficiency.

These results support behavioural studies that suggested a steady, quantitative development in both featural and configural face processing abilities with age (Baenninger, 1994; Flin, 1985). They contrast with Carey's (1992) premise that behavioural developments are largely mature by the age of 10. Other developmental visual ERP studies (Taylor and Smith, 1995) show a similar developmental course and support the idea that face processing is not qualitatively different from processing of other complex stimuli, although it does engage separate neural structures (Nachson, 1995).

2. Infant visual perception

During pregnancy, the visual system develops in a dark environment which offers little visual stimulation to the developing foetus (Fifer and Moon, 2003). At birth the eye is hypermetropic and eye movements are uncoordinated and may be accompanied by brief deviation of the eyes. Towards the end of the neonatal period, however, good fixation and following is evident and accommodation (focusing) becomes better co-ordinated (Snell and Lemp, 1998).

2.1 Visual acuity and accommodation

It is widely accepted that neonates' visual acuity, which refers to the measure of the precision of detail resolution, is approximately one-thirtieth of the level displayed by adult acuity (Mohn and van Hof-van Duin, 1985). Infants' visual acuity is typically measured through the optokinetic nystagmus (a series of reflexive pursuit and saccadic eye movements elicited by a repetitive pattern moving through the visual field), the visual preference technique and the forced-choice preferential looking task, which allow to determine the finest stripes an infant can resolve. At 2 weeks of age, infants display a visual acuity level of about 2 cycles per degree, at 5 and a half months of age of 6 cycles per degree, and at 30 months of age of 60 cycles per degree. Adults' acuity levels average between 45 and 60 cycles per degree. Neurological immaturity (immaturity of the photoreceptors in the retina and limitations in the geniculostriate pathway) is likely to be the cause of these early acuity limitations rather than actual visual limitations (Teller, 1998; Maurer and Lewis, 2001).

In the particular case of infants who have been treated for congenital cataracts at an early age, researchers have demonstrated that, despite rapid improvements post-operation, acuity does not reach normal adult levels (Maurer, Lewis, Brent and Levin, 1999), presumably because early deprivation caused damage to the visual cortex (Maurer and Lewis, 2001). These results suggest that visual input is necessary for normal development of the visual system to occur and that, in the absence of patterned visual input, acuity stays inactive postnatally.

Similarly, studies on visually deprived monkeys report that damages to the visual cortex induce permanent deficits in grating acuity (Harwerth et al., 1991). Studies (Maurer and Lewis, 2001 for review) showed that early visual binocular deprivation manifests itself at the level of the primary visual cortex: cells respond more slowly, display abnormally large receptive fields, and are poorly tuned to orientation and spatial frequency. Furthermore, acuity across cells located in the primary visual cortex is reduced (Blakemore et al., 1983, 1990). In humans, studies of children who developed cataracts later in life suggest that connections for the development of normal visual acuity only become solid after the age of 10 years (Maurer and Lewis, 2001).

Young infants have also been found to demonstrate poor visual accommodation (i.e. focussing of the eyes), which typically enables the individual to create a sharp retinal image of perceived objects situated at various distances (Bremner, 2003). At around 2 months of age, visual accommodation starts to improve drastically and continues to do so until 4 months of age. Between 3 and a half and 4 months, visual accommodation is thought to be optimal, after which time it reaches adult levels (Aslin, 1985).

However, whereas these limitations are responsible for a loss of information on smaller details, perception of the larger-scale structure of visual stimuli should not be affected. Furthermore, both acuity and accommodation develop rapidly over the first half of the first year of life.

2.1.1 The visual field

The visual field is the area in which the infant can perceive a stimulus. It develops slowly during the first two months of life (Mohn and Van Hof-Van Duin, 1986). Between 2 and 20 weeks of age, the "effective visual field" (Tronick, 1972) improves and increases perception of stimuli between 15 and 40 degrees. Two- to 6-week-old infants perceive stimuli situated between 10 and 20 degrees from the central fixation point. Later, between 6 and 10 weeks of age, stimuli can be perceived at 40 degrees (Tronick, 1972). These data corroborate previous findings (Mohn et al., 1986) that established that the visual field increases with age but that around the age of 1 month, there is a standstill in development (perhaps even a regression).

When a stimulus is presented in the temporal visual hemifield rather than in the nasal visual hemifield, detection at 1 month of age is improved (Lewis and Maurer, 1980; Maurer et al., 1986; Mohn et al., 1986), whereas at 2 months of age, like adults, detection is superior in the nasal visual hemifield (Johnson and Morton, 1991; Maurer and Barrera, 1981). This improvement is probably due to the myelination of the nerve fibres projecting from the lateral geniculate body to the visual cortex which takes place between the first and the second month of life.

2.2 Investigating infant perception

Over the years, the visual preference technique and various habituation techniques have emerged as essential tools in the investigation of infant perception, primarily because they do not call upon the participant's ability to speak.

In the spontaneous visual preference technique, infants are presented with two different visual stimuli while the experimenter measures the amount of time spent looking at them. A difference in looking times is interpreted as a visual preference. Making such a preference involves and demonstrates an ability to discriminate (Bremner, 2003). In order to ensure that the observed preference is not a consequence of a lateral bias on the infant's part, the stimuli are presented in a series of trials counterbalancing the position of the stimuli. This technique has a long history of use in infant literature (Banks and Salapatek, 1983; Fantz, 1958).

The habituation technique relies on the observation that when a visual stimulus is presented repeatedly over a series of presentations, the time spent looking at it gradually declines as the infant habituates to it (Bremner, 2003). Habituation implies that the infant refers to a form of visual memory as he or she progressively memorises the presented stimulus. This occurrence can be used to investigate visual discrimination by looking at whether looking times increase again when a new stimulus is presented after the infant has habituated to the first stimulus. A more sensitive variant on this technique proposes to habituate the infant to one stimulus and, subsequently, offer a paired presentation of familiar and novel stimuli (Bremner, 2003). If the infant is able to discriminate the two stimuli, he or she should look longer towards the novel stimulus.

3. Infant face processing

Early on, the human face is undoubtedly the most commonly encountered visual stimulus by the newborn infant. It is a dynamic (D'Entremont and Muir, 1997), three-dimensional stimulus which displays areas of both high and low contrast, and contains internal features that appear both in changing (expressions) and invariant (e.g. position of the eyes) relationships (e.g. Freire and Lee, 2003). Faces challenge the infant's immature face processing system's capacity to learn to differentiate stimuli that differ only in subtle ways.

Fantz (1961) found that infants as young as 1 month old showed a small but consistent spontaneous preference for face-like stimuli over non face-like patterns. Subsequent researchers have attempted to replicate these data using more controlled experimental set-ups and a wider range of ages.

On a behavioural level, testing infants' visual preference for face-like patterns over non face-like patterns has been executed by presenting schematic drawings of a face with the internal features arranged naturally and unnaturally, and verifying that infants look longer towards the natural arrangement (see Valenza, Simion, Macchi Cassia and Umiltà, 1996). However, early on, this technique permitted only to confirm preference for face-like patterns in infants aged two months or more (e.g. Fantz, 1966; Fantz and Nevis, 1967; Koopman and Ames, 1968; Lewis, 1969; Wilcox, 1969; Maurer and Barrera, 1981). The absence of evidence of a preference for face-like patterns in infants younger than 2 months of age was imputed to a number of factors such as the externality effect found in young infants (e.g. Bushnell, Gerry and Burt, 1983; Bushnell, 1979; Hainline, 1978; Haith, Bergman and Moore, 1977; Maurer and Salapatek, 1976; Milewski, 1976) and an immature visual system, both limiting the amount of information obtainable from a face in early infancy (Banks and Salapatek, 1981; Atkinson, Braddick and Moar, 1977). In contrast, Morton and Johnson (1991; Johnson and Morton, 1991) claimed that ill adapted testing techniques were responsible for failing to observe a preference for face-like patterns in infants younger than 2 months of age. Indeed, some studies (Johnson, Dziurawiec, Ellis and Morton, 1991; Maurer and Young, 1983; Goren, Sarty and Wu, 1975) showed that moving face-like patterns clearly yield greater tracking behaviour than non face-like patterns. For instance, Johnson et al.'s (1991) and Goren et al.'s (1975) findings established that neonates track moving face-like patterns further than other non face-like patterns, even within an hour of birth, thus strengthening the argument that neonates have access to a complex perceptual organisation at birth. Neonates seem to find moving face-like patterns with high contrast definition particularly attractive. However, these results could not be replicated in other studies using a preferential looking technique (e.g. Hershenson, Kessen and Munsinger, 1967; Slater, 1993).

Maurer and Barrera (1981) systematically tested 1- and 2-month-old infants' ability to discriminate schematic drawings of a face with internal facial features arranged naturally, symmetrically and scrambled, or asymmetrically and scrambled. This was done using a visual preference technique. Like Fantz (1961), they came to the conclusion that only by the age of 2 months can infants reliably recognise how the features of a natural human face are arranged and generalise this information to schematic faces. These results are consistent with studies demonstrating that 2-month-olds spend long periods of time looking at internal facial features (Hainline, 1978; Haith et al., 1977; Maurer and Salapatek, 1976; Salapatek, 1975). However, it appears that, at this young age, a preference for the natural arrangement only becomes apparent if the infant is given enough looking time (Haaf, 1974; Haaf and Brown, 1976; Koopman and Ames, 1968; Wilcox, 1969). No preference was observed for 1-month-old infants, confirming past findings illustrating that 1-month-olds rarely look at internal facial features (Hainline, 1978; Haith et al., 1977; Maurer and Salapatek, 1976).

In a second experiment, using a habituation technique, Maurer and Barrera (1981) confirmed that 2-month-olds were able to discriminate two scrambled arrangements. Consequently, the authors hypothesised that, by 2 months of age, infants are able to generalise the information they have acquired about facial features and extend this knowledge to two-dimensional face-like patterns. The habituation technique also confirmed that 1-month-old infants cannot discriminate the different arrangements of facial features, even after having been habituated to one particular arrangement, thus confirming that 1-month-olds cannot discriminate between two shapes contained within a frame (Milewski, 1976). The lack of evidence for a preference at the age of 1 month led to the supposition that no preference would be found in newborn infants either.

In contrast, an earlier study by Goren et al. (1975), measuring 3- to 27-minute-old neonates' head and eye movements, demonstrated that neonates orient more readily towards a face-like stimulus than a moderately scrambled stimulus, a severely scrambled stimulus, a linear stimulus, or a blank stimulus.

Subsequent studies with neonates (Maurer and Young, 1983; Morton and Johnson, 1991; Easterbrook, Kisilevsky, Hains and Muir, 1999) did not find a preference for face-like stimuli when contrasted with a moderately scrambled stimulus or an inverted stimulus. They did, however, find a preference for a face-like stimulus when contrasted with a severely scrambled stimulus, a linear stimulus or a blank stimulus. These early findings implied that infants are born with an innate perceptual knowledge and also raised the question of the possible uniqueness of faces as visual objects (e.g. Ellis, 1975; Hay and Young, 1982).

In these studies, it became apparent that infants expected a correct orientation and coupling of elements to treat a stimulus as a face. Indeed, visual behaviour was the same for a face-like stimulus and for stimuli in which the correct orientation of the inner elements is respected and the eyes and eyebrows coupled. It differed when the orientation of the inner elements was incorrect and the eyes and eyebrows were separated. Easterbrook et al. (1999) confirmed that the coupling of the eyes and eyebrows plays a major part: neonates showed a preference for the face-like stimulus when paired with a head-shaped contour containing only one eye or a mouth and no preference when paired with a stimulus composed of a head-shaped contour containing eyes and eyebrows correctly positioned, oriented and coupled. Thus, from these data, Easterbrook et al. (1999) suggested that, rather than the complexity of the stimulus, it is the relative resemblance to a face that is responsible for the preference.

In a longitudinal study, Johnson, Dziurawiec, Ellis and Morton (1991) set out to replicate Goren et al.'s (1975) findings by observing preferential tracking of faces over the first five months of life using three sets of experiments. Results showed that neonates do appear to track moving face-like patterns further than other stimuli, thus confirming Goren et al.'s (1975) findings that, even within an hour of birth, infants seem to possess some specific information about the arrangement of particular features that compose a face. These findings strengthened the argument that a complex perceptual organisation is present at birth.

In contrast with Maurer and Barrera's (1981) findings, Johnson et al. (1991) showed that 1-month-old infants track a schematic face-like pattern further than stimuli that possess facial features in the wrong arrangement or non-facial features in a facial arrangement. They also demonstrated that there appears to be a decline of this preferential tracking between 4 and 6 weeks after birth.

It is possible that Maurer and Barrera (1981) did not find a preference for schematic faces over scrambled faces in their sample merely because they used a different preference technique and, contrary to Johnson et al. (1991), did not test infants under the age of 30 days. Two other studies (Fantz, 1966; Fantz and Nevis, 1967) with infants aged 1 to 4 weeks, also failed to find a preference for the face-like arrangement while using both infant control procedure and paired presentations of static stimuli, suggesting that the technique might account for the observed discrepancy.

In conclusion, Johnson et al.'s (1991) results suggest that neonates, within an hour of birth, possess specific information about the arrangement of facial features, and that the preferential tracking of face-like patterns declines after about 30 days of age (Maurer, 1983; Maurer and Barrera, 1981; Morton and Johnson, 1991). This period is thought to correspond with the transition from predominantly subcortical mechanisms to a cortical processing of visual information (Morton and Johnson, 1991). At around 2 months of age, the preference for face-like patterns resurfaces (Maurer and Barrera, 1981; Morton and Johnson, 1991).

3.1 Specific changes at about 2 months of age

It has been suggested that the period between 1 and 2 months of age corresponds with the transition from predominantly subcortical mechanisms to a cortical processing of visual information (e.g. Gamé, Carchon and Vital-Durand, 2003; Johnson and Morton, 1991).

At about 2 months of age, infants' visual behaviour is dominated by cortical systems and infants' visual responses are mostly determined by geniculocortical (i.e. nasal hemifield) information, reducing nasal-temporal asymmetries (Johnson, 1990). The emergence of a functional cortical system comes with certain changes in face processing that seem to enable the infant to encode faces in a more adult-like manner. However, these changes do not appear to be specific changes in face processing but rather general changes in visual pattern processing.

At about 6 weeks of age, preferential orienting to faces decreases (Johnson et al., 1991). Then, by 2 to 3 months of age infants start to prefer faces with features naturally arranged over scrambled faces, and faces with typical contrast over faces with reversed contrast (Dannemiller and Stephens, 1988) in the central visual field (Maurer and Barrera, 1981).

At about 2 months of age, infants become more sensitive to the internal facial features of static faces. Several studies demonstrated that 2-month-old infants spend long periods of time looking at internal facial features (Hainline, 1978; Haith et al., 1977; Salapatek, 1975), especially around the eyes (Maurer and Salapatek, 1976). Furthermore, infants aged 3 months can recognise a familiar face presented from a novel viewpoint, based only on internal features and are capable of remembering faces from their internal features after a 2-hour and 24-hour delay (Pascalis et al., 1998). This kind of scanning behaviour with increased and improved sensitivity to internal facial features is reminiscent of adult scanning of faces, when facial identity is encoded by extracting information from the spatial relations between the facial features (e.g. Diamond and Carey, 1986; Rhodes et al., 1993). However, this behaviour does not seem specific to faces as infants also tend to have an increased sensitivity to internal features of non-face patterns (Hainline, 1978; Milewski, 1976).

Infants aged 2 months also begin to establish a relation between individual faces, thus making face processing more adult-like. For instance, following a familiarisation to four individual faces, 3-month-old infants have been found to be able to recognise both the individual faces and a composite average of the four. In contrast, 1-month-olds could only recognise the individual face (de Haan et al., 2001; Langlois et al., 1995).

3.2 Recognition of individual faces and average face prototypes

Infant face processing is thought to differ from adult face processing in that information about an individual face is not compared with a prototypic face representation (Johnson and de Haan, 2001).

However, evidence from Slater and Morison (1987, cited in Slater, 1989) offers support for the idea that young infants can refer to perceptual categories. Neonates and 3- to 5-month-olds were familiarised with six exemplars of the same shape and later tested with a new exemplar of the same shape and a different shape. Three- to 5-month-old infants looked longer towards the different shape, thus suggesting that they can form categories based on perceptual similarity.

Quinn, Eimas and Rosencrantz (1993) argued that already between 2 and 4 months of age, infants are able to form perceptual categories of complex visual stimuli. They demonstrated that after familiarisation to the category 'cats' or 'dogs', infants of this age group looked longer at an exemplar of a new 'birds' category, than the familiar category.

In a subsequent study, Quinn and Eimas (1998) demonstrated that 3- and 4-month-olds could also represent humans as a separate category from other animal species. Infants familiarised with humans could form a category of humans that included other animals such as horses and fish (but excluded cars), while infants who had been familiarised with horses formed a category that included novel horses, but excluded humans, fish and cars. These data suggest that infants may have formed a global category that includes other animals and perhaps serves as a reference point for infants (Carey, 1985; Rosch, 1975). Quinn and Eimas (1998) also found that 3- and 4-month-olds represent humans differently from cats: infants familiarised with humans did not prefer novel cats over novel humans, but did prefer novel humans over familiar humans. In contrast, infants who had been familiarised to cats did prefer novel humans over novel cats while showing no preference for novel over familiar cats. These results suggest that, for human stimuli, infants developed a categorical representation that was inclusive of individual exemplars, but that they did not for cats. Further testing (Quinn and Eimas, 1998), using cats and horses, also confirmed that this asymmetry is specific to categorical representation for humans as opposed to non-human animal species.

Rubenstein et al. (1999) conducted a study in which 6-month-old infants were familiarised to eight individual photographs of faces, each presented for two 15-s trials. When tested, the infants looked longer at a novel face or at one of the familiar individual faces than at a prototype created by averaging the familiar faces.

In contrast, Walton and Bower (1993) demonstrated that newborn infants look longer at a composite of four familiar faces (prototype) than a composite of four unfamiliar faces. However, these results do not necessarily mean that neonates can form prototypes as the infants could simply have failed to discriminate the prototype from the exemplars.

De Haan, Johnson, Maurer and Perrett (2001) verified whether younger infants differ from older ones in their ability to form prototypes of faces. Eight faces of individual female faces were used as well as one "averaged" composite face, morphed and blended from four of the eight original stimuli. Following familiarisation to 4 individual female faces, both 1- and 3-month-old infants showed evidence of recognising the individual faces by looking longer at the novel face than at the familiar face. However, only 3-month-olds showed evidence of recognising, and thus having mentally computed, the averaged face. Three-month-olds looked longer at the familiar face than at the averaged face, presumably because the averaged face looked even more familiar than each of the individual faces. Additional experiments showed that 1-month-olds could not recognise the averaged face even when the task was made easier by pairing the averaged face with an entirely novel face. These results supported the idea that 1-month-old infants are able to encode individual faces but cannot recognise an average of a set of individual faces. These additional experiments also indicated that results could not be attributed to pre-existing preferences for particular faces. Thus, this study showed that 1-month-olds do not demonstrate evidence of forming average prototypic representations of faces when tested with the same procedures as older infants. This suggests that, while infants can remember individual faces from birth (e.g. Pascalis and de Schonen, 1994), it is only around the ages of 1 to 3 months that they begin to be able to link and share the information collected about individual faces.

Together, these results would suggest that infants appear to be able to form perceptual categories of faces by 3 months of age and, at least by 6 months of age, the nature of this representation may be prototypic (Rubenstein et al., 1999; Sherman, 1985; Strauss, 1979).

In contrast, evidence that neonates can recognise their mother's face (Pascalis et al., 1995) suggests that prototypic representation could in fact emerge before the age of 3 months. However, apparent generalisation of different views of the mother's face may be due to a lack of discrimination. Furthermore, evidence suggests that neonates do not have a generalised representation of the mother's face which, at this age, seems to be recognised by using external features rather than internal features (Pascalis et al., 1995) and not recognised when presented in profile (Sai and Bushnell, 1988).

There is some evidence that early prototypic representation is not face-specific. Bomba and Siqueland (1983) demonstrated that 3-month-old infants can form prototypes of dots. These results suggest that, contrary to adult face processing that is mediated by specialised cortical systems, infants' ability to form prototypic representations is not specific to faces. Specialisation of the cortical systems subserving face processing may emerge later due to the subcortical systems that orient the infant's visual attention to faces, thereby biasing the system's input, as well as increasing experience with faces.

3.3 Featural and configural processing in infancy

What information do infants process and encode when they discriminate, recognise and learn about faces?

From past studies, Cohen (1991, 1998) assumed that young infants' processing of visual information must progress through a series of levels. This view was supported by studies not concerned with facial stimuli, that demonstrated that infants from the age of 6 months appear to be able to process more than the independent features of a complex stimulus (Younger and Cohen, 1986; Needham and Baillargeon, 1997; Wilcox and Baillargeon, 1998). For instance, Younger and Cohen (1986) demonstrated that 7-month-old infants were able to respond holistically to schematic drawings of imaginary animals, while 4-month-olds did not. Cohen and Cashon (2001) verified whether 7-month-old infants respond to one or more independent features versus a configuration of features using a "switch" design (Cohen et al., 1998). After being initially habituated to two adult female faces, infants were tested with a composite face constructed from the internal features of one face pasted onto the outer features of the other face. Results showed that, in the upright condition, infants looked longer at the composite "switched" face than the familiar face. This indicates that infants must have processed at least some configural properties of the face. However, infants could have combined all or only a number of internal and external features. In the inverted condition, infants did not look longer at the composite face than the familiar face, showing no evidence of being able to process the configuration of inverted faces. Another series of studies, led by Kestenbaum and Nelson (1990), showed that by the age of 7 months, infants can form a category of the facial expression "happiness" when the faces are presented upright but not when they are inverted. These results indicate that 7-month-olds probably process upright faces holistically while they process inverted faces featurally.

The question remains, however: what information do infants process and encode when discriminating faces?

There is evidence that suggests that young infants essentially attend to external facial features. Pascalis et al. (1995) found that a preference for the mother's face over a female stranger's face disappears when the external features (outer contour and hairline) were masked and the neonates could only see the internal features. This led to the conclusion that neonates use the external facial features to recognise the mother's face. These results are consistent with other findings showing that neonates tend to attend to the external features rather than the internal features when presented with a geometric shape (Bushnell et al., 1983; Fantz and Miranda, 1975; Maurer, 1983), as do infants in the first two months of life. This is known as the "externality effect" (Bushnell, 1979; Milewski, 1976).

However, infants might have processed both internal and external features and removing the outer features might have disrupted recognition of the habituated configuration (Slater, 1998; Slater et al., 2000). It is equally as important to remember that Maurer (1983) did not find a bias for external features when using schematic faces rather than real live faces. Finally, Bartrip, Morton and de Schonen (2001) demonstrated that when the external facial features alone are present, the mother's face is not discriminated from a female stranger's face until the infant reaches 4 months of age.

There is also evidence that suggests that young infants essentially attend to internal facial features: Farroni, Valenza, Simion and Umiltà (2000) established that, despite poor visual acuity and the externality effect, neonates can discriminate the shape of local elements contained in a complex visual pattern, even when the stimuli are enclosed by identical frames. Additionally, studies concerned with the attractiveness effect at birth have brought evidence forward that neonates attend to, and process, the internal configuration of facial features when they show a preference for attractive over unattractive faces: Slater et al. (2000) demonstrated that a spontaneous preference for attractive photographic faces (Slater et al., 1998) appears when the external facial features are kept unchanged while the internal arrangement of the features is changed, thus suggesting that neonates use internal facial features rather than external features when discriminating attractive and unattractive faces. However, the evidence is not sufficient to resolve the question whether infants process the information transmitted by the shape formed by the internal facial features, or the configural information conveyed by the relation between the internal features (or the relation between these features and the outer frame for that matter).

In adults, inversion disrupts the configural processing of faces, which explains why inverting face stimuli impairs their ability to recognise and process faces holistically (Sergent, 1984). Simion et al. (2002) created an experimental paradigm verifying neonates' ability to discriminate and maintain over a two minute delay the information associated to the shape of the internal features in schematic face-like and non face-like (i.e. internal features presented in an upside-down configuration) patterns (see Figure 1).

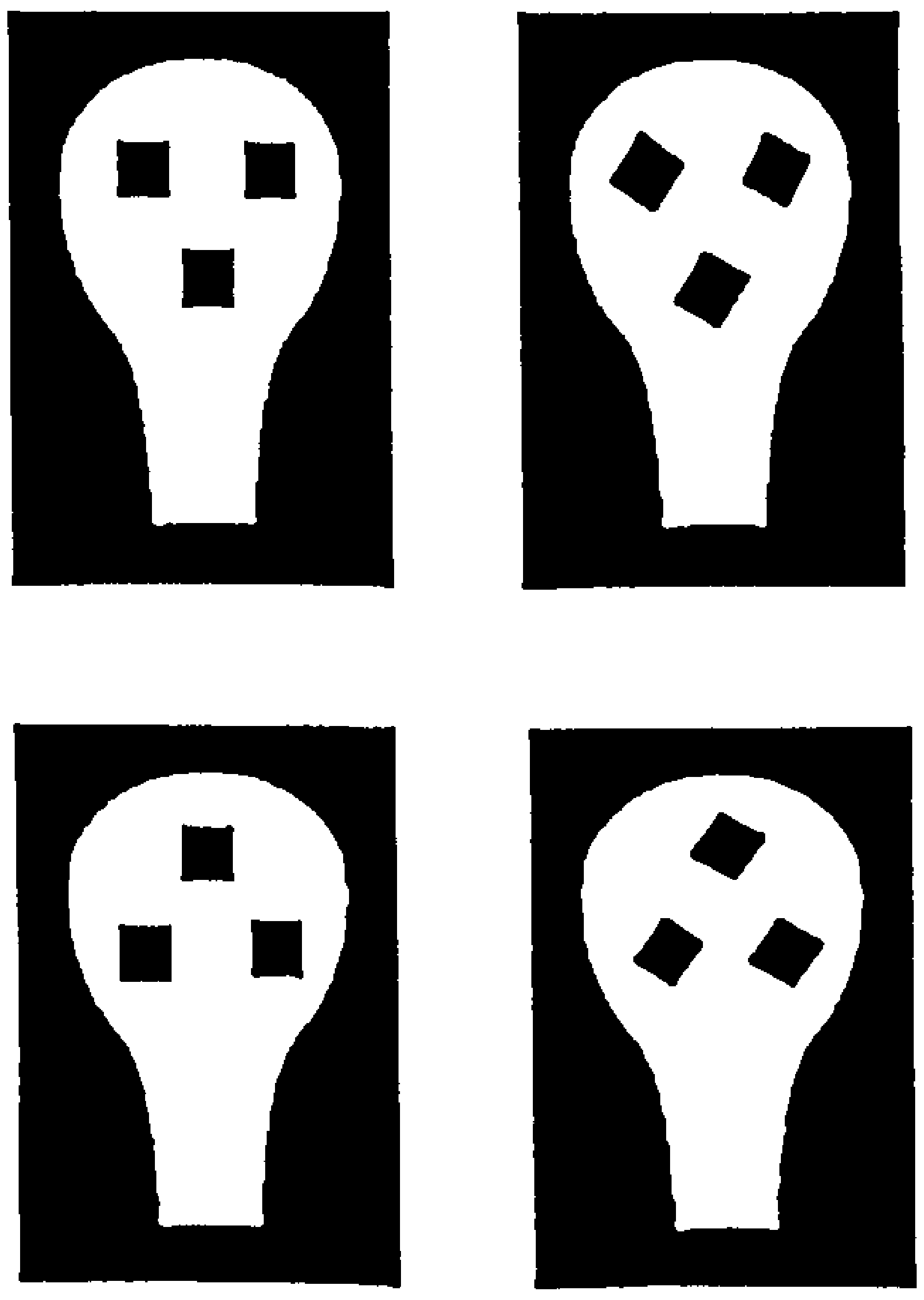


Figure 1: The two pairs of face-like and non face-like stimuli presented to infants in Simion et al.'s (2002) experiment.

The local information was manipulated by changing the shape of the internal components (either square- or diamond-shaped blobs), while the outer contour and the relation between the internal elements were maintained constant. Results showed that infants detected and discriminated the shape of the internal features in both the face-like and non face-like patterns, indicating their ability to process the local information conveyed by the shape of the internal features. In addition, the authors also found the presence of general delayed recognition memory abilities in neonates, not related to the stimulus material, thus replicating and extending evidence obtained with real faces by Bushnell (2001) who observed recognition of the mother's face after a 15-minute delay. The existence of the same memory abilities for face-like and non face-like stimuli supports the idea that there is a general visual pattern-learning mechanism at birth that allows neonates to learn about visual stimuli, in particular faces (de Schonen and Mancini, 1995; de Schonen et al., 1998; Johnson, 1997).

However, because of poor visual acuity and sensitivity to contrast at birth (Atkinson et al., 1977; Norcia, Tyler and Hamer, 1990), it is possible that local processing in neonates is improved for schematic face-like stimuli as a result of the high-contrast internal features. Indeed, the salience of the differences between the shapes of the features in the face-like patterns used in this study is stronger than the salience of the shapes of the features of real faces. With real faces however, neonates might rely more on configural information because of early visual limitations, even if both configural and local informations are processed (Simion et al., 2002).

This particular point was considered in Experiments 1 to 4 when we used photographs of real human faces contrasted with a series of control stimuli.

4. Models of development of face processing

Face processing follows a prolonged developmental course before becoming adult-like. Nevertheless, neonates demonstrate a remarkably early competency in orienting towards face-like patterns. Consequently, the observation of early face processing gives us the opportunity to examine which abilities are present from the start and allows the development of a model of specialisation of function in the brain by understanding the way face processing systems develop. Specific models of face processing have been elaborated with a view to explaining early preferences as highly specialised processes that differ from the processes involved in non face stimuli

The development of face processing poses two main questions: are the systems involved in face processing specific to faces? And: to what extent does experience shape this development? Several theoretical models have been proposed to answer these questions.

4.1 The sensory hypothesis

According to the sensory hypothesis, neonates' visual system does not respond specifically to faces but, rather, reacts to visual stimuli based on their intrinsic degree of visibility. It proposes that preferential orienting to faces is a result of more general processes linked to visual attention. This model accurately predicts visual preferences in the first months of life, especially for high-contrast stimuli (i.e. face-like stimuli). For instance, the linear systems model (LSM) claims that visual preferences are based on the amplitude spectra of the stimuli (i.e. the amount of energy in a visual pattern, defined by the amplitudes and orientations of the component spatial frequencies; Banks and Ginsburg, 1985; Banks and Salapatek, 1981). This model predicts that faces will only be preferred if they have an amplitude spectrum that makes them more visible than other stimuli (Kleiner and Banks, 1987). However, Kleiner (1990, 1993) introduced a revised version of the hypothesis suggesting a hierarchical model in two stages: first the visual stimuli are compared for their amplitude. Then, if they do not differ on this level, their structures are compared. This means that only if both patterns meet a minimum visibility requirement and have similar spatial frequencies, will infants discriminate them on the basis of structural information (phase spectrum). Thus, the structure of the stimulus elicits a preference only when the sensory features are matched.

A visual tracking task performed by Easterbrook et al. (1999) established evidence in support of the sensory hypothesis. Neonates were tested in order to determine whether facedness (i.e. the general arrangement of facial features into the face contour) or complexity are responsible for face preference at birth. Easterbrook et al. (1999) showed that neonates equally track a schematic face and other patterned stimuli with different arrangements of the same elements. Indeed, the amount of amplitude and phase information contained in one single stimulus appeared to predict infant tracking behaviour most accurately.

Evidence in favour of the revised version of the LSM (Kleiner, 1990, 1993) comes from Simion et al. (2001) who presented neonates with pairs of stimuli, each composed of an upright configuration with more high-contrast areas in the upper part, and an upside-down configuration with more elements in the lower part. Simion et al. (2001) showed that neonates orient more frequently and look longer at the upright configurations, regardless of the type of stimuli. These results are supported by Turati, Simion, Milani and Umiltà (2002) who showed that, when presented with upright and upside-down schematic configurations, each composed of three internal high-contrast areas surrounded by a head-shaped contour, neonates prefer the upright stimulus with two blobs randomly located in the upper part of the configuration and one in the lower part, over the upside-down configuration, with two blobs located in the lower part and one in the upper part. Turati et al. (2002) observed a preference for the upright configuration even when the relation between the inner elements within the head-shaped contour did not correspond to facedness (the elements were not placed in the correct locations for the mouth and eyes). These results confirm that more elements in the upper portion of the pattern produced more orienting responses and fixations, regardless of whether infants were presented with geometrical patterns, head-shaped configurations or face-like stimuli. Thus, Turati et al. (2002) suggested that, even in the case of face-like patterns, neonates' preference is commanded by the visibility of the structural configuration of the stimuli. However, neonates did show longer looking times towards face-like patterns (upright and inverted) than geometrical patterns (upright or upside-down). According to Simion et al. (2001), the reason for this is likely to be the curvilinear shape of the external contour surrounding the three blobs.

The sensory hypothesis was founded on the assumption that neonates' visual perceptual capabilities are limited to psychophysical, low-level information, such as spatial frequency and amount of contrast (Banks and Ginsburg, 1985). More recent evidence, however, suggests that neonates possess a much more flexible visual processing system, open to receiving higher-level or second-order configurational properties, thus allowing them to process a wider range of information at more than one structural level (e.g. Farroni et al., 2000; Macchi Cassia et al., 2002; Slater et al., 1991). For instance, neonates can process visual information at both local and global levels, albeit the global information shows a slight advantage over the local one (Macchi Cassia et al., 2002).

We believe the sensory hypothesis has a limited interpretative power and, while it seems to offer accurate predictions of visual preferences for the neonatal period (especially for high-contrast stimuli such as face-like patterns), it cannot account for some of the specific preferences observed in infants during the developmental course leading to an adult-like face processing system.

4.2 The structural hypothesis

According to the structural hypothesis, it is the combined action of stimulus visibility and detailed information of facial configuration that is responsible for infants' innate preference for face-like stimuli. For example, Johnson and Morton (1991) and Morton and Johnson (1991) argued that neonates' preferential orienting towards face-like patterns can be explained by the spatial arrangement of the inner elements of the pattern which convey structural information. They suggest that neonates orient more frequently towards faces because of a subcortical mechanism (Conspec) which contains a crude specification of the arrangement of the main facial features (eyes and mouth) and triggers attention to face-like patterns. Another system (Conlern), controlled by cortical circuits specialised for processing faces, is thought to appear at around 2 months of age as a result of the developing cortex being exposed to faces.

Johnson and Morton proposed that Conspec is located in the superior colliculus, receives information mediated by the retinotectal pathway (the pathway responsible for the eyes' orientation towards the stimulus), and only serves the purpose of directing neonates' attention to face-like stimuli appearing in the visual field. The subcortical mechanism is activated when tracking of a moving stimulus (Johnson and Morton, 1991), or looking at static patterns (Macchi Cassia et al., 2001) located in the periphery of the visual field is required.

Conlern is thought to be a cortical, non specific learning mechanism, responsible for maintaining foveal fixation on faces (Johnson and Morton, 1991). It acquires knowledge about faces solely because neonates pay attention to them, thus facilitating learning about the specific features of a human face (as opposed to those of other species). Conlern is believed to receive information mediated by the geniculostriate pathway.

Researchers using looking tasks such as preferential looking and habituation have provided evidence for Conlern. For example, Valenza et al.

(1996) used a visual preference task to demonstrate that neonates prefer face-like patterns even when they are presented alongside stimuli of high physical salience.

However, researchers using stimuli paired for quantity of energy (making them equally visible in terms of physical properties), have provided evidence supporting the view that other stimuli than faces are preferred by neonates on the basis of their structural configurations. Several researchers (Slater and Sykes, 1977; Slater, Earle, Morison and Rose, 1985; Farroni et al., 2000) demonstrated that neonates prefer horizontal over vertical gratings, even though both stimuli were equally visible in terms of psychophysical properties, thus suggesting that the structural properties of the stimuli determined the preference. Thus, the structural configuration of a pattern is essential in determining neonates' preference for geometrical stimuli as well as for faces since orientation is a structural property of the stimulus. These data suggested that neonates can encode the configural properties of stimuli other than faces.

In a series of visual preference tasks, Mondloch et al. (1999) attempted to resolve the inconsistent results of past studies, employing pairs of face and non face stimuli used in these earlier studies (Dannemiller and Stephens, 1988; Johnson et al., 1991; Kleiner, 1987; Kleiner and Banks, 1987). Two-hour-old neonates were tested alongside 6- and 12-week-old infants using a stimulus pair composed of a *config* stimulus (i.e. a head outline with three blobs in the locations of eyes and mouth) and its inversion (Johnson et al., 1991), a pair composed of a stimulus with the phase spectrum of a face but the amplitude spectrum of a lattice, and vice versa (Kleiner, 1987), and a pair composed of a positive-contrast face and a negative-contrast face (Dannemiller and Stephens, 1988).

Mondloch et al. (1999) established that neonates' preferences are influenced by the visibility of the stimulus as well as its resemblance to a human face. When presented with a pair comparing the amplitude of a face with the phase of a face, newborn infants preferred the amplitude of a face. However, when presented with two stimuli with similar amplitude spectra but with differing resemblance to a face, they preferred *config* over its inverted version. They expressed no preference when both stimuli had the same features in the same face-like arrangement (positive-contrast versus negative-contrast face). Mondloch et al. (1999) suggested that these results indicate that there is an innate mechanism predisposing neonates to look towards faces. Since the *config* stimulus was adequate to activate this mechanism and it was indifferent to the luminance of the face when contrast was reversed, it is likely to contain a basic representation of a face. Because the preference for *config* disappeared by 6 weeks of age, Mondloch et al. (1999) hypothesised that the mechanism that underlies face preference at birth is likely to be subcortical. In contrast, because both 6- and 12-week-old infants preferred the stimulus with the phase spectrum over the stimulus with the amplitude spectrum of a face, Mondloch et al. (1999) suggested that, by 6 weeks of age, the developing cortex regulates infants' attention for faces as this is consistent with other evidence of increased cortical activity at about 6 weeks of age (Atkinson, Hood, Wattam-Bell, Anker and Tricklebank, 1988). The only group to show a preference for the positive-contrast schematic face (Dannemiller and Stephens, 1988) were the 12-week-olds. The authors suggested that, like adults (Kemp, Pike, White, and Musselman, 1996), they may have difficulty recognising a negative-contrast face because they rely on shading when processing shape. Contrary to adults, neither 6- nor 12-week-olds expressed a preference for the *config* stimulus over its inversion, possibly suggesting that it requires more than 12 weeks of experience with faces before infants can identify a very basic stimulus representation such as *config*, as face-like.

Although the visual system is clearly developing rapidly, one must take other lines of evidence (e.g. intermodal matching) into consideration before deciding whether all of infants' early visual preferences can be ascribed solely to subcortical structures. Indeed, it is possible that cortical structures participate in these patterns of behaviour.

Both Kleiner's (1987) and Johnson and Morton's (1991) hypotheses have limitations and fail to explain some discrepant findings. For example, Johnson and Morton's (1991) hypothesis cannot explain why neonates do not track the *config* stimulus farther than its inverted version (Johnson et al., 1991). Kleiner's (1987) model cannot explain why neonates prefer a schematic face, with both the phase and amplitude of a face, over a hybrid stimulus with the amplitude of a face and the phase spectrum of a lattice (Morton, Johnson and Maurer, 1990). While Kleiner's model predicted the results for amplitude versus phase of a face correctly, the original model (1987) could not explain why newborn infants preferred the *config* over its inversion. The revised hierarchical model (1990, 1993), that Kleiner developed to address some of the limitations encountered by the first model, could not explain the disappearance of the preference in older infants. Johnson and Morton's model could not explain that a preference for phase of a face over amplitude of a face emerges between birth and 6 weeks of age when their model predicted that Conlern only emerges between the second and the third month.

4.3 The sensory-ecology model

According to the sensory-ecology model (Bushnell, 1998), early preference for the human face originates from the fact that the human face is a particularly salient stimulus that best matches neonates' sensory, perceptual and cognitive system, and that, early on, it is typically the most perceived stimulus in periods of alert and active attention. The model suggests that the neonate is born with haptic knowledge of the human face acquired from proprioceptive exploration of its own face in the womb and made available to him/her through intersensory mapping. Meltzoff and Borton (1979) demonstrated intermodal matching (or equivalence of texture information) between the sense of touch and the sense of vision at 4 weeks of age. Furthermore, intersensory mapping is corroborated by evidence of early imitation in neonates and 1-month-old infants (Meltzoff and Moore, 1977, 1983). More recently, Streri and Gentaz (2003) observed that infants as young as 3 days old already demonstrate intermodal matching between the sense of touch and vision, thus suggesting that, very early, neonates can rely on some form of cortical intervention.

4.4 Models of cortical development

Both the sensory and the structural hypotheses have reported a transition in infant face processing by two months of age due to cortical development. There are three hypotheses concerning the development of the cortical system: the experience-independent hypothesis, the experience-expectant hypothesis and the experience-dependent hypothesis.

4.4.1 The experience-independent hypothesis

Authors such as Fodor and Farah (Fodor, 1983; Farah, Rabinowitz, Quinn and Lui, 2000) proposed that face processing is subserved by an innate, face-specific cortical system. Experience does not shape its development but may be a trigger for the domain-specific system. According to this hypothesis, the changes observed in face processing skills in the second month of life are interpreted as general progress in processing visual information, an increase in processing speed, or the emergence of new trajectories of incoming and outgoing information.

For instance, Farah et al. (2000) argued that a cortical "face module", containing a prototype used for face processing, is present very early in infancy. Three lines of evidence support the authors' claim: the specific activation of a ventral temporal lobe area in response to faces (the fusiform face area, i.e. FFA), the existence of face responsive cells in infant monkeys as young as 6 weeks of age, and neonates' preferential orienting towards face-like patterns.

4.4.2 The experience-expectant hypothesis

The experience-expectant hypothesis proposes that the observed cortical development occurs in preparation for an experience common to all members of the species (Greenough and Black, 1992). This view supports the idea that there is a critical time at which the experience of face processing needs to occur. It is thought that the neural system is sensitive to environmental influence for a limited time and that visual experience must occur in this particular period of development in order for face processing to develop normally. Three hypotheses fall into this category: the Conspec/Conlern hypothesis (see above), the perceptual narrowing hypothesis and the hemispheric specialisation hypothesis.

4.4.2.1 The perceptual narrowing hypothesis

The perceptual narrowing hypothesis (Nelson, 2001) emerged from the comparison between the specialisation of the development of the cortical face processing system and the development of the cortical speech processing system. For instance, while 6-month-old infants can discriminate speech sounds from both native and non-native languages, 12-month-old infants and adults can only discriminate speech sounds from their native language (Werker and Lalonde, 1988; Werker and Tees, 1984). Similarly, the perceptual narrowing hypothesis proposes that cues for human face recognition may at first be part of a larger class but, with experience, the category might be reduced to comprise only human faces, and then perhaps narrowed even further to include only signals that are relevant to very specific aspects of face processing (e.g. identity, emotion). With increasing exposure to faces and narrowing of the perceptual window to this class of stimuli, the selectivity of the infant's neural and behavioural responses to faces would increase (Nelson, 2001). This model explicitly addresses the issue of how different aspects of face processing (e.g. identity, emotion, facial speech) end up being processed by different neural systems in adults (Campbell et al., 1996).

A number of researchers have found evidence in support of this hypothesis. For instance, using event-related potentials (ERPs), Nelson (1993, cited in Nelson, 2001, 2003) demonstrated that young infants can discriminate monkey faces across changes in facial orientation, whereas adults cannot, suggesting that prolonged exposure to human faces leads to a perceptual narrowing of the faces that can be discriminated with ease. Another ERP study (de Haan et al., 2002) observed a component similar to the adult N170 that was larger for human than for animal faces, in 6-month-old infants. However, it appears that at 6 months of age the infant's face processing system may be broader and less specifically tuned to upright human faces than the adult's face processing system, as the observed infant N170 is of longer latency and is not influenced by face inversion until 12 months of age (Halit, de Haan and Johnson, 2003). (Early latency sensory components of the ERP were different for human and monkey faces for both ages, thus confirming that the two species had been discriminated). Moreover, 6-month-old infants have been found to be equally good at discriminating faces of both human and non-human primates, whereas 9-month-olds and adults show a clear advantage for recognising human faces (Pascalis, de Haan and Nelson, 2002). Collectively, these results suggest that the perceptual window narrows with age and that during the first year of life, face processing is being tuned to a human template.

Nelson (2001, 2003) proposes that face recognition is acquired through exposure to faces, hereby specialising tissue in the inferotemporal cortex for face recognition within the first months of life. In addition, early specialisation may lead to a lack of developmental plasticity, which may explain why both children and adults fail to show recovery of function after neural lesions (Nelson, 2001, 2003).

Studies of human (and monkey) infants born prematurely and studies of selective rearing could possibly help establish which experiences are necessary for such a specialisation to occur, when they need to take place, or even for how long. Infants born with specific brain damage may also help in finding out more about plasticity in the infant's brain, and especially in the face recognition system (Nelson, 2001, 2003). (Part two of this thesis looked at how extra visual stimulation affected the long-term development of children born prematurely.)

In line with the perceptual narrowing hypothesis, we designed a number of visual preference tasks to be applied to different age groups with a view to understanding how early in life visual preferences set in and a narrowing of the perceptual window can be identified.

4.4.2.2 The hemispheric specialisation hypothesis

The hemispheric specialisation hypothesis (de Schonen, Gil de Diaz and Mathivet, 1986; de Schonen and Mathivet, 1989, 1990) proposes that the right hemisphere plays a singularly important role in face recognition. It provides an explanation for some of the specific features of the adult face processing system, such as the right hemisphere bias for face processing and the bias for configural encoding of faces (Farah, 1990; Rhodes et al., 1998). De Schonen and colleagues (de Schonen et al., 1986; de Schonen and Mathivet, 1989, 1990) claimed that the reason why the right hemisphere becomes specialised for representing faces configurally is, firstly, because the right hemisphere develops faster than the left, and, secondly, because, before any other stimulus, babies first learn about faces because their visual system is more sensitive to low than high spatial frequency visual input. The theory assumes that, as infants' contrast sensitivity function (CSF – a measure of a visual system's sensitivity to a range of sinewave gratings) improves, experience with face stimuli further encourages the development of the right hemisphere face system, which steadily leads to greater neural specialisation. However, with time, the left hemisphere benefits from this experience too, thus providing an explanation for bilateral activation of regions like the fusiform gyrus when processing faces.

Studies with patients treated for congenital cataracts (e.g. Le Grand et al., 2001; Geldart et al., 2002) have provided evidence supporting the idea that specialisation occurs very early in life and that, at the very least, visual experience activates a domain-specific system.

Studies using a divided visual field procedure have also generated evidence of hemispheric differences in face processing. In adults, the left visual field (LVF), that is to say the right hemisphere, is thought to have an advantage for face processing (Farah, 1990; Rhodes et al., 1998) as faces are detected more quickly and with more precision in the LVF than in the right visual field (RVF). Because of the nature of the neural projections from the retina to the primary visual cortex, information relating to stimuli presented in the LVF reach the right hemisphere before the left hemisphere, while information presented in the RVF will reach the left hemisphere before the right hemisphere. Several studies suggested that by 4 to 9 months of age the right hemisphere could be better at recognising faces than the left hemisphere.

For instance, de Schonen et al. (1986) and de Schonen and Mathivet (1990) demonstrated that 4- to 9-month-olds orient more readily to the mother's face than a stranger's face if the faces are presented in the LVF but not if they are presented in the RVF, whereas simple geometrical shapes are discriminated at the same level in either visual field (if anything, better in the RVF; de Schonen et al., 1986). Similarly, ERP studies show that by 6 months of age the negative central (Nc) potential is larger for a familiar face (i.e. the mother's face) than for an unfamiliar face over the right-sided electrodes for anterior temporal recordings (de Haan and Nelson, 1997, 1999). In contrast, when the stimuli are familiar and unfamiliar objects, the Nc is larger for familiar objects in both hemispheres (de Haan and Nelson, 1999). Together, these findings indicated that, by the age of 4 to 9 months, a right hemisphere advantage has developed for face processing. The right hemisphere is better at detecting changes in spatial arrangement of features whereas the left hemisphere is better at detecting differences in the detail of the features (Deruelle and de Schonen, 1995).

Although these findings are useful for methodological and interpretative reasons, we did not test for the validity of this particular hypothesis, as it was beyond the scope of our study.

4.4.3 Experience-dependent hypothesis

The experience-dependent hypothesis supports the idea that the development of the cortical system for face recognition is essentially influenced by visual experience. However, in this case, experience can occur at any time during development and also for visual stimuli that are not faces as the mechanism is a non-specific general learning process. Some authors (Diamond and Carey, 1986; Gauthier and Tarr, 1997) have argued that the reason we become such experts at recognising human faces is because facial stimuli are the most commonly encountered category of stimuli and can be recognised at a subordinate (within-class) exemplar-specific level (because they require discrimination between almost identical exemplars). In other words, face recognition involves expert-level subordinate classification within a homogeneous object category. Because faces are very similar to each other, an increased sensitivity to configural differences is required (e.g. Tanaka and Sengco, 1997). Thus, development of expertise in face processing is comparable and similar to the development of expertise in processing other categories of visual stimuli. This hypothesis claims that face recognition is special simply because faces constitute a homogenous category of stimuli for which within-category discrimination is ecologically advantageous for the individual early in life (Dailey and Cottrell, 1999).

The experience-dependent hypothesis also claims that acquisition of expertise in subordinate classification of a novel object category leads to a similar sensitivity to configuration information (Gauthier and Tarr, 1997) – i.e. the visual system is sensitive to information throughout life and, under certain circumstances, individuals may acquire a comparable level of expertise for non-human face stimuli. For instance, testing adult participants, Gauthier, Tarr, Anderson, Skudlarsky and Gore (1999) observed a similar activation of the fusiform face area (FFA) with non face-like stimuli (Greebles) that share a common spatial structure after extensive training.

5. Experiments 1 to 4: Face processing in infants

5.1 Introduction

The various models of development of face processing described in chapter 4 do not offer a definitive answer to the question whether the systems involved in face processing are specific to faces. Thus, we designed four experiments to clarify whether face processing is indeed special. We hoped to achieve this by presenting a number of visual stimuli alongside a human face stimulus and by confirming that infants would display a preference for the latter.

Unlike the structural hypothesis (Morton and Johnson, 1991) which claims the existence of an innate subcortical attraction for the structural configuration of faces, proponents of the sensory (Banks and Salapatek, 1981) and the sensory-ecological (Bushnell, 1998) hypotheses dispute any innate ability to recognise faces. They argue that newborns' preference for faces results from the visibility of the stimulus or from haptic experience during the pre-natal period.

Like Bushnell (1996), we hypothesised that the human face is a particularly salient stimulus and that the neonate is born with haptic knowledge of the human face acquired from proprioceptive exploration of its own face in the womb. In line with the perceptual narrowing hypothesis (Nelson, 2001), we designed visual preference tasks for neonates and 1- and 3-month-old infants to verify how early in life visual preferences set in and whether a narrowing of the perceptual window can be identified.

In Experiments 1 to 4, we contrasted four control stimuli with human faces to determine if there was a preference for the photographic representation of the human face early in life.

We tested infants' face recognition abilities at birth, but also at 1 month of age, when visual behaviour is thought to be dominated by subcortical systems, and at 3 months of age, when it is thought to be cortically driven (e.g. Gamé et al., 2003; Johnson and Morton, 1991).

We used a preferential looking technique in which each pair of stimuli was presented until the infant had either looked at the presentation for a 10-second period of accumulated time, or looked away from the presentation for 10 or more consecutive seconds. To be included in the study, the infant had to orient to each stimulus in each pair.

Some infants were used in all 4 experiments. However, no infants were used twice at different ages.

5.2 Experiment 1 : Human face versus Fourier transform

The sensory hypothesis claims that faces do not constitute a special class of stimuli for neonates and that they are preferred solely because of their psychophysical properties which match those of the neonates' sensory channels. However, research by Acerra et al. (2002) and Simion et al. (2001), revealed that neonates' preference for faces might be determined by more general visual structural properties that face-like patterns share with other non face-like patterns. The combined effects of these properties would guarantee a preference for face-like patterns over non face-like patterns.

Some early comments suggested that the ability to recognise faces is innate (Bühler, 1933; Bowlby, 1969, cited in Nelson, 2001) and adaptive, enabling young infants to recognise potential caretakers and emotional signals. Conversely, Turati (2004) suggested that faces carry a number of non specific perceptual characteristics (such as complexity of the facial configuration and high contrast of the inner features) that strongly attract neonates' attention on their own. However, it is particularly difficult to interpret findings reported in the literature because the facial and non facial stimuli differ in luminance and in contour density, both of which are known to influence infants' fixation time (Valenza et al., 1996).

With the aim of demonstrating that general, non specific constraints of visual processing may be sufficient to generate a specialisation for faces in neonates, Simion et al. (2002) and Macchi Cassia, Valenza, Pividori and Simion (2002) looked at up-down asymmetry and congruency, respectively. Up-down asymmetry refers to the presence of more elements in the upper than in the lower part of the configuration, while congruency refers to the existence of a congruent spatial relation between the configuration of the inner features and the shape of the outer contour, with the greater number of inner elements located in the widest portion of the pattern. Results showed that neonates oriented more to, and looked longer at, the congruent patterns and the stimuli with a higher density of elements in the upper part, thus suggesting that face preference might be explained by non specific perceptual biases present shortly after birth.

Turati et al. (2002) demonstrated that early preference for faces was not elicited by the specific structure of faces. Infants were shown a presentation of a face-like pattern contrasted with a top-heavy non face stimulus. They were also shown a presentation of a face-like pattern in which the inner elements were positioned in the lower portion, contrasted with a top-heavy non face-like arrangement with the inner elements positioned in the upper portion of the pattern (see Figure 2).

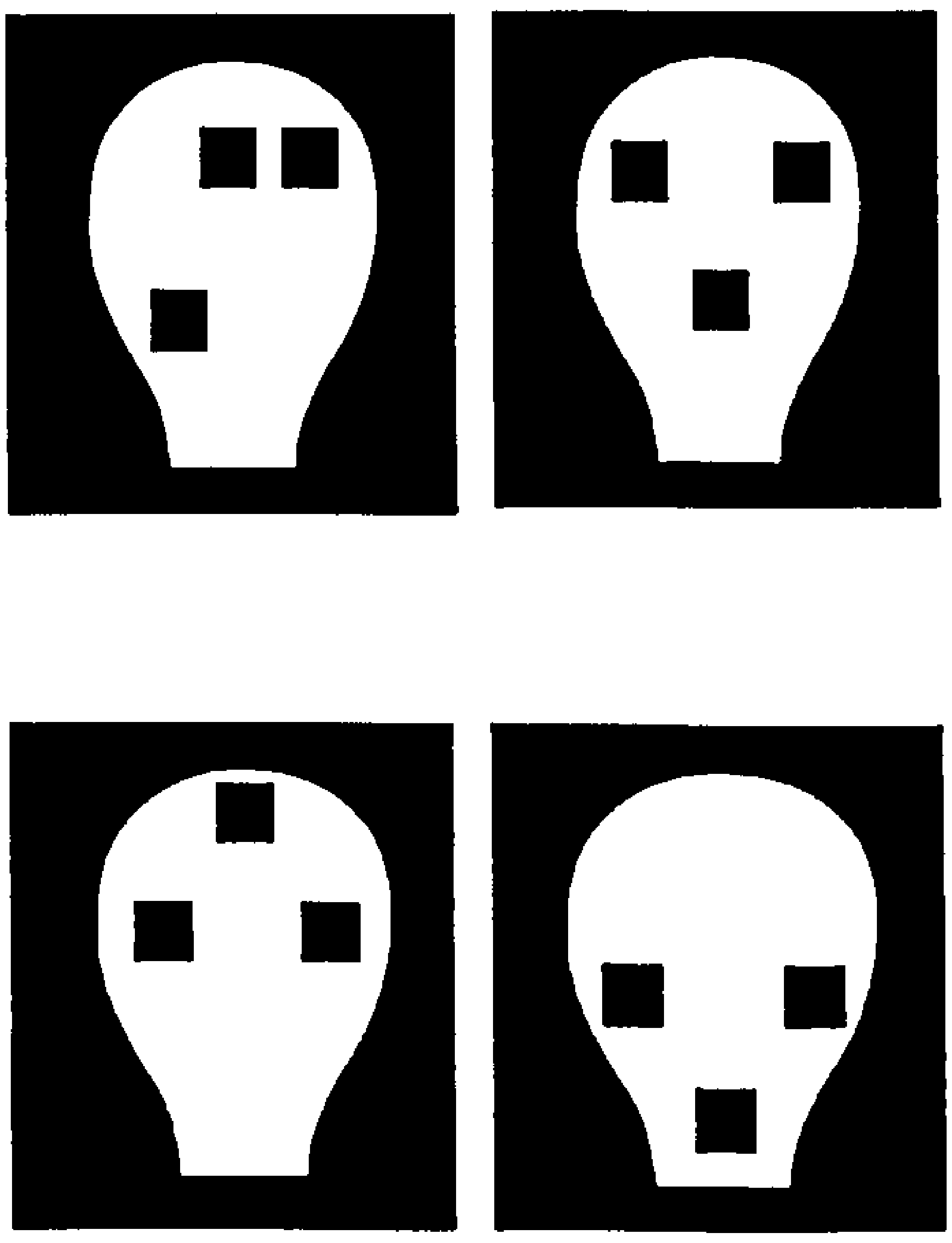


Figure 2: The two pairs of stimuli presented to infants in Turati et al.'s (2002) experiment.

Results indicated that preference was determined by the up-down asymmetry rather than the specific spatial arrangement. These results confirmed previous findings that the presence of a sufficient number of features in the upper portion of a visual face-like configuration can induce a preference similar to, or even greater than, that induced by a full schematic face (Easterbrook et al., 1999; Turati et al., 2002). Furthermore, neonates did not express a preference for face-like stimuli over non face-like stimuli with the same number of elements in the upper part of the configuration. This means that a face-like configuration of the inner elements did not affect neonates' visual preferences. These results also showed that the phase spectrum plays a role in determining neonates' preference but is by no means essential. This view is in line with the sensory model (Kleiner and Banks, 1987) which predicts that faces are preferred if they have an amplitude spectrum that makes them more visible than other stimuli.

Macchi Cassia et al. (2004) pointed to the fact that the structural information contained in schematic faces might be more easily detectable than in real faces. They explored this matter in a set of experiments using photographs of real faces. Neonates were presented with three sets of pairs of stimuli: the first presentation was an upright face contrasted with an inverted face (inner features rotated through 180°), the second presentation was a top-heavy configuration contrasted with a bottom-heavy configuration, and the third presentation was an upright face contrasted with a top-heavy configuration (see Figure 3).

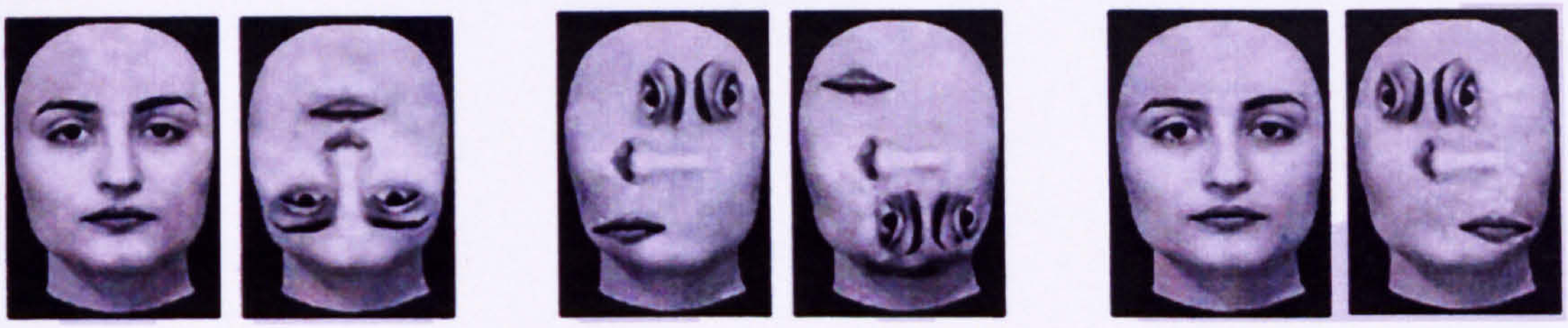


Figure 3: The three pairs of stimuli presented to infants in Macchi Cassia et al.'s (2004) experiment.

Neonates showed a preference for the upright face in the first presentation and for the top-heavy configuration in the second presentation. No preference was observed in the third presentation. These results suggested that neonates' preference for faces results from a domain-general attentional tendency towards top-heavy stimuli. Macchi Cassia et al. (2004) proposed that face specificity develops from general perceptual processes through extensive experience with this particular stimulus category.

With the aim of eliminating the interpretative difficulty linked to differences in psychophysical properties (i.e. differences in luminance and in contour density in facial and non facial stimuli) and to verify whether faces are indeed special, we contrasted photographs of upright human faces with Fourier transforms of other upright human faces. The control stimulus for Experiment 1, the Fourier transform, is the result of an image processing tool, the Fourier transformation, used to decompose an image into its sine and cosine components. Each point in the Fourier transform represents a frequency contained in the original photograph of a human face.

When presented with two stimuli of equal frequencies (equal contrast, brightness, spatial frequency, amplitude and orientation) but different organisations, do neonates, and infants aged 1 and 3 months express a preference for the stimulus that displays the structure of a face?

We put the (original) sensory hypothesis to the test, as this hypothesis claims that faces are preferred solely because of their psychophysical properties, thus suggesting that faces are not special and that no preference should be observed in Experiment 1.

In contrast with the sensory hypothesis and in line with evidence detailed above, we proposed that neonates would show a preference for the human face as they have been shown to preferentially orient to and look at a face-like structure (e.g. Johnson et al., 1991; Goren et al., 1975). We hypothesised that 1- and 3-month-old infants would also display a preference for the human face as a preference for face-like structures has been observed for older infants (e.g. Fantz, 1961; Johnson et al., 1991; Maurer and Barrera, 1981; Morton and Johnson, 1991).

Stimuli

Infants were presented with two pairs of stimuli composed of a full face (i.e. external as well as internal features were displayed), black and white photograph of a man or woman, depicted from the crown of the head to the jaw, and a Fourier transform of a full-face black and white photograph of a man or woman (see Figure 4). Photographs measured 17 cm in height and 14 cm in width.

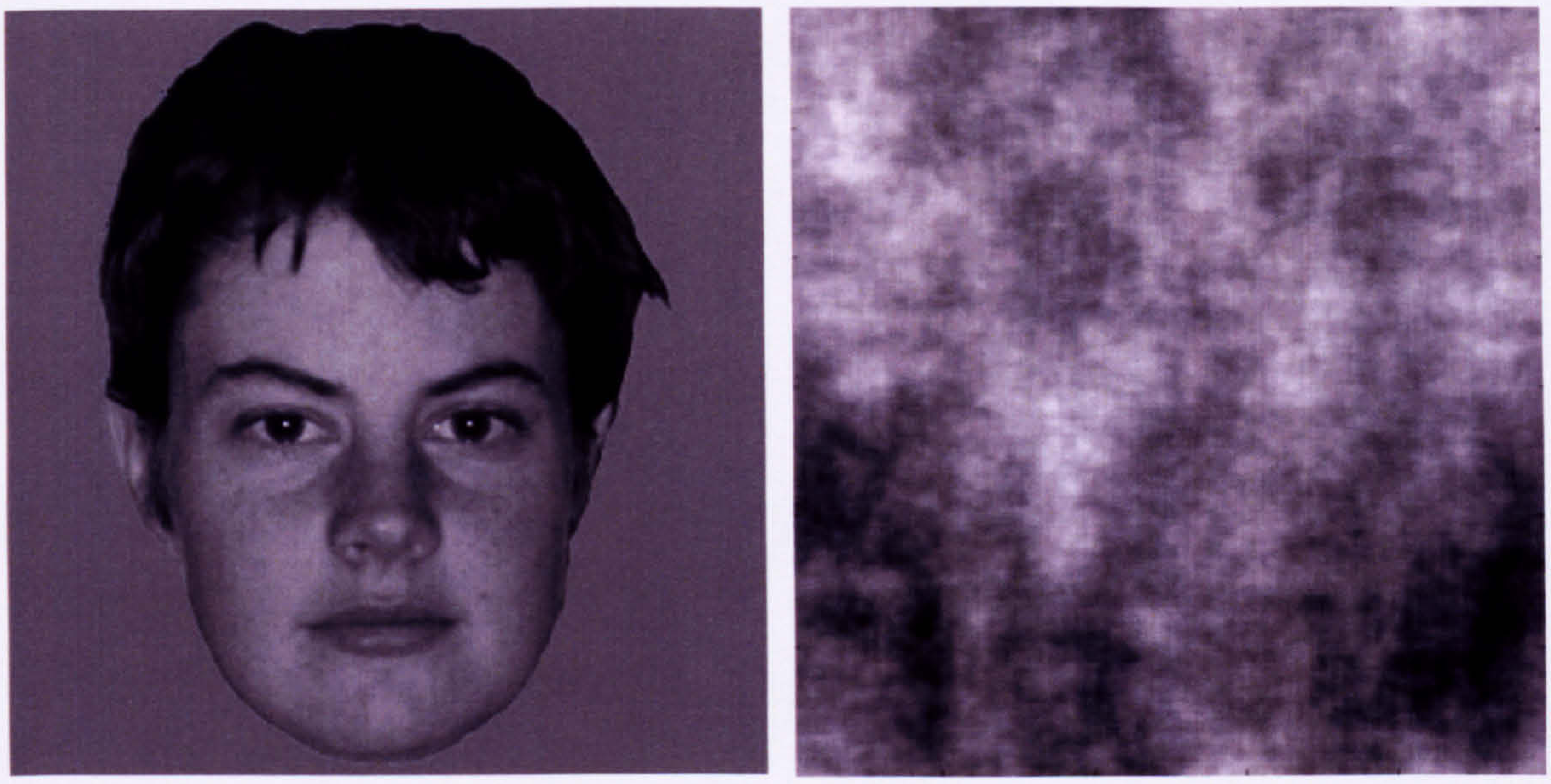


Figure 4: A human face photograph and a Fourier transform as used in Experiment 1.

Neonates have a limited ability to make chromatic discriminations (Allen, Banks and Norcia, 1993), only allowing them to discriminate between red and white (Adams et al., 1994). Progress is rapid though as, by the age of two months, infants can discriminate several colours from white: orange, blue, and some shades of green and purple (Teller et al., 1978). By 12 weeks of age, most infants can discriminate a variety of hues (Allen et al., 1993). Black and white pictures were used to maintain a degree of constancy between the various age groups we tested.

5.2.1 Condition 1: Neonates

Participants

Eighteen healthy, full-term newborn babies (9 boys and 9 girls) were selected from the maternity ward of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield and tested. All infants met the screening criteria of normal delivery, a birth weight between 2,600 and 4,600 g, and an Apgar score of at least 8 at 5 minutes. All were tested after the first 12 hours of life: at the time of testing, neonates were aged between 12 and 144 hours postnatal, with most babies being tested between the first and the third day of life. Testing took place when the baby was in an awake and alert state. Informed consent was obtained from the parents.

A further 34 babies were selected but removed from the study for the following reasons: 6 babies failed to complete testing, 10 babies had a strong position bias (i.e. 95% or more of the looking time was spent scanning one stimulus only in one or both trials; Turati et al., 2002), 8 babies changed their state during testing (i.e. the infant became too fussy, too drowsy, or cried), and 10 babies because of an error on the part of the experimenter (i.e. poor quality of film and lost videos). These figures of participant drop-out are not unusual when testing neonates. For instance, Easterbrook et al. (1999) had a participation rate of 34.5% and 37.5% in two neonatal experiments, whereas

Valenza et al. (1996) described two experiments in which participation rates varied between 47.8% and 55.5%.

Apparatus

Neonates were tested in a quiet room on the neonatal intensive care unit of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield.

Stimuli were projected from a Sony projector VPL-CS5 onto a screen, measuring 43 x 60 cm. The child was seated in a baby car seat, facing the stimulus screen at a distance of 25 cm from the centre. Photographs were presented in pairs and were equidistant from the centre, separated by 8.5 cm.

The lighting in the room was minimal (i.e. dimmed room lights with natural light coming through closed blinds) to ensure that the baby's attention would not be distracted from the projected pictures. A camera operated by the experimenter, mounted on top of the screen and linked to a VCR, recorded the infant's eye movements (see Figure 5).

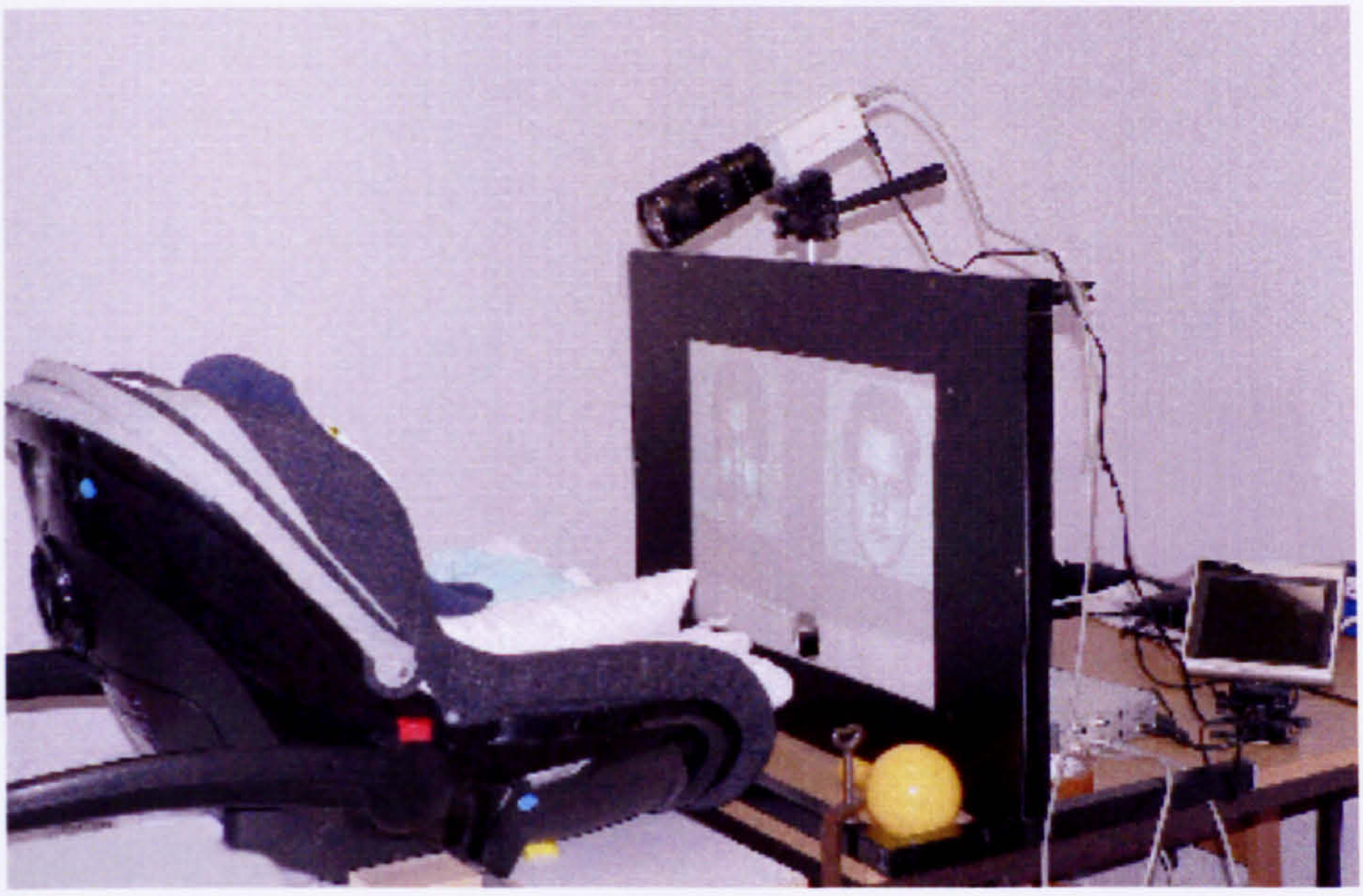


Figure 5: Set-up at the Jessop Wing of the Royal Hallamshire Hospital of Sheffield.

Procedure

When a baby was considered to be in the behavioural state of alert inactivity (Ashton, 1973), he or she was brought to the experimental room, accompanied by either one or both parents. Parents were asked not to talk to their baby during testing.

Once the infant was comfortable and settled, two 10-second trials were commenced. Stimulus presentation was counterbalanced across infants and stimuli (i.e. overall, each stimulus in the database was shown an equal number of times on either side of the screen). When the child had accumulated 10 seconds of looking time for the first trial, the lateral position of the second pair of stimuli was counterbalanced for the second trial. However, if the infant looked away from the stimuli for 10 consecutive seconds or more, the trial was aborted (Turati et al., 2002).

The experimenter followed progression on a monitor screen, therefore unaware of the stimuli presented.

All testing sessions were videotaped. Using Coleman's video analysing software Videolab (2001), videos were analysed frame by frame by the experimenter and an experienced observer. Both were blind to the lateral location of the stimuli. Pearson correlation between observers was high (r=.89).

5.2.2 Condition 2: 1-month-olds

Participants

Sixteen healthy, full-term 1-month-old infants (8 boys and 8 girls) were recruited on the maternity ward of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield and tested. All infants met the screening criteria of normal delivery, a birth weight between 2,600 and 4,820 g, and an Apgar score of at least 8 at 5 minutes. The range of ages at the time of testing was 29-40 days. Testing took place when the infant was in an awake and alert state.

A further 21 infants were selected but removed from the study for the following reasons: 3 infants failed to complete testing, 14 infants had a strong position bias, 1 infant changed state during testing, and 3 infants because of an error on the part of the experimenter.

Informed consent was obtained from parents in the first week following birth.

Apparatus

Infants were tested in an anechoic room at the University of Sheffield. The stimuli were projected using a Sony LCD projector CPJ-D500 onto a screen, measuring 31 x 46 cm. The child was seated on the parent's lap, facing the stimulus screen at a distance of 25 to 30 cm from the centre. Photographs were presented in pairs and were equidistant from the centre, separated by 8.5 cm.

Lighting in the room was minimal (i.e. a single desk lamp was switched on and placed out of the baby's field of vision) to ensure that the infant's attention would not be distracted from the projected pictures. A camera operated by the experimenter, mounted on top of the screen and linked to a VCR, recorded the infant's eye movements (see Figure 6).

Figure 6: Set-up at the Department of Psychology of the University of Sheffield.

Procedure

The infant was seated on his/her mother's lap facing a screen. Parents were asked not to talk to their baby during testing.

Once the infant was comfortable and settled, a red flickering light in the centre of the screen attracted the infant's attention and was immediately followed by two 10-second trials. Stimulus presentation was counterbalanced across infants and stimuli. When the child had accumulated 10 seconds of looking time for the first trial, the lateral position of the second pair of stimuli was counterbalanced for the second trial. If the infant looked away from the stimuli for 10 consecutive seconds or more, the trial was aborted (Turati et al., 2002).

The experimenter followed progression on a monitor screen, therefore unaware of the stimuli presented.

All testing sessions were videotaped. Using Coleman's video analysing software Videolab (2001), videos were analysed frame by frame by the experimenter and also an experienced observer. Both were blind to the lateral location of the stimuli. Pearson correlation between observers was high ($r = .89$).

5.2.3 Condition 3: 3-month-olds

Participants

Nineteen healthy, full-term 3-month-old infants (11 boys and 8 girls) were recruited on the maternity ward of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield and tested. All infants met the screening criteria of normal delivery, a birth weight between 2,600 and 4,600 g, and an Apgar score of at least 8 at 5 minutes. At the time of testing, infants were aged between 90 and 100 days. Testing took place when the infant was in an awake and alert state.

A further 14 infants were selected but removed from the study for the following reasons: 9 infants had a strong position bias, 4 infants changed their state during testing, and 1 infant because of an error on the part of the experimenter.

Informed consent was obtained from the parents in the first week following birth.

Apparatus and procedure

The apparatus and procedure were identical to those used in condition 2. Pearson correlation between observers was high (*r*=.93).

5.2.4 ANOVA

A one-way ANOVA was performed where age (neonate, 1 month, 3 months) was the factor and the percentage of looking time towards the human face was the dependent variable. An effect was found ($F(2,50) = 5.03$, $p < 0.05$).

Because sample sizes were slightly different and a test of homogeneity of variances revealed no differences, a Gabriel post-hoc test was performed (Field, 2000). Tests revealed that 1-month-olds looked significantly less at the human face stimulus compared to neonates ($p < 0.05$) and 3-month-olds ($p < 0.05$). These results indicated that 1-month-olds followed a different pattern from the one observed with neonates and 3-month-olds.

Looking times towards the human face and the Fourier transform stimulus were compared within each age group using t-tests. Because neonates and 1- and 3-month-old infants have been shown to preferentially orient to and look at face-like structures (e.g. Johnson et al., 1991; Goren et al., 1975; Fantz, 1961; Maurer and Barrera, 1981; Dannemiller and Stephens, 1988; Morton and Johnson, 1991), we hypothesised that a preference for the human face would be observed. This justified using one-tailed t-tests.

Table 1 displays the length of time spent looking at each stimulus as a percentage of the total looking time. One-tailed t-tests by chance showed that neonates ($t(17)= 1.84$, $p< 0.05$) and 3-month-olds ($t(18)= 1.80$, $p< 0.05$) displayed a preference for the human face that was significant, while 1-month-olds showed no difference in looking times ($t(15)= 1.33$, $p> 0.05$).

	Neonates (n=18)		1-month-olds (n=16)		3-month-olds (n=19)	
	HF	FT	HF	FT	HF	FT
% of total looking time (SD)	56.85 (27.30)	43.15 (23.94)	44.21 (26.33)	55.79 (25.36)	57.72 (28.33)	42.28 (26.44)
t-value	1.84		1.33		1.80	
P	0.04		0.10		0.04	

Table 1 – Experiment 1: Percentage of looking time towards Human face (HF) and Fourier transform (FT) with comparison by chance

5.2.5 Discussion Experiment 1

A visual preference for the human face stimulus was observed for neonates and 3-month-olds who displayed similar looking patterns. One-month-olds showed no preference for either stimulus. The ANOVA revealed that, 1-

month-olds displayed significantly shorter looking times towards the human face stimulus compared to neonates and 3-month-olds.

Results confirmed that faces are 'special' in the sense that, soon after birth, infants looked longer towards face-like patterns. These results do not support the sensory hypothesis and go against the suggestion that faces carry a number of non specific perceptual characteristics that attract neonates' attention on their own (Turati, 2004) as stimuli used in Experiment 1 displayed equal frequencies (equal contrast, brightness, spatial frequency, amplitude and orientation) and only differed in their organisation.

Poor visual acuity and accommodation may explain why the Fourier transform failed to attract the neonates' attention over the human face. The psychophysical elements of the human face could be a better match for the newborn's visual system.

Large standard deviations were observed in each age group. Other than young age and the tiredness factor, this could also be an indication that the stimuli we used were not sufficiently engaging for young infants, possibly causing boredom for some of them.

5.3 Experiment 2 : Upright human face versus inverted human face

An effect comparable to the adult face inversion effect (FIE) has been found in neonates who preferred looking at upright than inverted face-like configurations (Valenza et al., 1996). Recently, the same preference has been observed using photographs of faces (Macchi Cassia et al., 2004). However, some authors have suggested that newborns prefer the upright configuration of any pattern that contains more elements in the upper part than in the lower part of the configuration (Simion et al., 2001; Mondloch et al., 1999; Morton and Johnson, 1991; Valenza et al., 1996). Thus, any preference for upright configurations in infants could merely reveal this principle and, consequently, this effect cannot be used as evidence for an innate basis to face processing (Rossion and Gauthier, 2002). Similarly, Simion et al. (2002) established that neonates prefer geometrical stimuli with a greater number of high-contrast elements in the upper part of the pattern rather than in the lower part. Furthermore, Easterbrook et al. (1999) found that an entire schematic face and two normally positioned schematic eyes were equally tracked by newborns, suggesting that neonates respond to the upper part of a face as they would respond to the entire face.

Turati et al. (2002) suggested that the visibility of the upper elements is likely to be due to the fact that the superior colliculus – a subcortical structure that strongly affects neonates' visual behaviour (Atkinson et al., 1992; Braddick et al., 1992; Bronson, 1982; Johnson, 1990, 1995) – plays a major role in visual exploration oriented towards the upper visual field (Sprague, Berlucchi and Rizzolatti, 1973). Turati et al. (2002) suggested that neonates' preference for faces is not exclusively determined by the unique structure of the face, and rather, that the neonates' visual system might be activated by a general structural property, characterised by a greater number of high-contrast areas in the upper portion of the pattern, shared by faces with other stimuli. These data indirectly lent support to the idea that neonates might already be sensitive to face inversion.

Slater (2000) found that neonates preferred looking at attractive upright human faces when paired with attractive inverted human faces, thus suggesting that infants' early representation of faces contains information that is orientation-specific.

Neuroimaging studies conducted with infants at 6 months of age showed that ERP responses to upright faces differ from the ERP responses to inverted faces (de Haan et al., 2002). These differences, however, were not the same as those observed in adult participants (de Haan et al., 2002). Years of experience with a face seems an essential condition for the emergence of an adult-like inversion effect in individual face processing and recognition (Sangrigoli and de Schonen, 2004).

Cohen and Cashon (2001) found signs of the inversion effect at 7 months of age: whereas upright faces were treated as configurations, inverted faces were processed as a collection of features. However, Cashon and Cohen (2003) did not find a differential response to upright and inverted faces at 4 months of age when familiar internal and external facial features were combined.

Kestenbaum and Nelson (1990) reported that, following familiarisation with an expression (happiness) posed by a single face, 7-month-olds were able to discriminate this expression from two other expressions (fear and anger), regardless of the stimulus orientation. In contrast, when various faces posed the same expression, infants could discriminate the posed expression over various identities only when the stimuli were presented upright. These results indicated that the capacity to recognise emotional expressions across various identities depends on the unchanging orientation-specific configuration of facial features. However, when the expression is posed by a single face, discrimination may rely on featural elements – inverting the stimuli would therefore not disrupt the recognition process.

Turati et al. (2004) suggested that 4-month-old infants' ability to recognise inverted faces with standardised external features is impaired when stimuli are learned through various poses. In contrast, infants were able to recognise faces both in the upright condition and the inverted condition when familiarisation was done with a three-quarter view of a single face. Thus, like Cashon and Cohen (2003), no sensitivity to face orientation was observed when a single photograph of a face was presented.

The aim of Experiment 2 was to replicate and extend data produced by Macchi Cassia et al. (2004). However, unlike their study, we used photographs of human faces *fully* rotated through 180° (i.e. internal and external features, as opposed to the internal features alone) contrasted with upright human faces. Furthermore, Macchi Cassia et al.'s (2004) stimuli were photographs of faces depicted from the crown of the head to the neck, whereas our stimuli were photographs of faces depicted from the crown of the head to the jaw (see Figure 7).

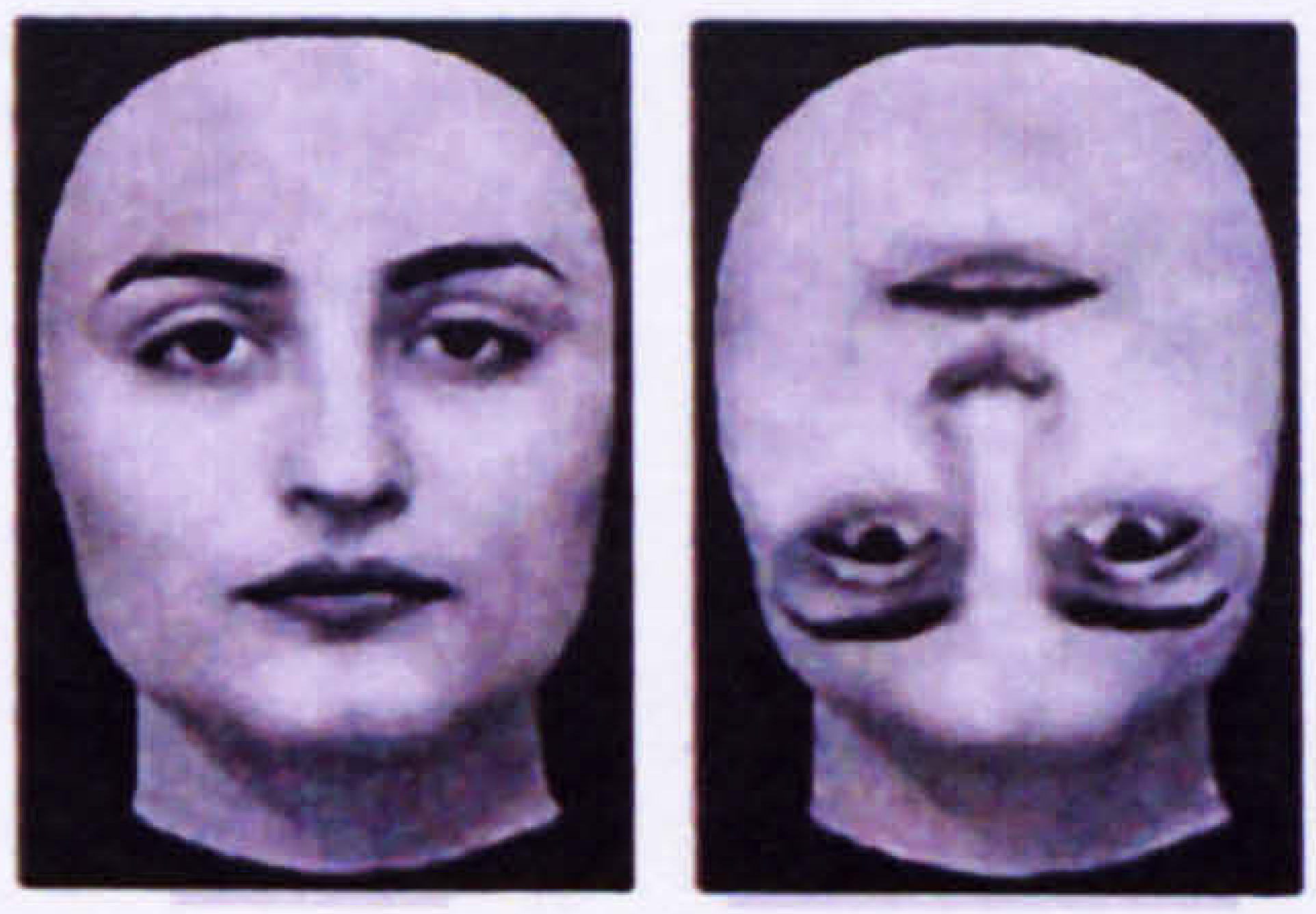


Figure 7: An upright and an inverted human face stimulus, as used in Macchi Cassia et al.'s (2004) experiment.

Stimuli

Infants were presented with two pairs of stimuli composed of a full face (i.e. external as well as internal features were displayed), black and white photograph of a man or woman, depicted from the crown of the head to the jaw, and a full-face black and white photograph of a man or woman, rotated through 180°. Photographs measured 17 cm in height and 14 cm in width (see Figure 8).

Figure 8: An upright human face and an inverted human face, as used in Experiment 2.

5.3.1 Condition 1: Neonates

Participants

Sixteen healthy, full-term newborn babies (10 boys and 6 girls) were selected from the maternity ward of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield and tested. The criteria for selection of the babies were identical to those used in Experiment 1.

A further 38 babies were selected but removed from the study for the following reasons: 4 babies failed to complete testing, 10 babies had a strong position bias, 14 babies changed their state during testing (the infant became too fussy, too drowsy, or cried), and 10 babies because of an error on the part of the experimenter.

Apparatus and procedure

The apparatus and procedure were identical to those used in condition 1 of Experiment 1. Pearson correlation between observers was high ($r = .97$).

5.3.2 Condition 2: 1-month-olds

Participants

Sixteen healthy, full-term 1-month-old infants (5 boys and 11 girls) were recruited on the maternity ward of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield and tested. The criteria for selection of the infants were identical to those used in Experiment 1.

A further 21 infants were selected but removed from the study for the following reasons: 3 infants failed to complete testing, 14 infants had a strong position bias, 2 infants changed their state during testing, and 2 infants because of an error on the part of the experimenter.

Apparatus and procedure

The apparatus and procedure were identical to those used in condition 2 of Experiment 1. Pearson correlation between observers was high ($r = .94$).

5.3.3 Condition 3: 3-month-olds

Participants

Twenty-one healthy, full-term 3-month-old infants (10 boys and 11 girls) were recruited on the maternity ward of the Jessop Wing of the Royal

Hallamshire Hospital of Sheffield and tested. The criteria for selection of the infants were identical to those used in condition 3 of Experiment 1.

A further 12 infants were selected but removed from the study for the following reasons: 8 infants had a strong position bias, 3 infants changed their state during testing, and 1 infant because of an error on the part of the experimenter.

Apparatus and procedure

The apparatus and procedure were identical to those used in condition 2 of Experiment 1. Pearson correlation between observers was $r = .71$.

5.3.4 ANOVA

A one-way ANOVA was performed where age (neonate, 1 month, 3 months) was the factor and the percentage of looking time towards the upright human face was the dependent variable. No effects were observed ($F(2,50) = 1.39, p > 0.05$).

Looking times towards the upright and the inverted face were compared within each age group using t-tests. Because neonates have been found to prefer upright to inverted face-like configurations (Valenza et al., 1996) and faces (Macchi Cassia et al., 2004), we hypothesised that neonates and 1-month-olds would display a preference for the upright face. This justified using one-tailed t-tests. In contrast, whereas some studies observed differences in looking times towards upright and inverted face stimuli in older infants (e.g. de Haan et al., 2002 ; Cohen and Cashon, 2001), others (Cashon and Cohen, 2003 ; Turati et al., 2004) did not. Therefore, a two-tailed t-test was performed with 3-month-olds.

Table 2 displays the length of time spent looking at each stimulus as a percentage of the total looking time. A one-tailed t-test by chance showed that neonates looked significantly longer towards the upright face ($t(15) = 1.72$, $p < 0.05$). A one-tailed t-test by chance showed no difference in looking times for 1-month-olds ($t(15) = 0.06$, $p > 0.05$). Similarly, a two-tailed t-test revealed no differences in looking times for 3-month-olds ($t(20) = 0.03$, NS).

	Neonates (n=16)		1-month-olds (n=16)		3-month-olds (n=21)	
	HFup	HFinv	HFup	HFinv	HFup	HFinv
% of total looking time (SD)	57.60 (25.83)	42.40 (25.91)	50.31 (29.24)	49.69 (29.36)	50.12 (27.19)	49.88 (27.01)
t-value	1.72		0.06		0.03	
P	0.047		0.48		0.98	

Table 2 – Experiment 2: Percentage of looking time towards Upright human face (HFup) and Inverted human face (HFinv) with comparison by chance.

5.3.5 Discussion Experiment 2

Results of a null-preference obtained with 1- and 3-month-olds corroborated previous findings in the literature and supported the hypothesis that, because infants have little experience with faces and do not use configural processing as much as adults do (Turati et al., 2004), there is no inversion effect.

In contrast, neonates displayed a visual preference towards the upright face stimulus, thus lending support to the hypothesis that there is a facial representation (possibly a prototype) accessible to neonates which is orientation-specific. This is in keeping with Slater's (2000) findings.

It is difficult to resolve the question whether this preference is due to an innate representation of a face or to experience with faces in the first hours of life. To decide between these two interpretations, testing would have to take place before any amount of experience with human faces takes place.

5.4 Experiment 3 : Human face versus monkey face

Adults encode individual faces in terms of how they diverge from a prototype tuned to human faces through extensive experience with human faces (Valentine, 1991). As infants only start to show evidence of prototype formation at 3 months of age (de Haan et al., 2001) and as the specificity of the face recognition system to human faces is thought to increase with age and experience (Nelson, 2001), young infants – who, by definition, have little experience with faces – should be better at discriminating individual faces of other species (Pascalis et al., 2002). There is indirect evidence for this hypothesis: in an ERP study, de Haan et al. (2002) observed that, in adults, inversion only affected the processing of human faces (not monkey faces), whereas for 6-month-old infants, inversion affected the ERPs for both human and monkey faces (the distribution of this effect varied between species). Furthermore, Pascalis and Bachevalier (1998) observed a species-specific effect in human adults and mature Rhesus monkeys which suggests that experience in viewing faces plays an important part in the discrimination of faces.

In addition, Pascalis, Demont, de Haan and Campbell (2001) demonstrated that, like adults, 5- to 8-year-olds show an inversion effect for human and monkey faces but not for sheep faces.

Using a visual-paired comparison (VPC) procedure, Pascalis et al. (2002) showed that, whereas 9-month-olds displayed a similar pattern to that of adults, 6-month-old infants displayed a novelty preference both when tested with human and with monkey faces. These data supported the idea that face processing is being tuned to a human template during the first year of life.

Like Pascalis et al. (2002) we hypothesised that neonates' particular lack of experience with faces would give them an advantage in recognising facial identity, regardless of species. Therefore, we suggested that neonates would not display preferential looking when presented with a photograph of a human face contrasted with a photograph of a monkey face.

As experience increases the specificity of the face recognition system to human faces (Nelson, 2001) and based on findings from Pascalis et al. (2002), we also hypothesised that 1- and 3-month-olds would show a similar pattern to neonates, that is to say no preference.

Stimuli

Infants were presented with two pairs of stimuli composed of a full face (i.e. external as well as internal features were displayed), black and white photograph of a man or woman, depicted from the crown of the head to the jaw, and a full-face, black and white photograph of a monkey's face, depicted from the crown of the head to the jaw. Photographs measured 17 cm in height and 14 cm in width (see Figure 9).

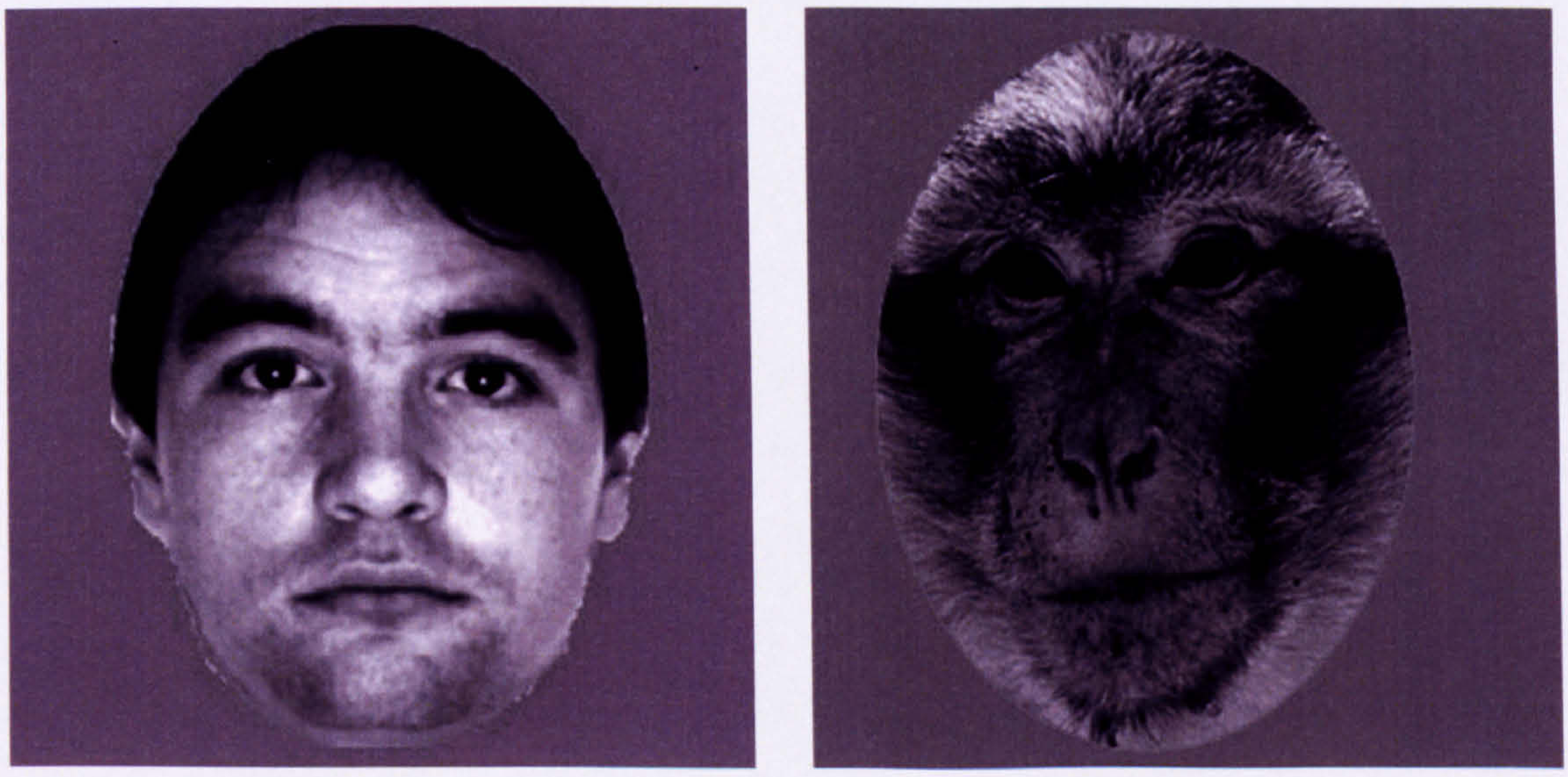


Figure 9: A human face and a monkey face, as used in Experiment 3.

5.4.1 Condition 1: Neonates

Participants

Eighteen healthy, full-term newborn babies (11 boys and 7 girls) were selected from the maternity ward of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield and tested. The criteria for selection of the babies were identical to those used in condition 1 of Experiment 1.

A further 37 babies were selected but removed from the study for the following reasons: 4 babies failed to complete testing, 11 babies had a strong position bias, 12 babies changed their state during testing, and 10 babies because of an error on the part of the experimenter.

Apparatus and procedure

The apparatus and procedure were identical to condition 1 of Experiment 1. Pearson correlation between observers was high ($r= .96$).

5.4.2 Condition 2: 1-month-olds

Participants

Seventeen healthy, full-term 1-month-old infants (6 boys and 11 girls) were recruited on the maternity ward of the Jessop Wing of the Royal

Hallamshire Hospital of Sheffield and tested. The criteria for selection of the infants were identical to those used in condition 2 of Experiment 1.

A further 22 infants were selected but removed from the study for the following reasons: 2 infants failed to complete testing, 15 infants had a strong position bias, 3 infants changed their state during testing, and 2 infants because of an error on the part of the experimenter.

Apparatus and procedure

The apparatus and procedure were identical to those used in condition 2 of Experiment 1. Pearson correlation between observers was high ($r = .89$).

5.4.3 Condition 3: 3-month-olds

Participants

Twenty healthy, full-term 3-month-old infants (10 boys and 10 girls) were recruited on the maternity ward of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield and tested. The criteria for selection of the infants were identical to those used in condition 3 of Experiment 1.

A further 16 infants were selected but removed from the study for the following reasons: 12 infants had a strong position bias, 3 infants changed their state during testing, and 1 infant because of an error on the part of the experimenter.

Apparatus and procedure

The apparatus and procedure were identical to those used in condition 2 of Experiment 1. Pearson correlation between observers was high ($r = .82$).

5.4.4 ANOVA

A one-way ANOVA was performed where age (neonate, 1 month, 3 months) was the factor and the percentage of looking time towards the human face was the dependent variable. No effects were observed ($F(2,52) = 1.61$, $p > 0.05$).

Looking times towards the human and the monkey face were compared within each age group using t-tests. Based on past findings (e.g. Pascalis et al., 2002), we hypothesised that no preference would be observed in any of the age groups. Therefore, two-tailed t-tests were performed.

Table 3 displays the length of time spent looking at each stimulus as a percentage of the total looking time. Neonates displayed a significant preference for the human face ($t(17) = 2.24$, $p < 0.05$). In contrast, 1-month-olds ($t(16) = 0.08$, $p > 0.05$) and 3-month-olds ($t(19) = 0.05$, $p > 0.05$) displayed no differences.

	Neonates (n=18)		1-month-olds (n=17)		3-month-olds (n=21)	
	HF	MF	HF	MF	HF	MF
% of total looking time (SD)	57.73 (24.28)	42.27 (26.30)	49.56 (30.84)	50.44 (30.51)	50.23 (28.92)	49.77 (27.34)
t-value	2.24		0.08		0.05	
P	0.03		0.93		0.96	

Table 3 – Experiment 3: Percentage of looking time towards Human face (HF) and Monkey face (MF) with comparison by chance.

5.4.5 Discussion Experiment 3

Neonates displayed a preference for the human face over the monkey face. No visual preferences were observed for 1- and 3-month-olds.

A null-preference at birth would have suggested that infants show equal interest in both species because of a lack of experience with faces in general (Pascalis et al., 2002). However, similarly to Experiments 1 and 2, a preference for the human face suggests that neonates might already refer to a representation of the human face. Because the human face is virtually the only stimulus and, perhaps more importantly, the most engaging (both visually and socially) stimulus neonates are confronted with since birth, instant recognition of this stimulus may have occurred.

Recognition suggests reference to a prototype: Walton and Bower (1993) already suggested that neonates can form a prototype within a minute of exposure to exemplars. If this is true, then Nelson's (2001) model does not reflect this particularly early development. Our data implied that face processing in neonates cannot be explained through Nelson's model. In line with Pascalis, Scott, Kelly, Shannon, Nicholson, Coleman and Nelson (2005) we believe it is unlikely that the mechanisms that subserve face processing and speech perception are the same. We hypothesise that neonates' preference may be founded on an early prototypical representation of the human face.

Additionally, it has been suggested that the developing visual system displays a lack of contrast sensitivity (Bartrip et al., 2001). Perhaps neonates do not perceive monkey faces as well as they do human faces because of lower contrast levels displayed in monkey faces, hence making the human face stimulus more attractive.

Conversely, 1- and 3-month-olds displayed no visual preference, in this way corroborating past studies (Pascalis et al., 2002) showing that, during the first year of life, face processing is being tuned to a human template. These results are also consistent with Quinn and Eimas (1998) who found that, at 3 and 4 months of age, infants did not show a preference for upright humans over upright cats or horses. However, in this case, the stimuli were whole, i.e. head and body were both displayed.

This pattern suggested that, at birth, infants refer to a prototype which becomes obsolete only a few weeks later. Indeed, because 1- and 3-month-old infants did not display a visual preference, it is implied that both stimuli were equally attractive (we can assume that the paradigm we used and the experimental set-up are both suited to this age group because significant differences were observed in condition 3 of Experiment 1). We hypothesise that, as the infant acquires more experience with faces, a new prototype is created which does not rely on the same properties as the first prototype to discriminate stimuli.

5.5 Experiment 4 : Human face versus car stimulus

Neuropsychological studies of brain damaged patients established a double dissociation between the recognition of faces and objects, indicating that these two functions require distinct processes (Newcombe, Mehta and de Haan, 1994). Evidence from functional neuroimaging techniques and ERP studies in subjects who did not suffer brain damage corroborated these findings (for review see Moscovitch et al., 1997).

The aim of Experiment 4 was to produce data showing a preference for faces over another set of typically mono-oriented stimuli (Want et al., 2003), namely cars. A preference for the human face over a stimulus that displayed no face-like features, nor social meaning, would indicate that faces and objects are processed differently.

Early studies (e.g. Fantz, 1965; Kagan and Lewis, 1965; Lewis, Meyers, Kagan, and Grossberg, 1963) showed that facial stimuli yield longer looking times in young infants than stimuli such as bull's eye, checkerboard, stripes, solid colours and other patterns. Therefore, we hypothesised that neonates and 1- and 3-month-old infants would display a preference for the human face over the car stimulus.

Stimuli

Infants were presented with two pairs of stimuli composed of a full face (i.e. external as well as internal features were displayed), black and white photograph of a man or woman, depicted from the crown of the head to the jaw, and a black and white photograph of a frontal view of a car. Photographs measured 17 cm in height and 14 cm in width (see Figure 10).

Figure 10: A human face and a car, as used in Experiment 4.

5.5.1 Condition 1: Neonates

Participants

Sixteen healthy, full-term newborn babies (11 boys and 5 girls) were selected from the maternity ward of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield and tested. The criteria for selection of the babies were identical to those used in condition 1 of Experiment 1.

A further 43 babies were selected but removed from the study for the following reasons: 6 babies failed to complete testing, 10 babies had a strong position bias, 15 babies changed their state during testing (the infant became too fussy, too drowsy, or cried), and 12 babies because of an error on the part of the experimenter.

Apparatus and procedure

The apparatus and procedure were identical to those used in condition 1 of Experiment 1. Pearson correlation between observers was high (*r*= .85).

5.5.2 Condition 2: 1-month-olds

Participants

Seventeen healthy, full-term 1-month-old infants (7 boys and 10 girls) were recruited on the maternity ward of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield and tested. The criteria for selection of the infants were identical to those used in condition 2 of Experiment 1.

A further 20 infants were selected but removed from the study for the following reasons: 4 infants failed to complete testing, 12 infants had a strong position bias, and 4 infants changed their state during testing.

Apparatus and procedure

The apparatus and procedure were identical to those used in condition 2 of Experiment 1. Pearson correlation between observers was high ($r = .93$).

5.5.3 Condition 3: 3-month-olds

Participants

Nineteen healthy, full-term 3-month-old infants (9 boys and 10 girls) were recruited on the maternity ward of the Jessop Wing of the Royal

Hallamshire Hospital of Sheffield and tested. The criteria for selection of the infants were identical to those used in condition 3 of Experiment 1.

A further 16 infants were selected but removed from the study for the following reasons: 8 infants had a strong position bias, 7 infants changed their state during testing, and 1 infant because of an error on the part of the experimenter.

Apparatus and procedure

The apparatus and procedure were identical to those used in condition 2 of Experiment 1. Pearson correlation between observers was high ($r = .99$).

5.5.4 ANOVA

A one-way ANOVA was performed where age (neonate, 1 month, 3 months) was the factor and the percentage of looking time towards the human face was the dependent variable. An effect was found ($F(2,50) = 8.51, p < 0.05$).

Because sample sizes were slightly different and a test of homogeneity of variances revealed no differences, a Gabriel post-hoc test was performed (Field, 2000). Tests revealed that 3-month-olds looked significantly longer towards the human face stimulus compared to neonates ($p < 0.05$) and 1-month-olds ($p < 0.05$).

Looking times towards the human face and the car stimulus were compared within each age group using t-tests. Because early studies (Fantz, 1965; Kagan and Lewis, 1965; Lewis et al., 1963) showed that facial stimuli yield longer looking times in young infants than other stimuli, we expected a preference for the human face over the car stimulus in all age groups. This justified using one-tailed t-tests in each condition.

Table 4 displays the length of time spent looking at each stimulus as a percentage of the total looking time. Neonates displayed no differences ($t(15)= 0.04$, $p> 0.05$). Similarly, 1-month-olds displayed no differences ($t(16)= 1.30$, $p> 0.05$). In contrast, a one-tailed t-test by chance showed a significant preference for the human face in 3-month-olds ($t(18)= 2.57, p< 0.05$).

	Neonates (n=16)		1-month-olds (n=17)		3-month-olds (n=19)	
	HF	Car	HF	Car	HF	Car
% of total looking time (SD)	49.81 (31.62)	50.19 (29.73)	44.15 (26.10)	55.85 (27.71)	62.24 (31.83)	37.73 (30.38)
t-value	0.04		1.30		2.57	
P	0.48		0.10		0.01	

Table 4 – Experiment 4: Percentage of looking time towards Human face (HF) and Car stimulus (Car) with comparison by chance.

5.5.5 Discussion Experiment 4

No visual preferences were observed for neonates and 1-month-olds. However, 3-month-olds displayed a preference for the human face.

By presenting cars in the *en face* view, we unintentionally created face-like patterns as the car stimuli tended to display three high-contrast areas, creating a variation on the *config* pattern. Null-preference results for neonates and 1-month-olds replicated Macchi Cassia et al.'s (2004) findings that suggested that neonates' preference for faces results from a domain-general attentional tendency towards top-heavy stimuli. Alternatively, these results suggested that neonates refer to a general face-like prototype which does not distinguish real faces from schematic face-like patterns.

On a psychophysical level, both stimuli were perceived as very salient. It has been suggested that, for neonates, face-like patterns with high contrast elements could possibly be even more salient than a real human face (Simion et al., 2002) because of neonates' poor visual acuity and accommodation (Atkinson et al., 1977; Norcia et al., 1990).

Three-month-old infants displayed a visual preference for the human face stimulus. These results could indicate that infants progressively become more tuned to the human face and, with experience, learn to discriminate a real human face from a schematic face-like pattern (i.e. the car stimulus).

5.6 General discussion: Experiments 1 to 4

Results of Experiments 1 to 4 confirmed that there is a strong tendency to prefer a photographic representation of the human face at birth. However, orientation towards the human face was not as systematic as expected and depended on the comparison stimulus that was being used.

Neonates' early preference for faces seems to involve a form of prototype based on structure, facedness, orientation, and level of contrast. Indeed, neonates displayed a preference for the human face when contrasted with the Fourier transform, the inverted face and the monkey face. However, no difference was observed when a human face was contrasted with an *en face* car stimulus. We hypothesised that this was because, to some extent, the car stimulus displayed a face-like pattern and a level of contrast (as interpreted through the neonate's visual system) that was similar to the human face.

Neonates' preference for the upright human face when contrasted with an inverted face corroborated evidence of a primitive form of the face inversion effect in neonates who have been found to prefer looking at upright face-like configurations when presented alongside inverted configurations (Valenza et al., 1996).

Neonates' preference for the human face when contrasted with a monkey face intimated that, early on, visual preferences are also based on contrast levels. Indeed, monkey faces do not share the same contrast levels as human faces and, therefore, cannot compete with a stimulus as salient as the human face. On a social level, however, results implied that faces from different species are likely to be associated with different social meanings.

Results from Experiment 4 seemed to indicate that, in neonates, prototype formation might still be rather crude and not yet fully mature. This is in line with de Haan et al. (2001) who suggested that, despite the ability to remember individual faces from birth (e.g. Pascalis and de Schonen, 1994), it is only around the ages of 1 to 3 months that infants begin to be able to link information about individual faces. They proposed that, at about 3 months of age, a prototype is built from experienced exemplars which enables the infant to display a greater novelty effect for a novel face than for an averaged face, even though this averaged face had never been encountered either.

Whereas Nelson's (2001) model predicted that with increasing exposure to faces and narrowing of the perceptual window to this class of stimuli, the selectivity of the infant's neural and behavioural responses to faces would increase, our results suggested that, depending on the control stimulus, a spontaneous preference for the human face can already be observed at birth.

Results also indicated that within a few weeks of birth, another prototype is being formed which is face-specific. Indeed, already by 1 month of age, this second prototype enables the infant to process inverted human faces and monkey faces as exemplars of the 'faces' category and, by 3 months of age, discriminate faces from non faces (e.g. Fourier transform) and schematic face-like patterns (e.g. car). However, a null-preference between human face and monkey face at 1 and 3 months of age intimates that a separate 'human face' category has not yet emerged.

These results are in line with previous studies (Pascalis et al., 2002) supporting the idea that face processing is being tuned to a human template during the first year of life. Pascalis et al. (2002) proposed that some time after 6 months of age the face prototype becomes more specific to the faces the infant encounters frequently.

Furthermore, the lack of visual experience at this age means that infants are not yet 'experts' and therefore do not display an adult-like inversion effect.

One argument in favour of an early prototype being replaced by a more face-specific prototype comes from findings concerning the recognition of the mother's face by neonates and older infants. Unlike infants between 4 and 9 months of age who recognise their mother's face even in the absence of outer facial features (de Schonen et al., 1986), neonates – who have also been reported to recognise their mother's face (e.g. Field et al., 1984) – do not seem to possess a representation of their mother's face in which internal and external facial features work independently, thus suggesting that the system operating in neonates and older infants is not the same (Pascalis et al., 1995).

Results also pointed towards limitations of the early visual system, i.e. neonates' low visual acuity and accommodation levels. Indeed, neonates displayed a preference for the human face in three out of four conditions, thereby indicating that most control stimuli were less salient visual stimuli than the human face. In terms of the neonate's visual system, the car stimulus was the only control stimulus that displayed similar levels of saliency and, therefore, attractiveness, as the human face because of its face-like configuration and similar psychophysical properties. By 3 months of age, the visual system seemed more sensitive to smaller details and the relationship between features (demonstrated by the fact that the human face was preferred over the car stimulus).

In summary, we tentatively suggest that, in the neonatal period, the infant can refer to a representation of a human face which could be based on a certain amount of haptic knowledge of faces (i.e. knowledge of the human face acquired from proprioceptive exploration of the baby's own face in the womb). This is in accordance with the sensory-ecology model (Bushnell, 1996). Postnatally, this prenatal information is corroborated by the mass of faces the neonate sees in the first hours and days of life. This could explain prototype formation so early in life. A preference for faces at birth is thus very much encouraged by the fact that faces are the most common stimuli a neonate sees. Furthermore, because these 'faces' provide the infant with food and comfort, prototype formation would be encouraged even more. Our findings also seem to suggest that this early prototype is orientation-specific, which is in line with Slater's (2000) findings.

Between the first and the third month of life, a more structured face-specific prototype would replace the early neonatal prototype. Indeed, by 3 months of age, the infant displays visual preferences that intimate that reference is made to a structured prototype that is in the process of becoming adult-like.

6. Experiment 5 : Recognition of the mother's face in 1-, 3-, 6-, and 9-month-olds

6.1 Introduction

In Experiments 1 to 4 we found that, depending on which stimulus was being used, infants could discriminate human faces very early in life. However, how soon do infants start to discriminate specific exemplars of the human face category and is there a developmental curve in the first year of life?

The mother's face is generally the most familiar face for a young infant. Thus, the most directly available manner of testing early face discrimination is by evaluating infants' ability to discriminate their mother's face from another woman's face.

In many species, recognition of other members of the social group has great survival value as it encourages proximity and ensures food and protection. For the human newborn infant, recognition of the mother is particularly important for the development of attachment and emotional bonds between mother and child (Bowlby, 1969).

6.2 Mother-stranger discrimination by the neonate

6.2.1 Recognition of the mother's live face

Field, Cohen, Garcia and Greenberg (1984) established that 4-day-old neonates with only a limited amount of exposure time to their mother's face, look longer at their mother's live face than at a stranger's face, even without vocal cues. These results suggested that neonates may have learned some distinctive features of the mother's face. After repeated presentations of the mother's face (or face and voice) until attainment of a habituation criterion, the initial preference for the mother's face shifted to a preference for the novel face as tested by a discrimination test. However, olfactory cues may have facilitated discrimination of the mother's face (MacFarlane, 1975).

A visual preference paradigm showed that neonates averaging 49 hours in age were able to demonstrate a preference for their mother's face (Bushnell, Sai and Mullin, 1989). This study controlled for olfactory information and used experimenters who were blind to the mother's identity. Furthermore, mothers and strangers were partially matched for hair colour and length.

Bushnell (2001) set out to identify the necessary amount of exposure for a familiarity preference to appear for the mother's live face contrasted with a female stranger (another mother with similar hair colouring and length). Results indicated that an increased opportunity to view the mother's face is associated with stronger visual preference levels. A subsequent study established that a 15-minute delay between the last exposure to the mother's face and preference testing does not affect the strength of preference, suggesting that memory for the mother's face is robust within a few days of birth.

A subsequent study (Bushnell, 2003) included two conditions. In the first condition, both mother and stranger wore a wig, making the external contours identical. In the second condition, the wigs were placed under the women's chins, leaving the external contour entirely visible. Neonates showed a preference for the mother's face in the inverted wig condition, but not in the upright wig condition. These results confirmed previous studies (Bushnell, 1982; Pascalis et al., 1995) which reported impaired recognition of the mother's face when the external outline is standardised, and challenged the hypothesis that the experimental manipulation may have created a distraction by using a particularly salient common external outline (wig), so that the internal elements were not attended to, thus preventing recognition of the mother's face. Another interpretation could be that, when women wore wigs over their natural hair, the added feature was salient enough to create a new gestalt. In contrast, the less salient inverted wigs did not create a new gestalt, causing the presentation to resemble an average mother-stranger discrimination. Bushnell (2003) used two conditions of delay between the last exposure to the mother's face and time of testing: less than 5 minutes, which is approximately the delay used in previous studies (e.g. Bushnell et al., 1989; Pascalis et al., 1995), and more than 15 minutes. In both conditions neonates showed a significant preference for the mother's face, suggesting that memory for the mother's face is very stable within a few days of life.

Sai (2005) looked at the role of the mother's voice in developing a preference for the mother's face. Neonates who had been exposed to their mother's voice immediately after birth for 5 to 10 minutes prior to testing were compared to neonates who had not been exposed to their mother's voice (but had been exposed to all other maternal cues). Results showed that neonates could only recognise their mother's face if a postnatal exposure to the mother's voice-face combination had previously been available. These results do not support the existence of an innate perceptual mechanism that detects and responds specifically to faces (e.g. Johnson and Morton, 1991).

6.2.2 The role of internal and external facial features

In adults, recognition of familiar faces is achieved by using predominantly the internal facial features. However, cases of prosopagnosic patients reveal that the external facial features alone carry enough information for identification (e.g. Davidoff, Matthews and Newcombe, 1986).

In the particular case of neonates, many facial details would not be visible because the visual system is still developing and there is a lack of contrast sensitivity (Bartrip et al., 2001). Evidence does suggest though that 4-day-old neonates can detect such details as the shape and contour of faces and have learnt something about their mother's face.

Pascalis et al. (1995) devised two experiments using visual cues only to clarify whether neonates employ a face-specific recognition mechanism rather than a more general learning mechanism for processing individual faces at 4 days of age. This approach contrasted with previous studies which used paradigms that systematically reproduced situations associated with the mother's presence (e.g. tactile stimulation, sucking response). Pascalis et al. (1995) found that when external facial features were masked, neonates did not show a visual preference for the mother's face anymore. These results were consistent with work on older infants using schematic face stimuli (Maurer and Salapatek, 1976). A bias towards using this information had been expected given the low spatial frequency information available from the external facial features. Pascalis et al. (1995) suggested that, unlike infants between 4 and 9 months of age who recognise their mother's face even in the absence of outer facial features (de Schonen et al., 1986), neonates do not possess a representation of their mother's face in which internal and external facial features work independently. Pascalis et al. (1995) thus suggested that the system operating in neonates and older infants is not the same.

6.2.3 Recognition of the mother's face from static images

Walton, Bower and Bower (1992) used images of the mother's face rather than real live faces. They found that neonates produced significantly more sucking responses to see an image of their mother's face on the screen as opposed to a stranger's face. These results confirmed previous results obtained by Bushnell et al. (1989) and Field et al. (1984) with the mother's live face, while avoiding the problem of possible changes in the mother's expression when she is looking at her baby.

In a subsequent study (Walton, Armstrong and Bower, 1997), neonates' ability to recognise a learned face over three visual transformations (a photonegative transformation, a size change and a rotation in the third dimension) was tested. Neonates succeeded with all three transformations, thus suggesting that they perceive faces as *gestalten* (i.e. organised wholes).

6.3 Mother-stranger discrimination by the infant

6.3.1 Recognition of the mother's face by 1-month-olds

Carpenter (1974) and Masi and Scott (1983) reported an ability to discriminate the mother's face at 1 month of age when the mother's face is presented live alongside a stranger's live face. However, in these studies, the mother's face had to be accompanied by her voice in order for the discrimination to occur. Indeed, DeCasper and Fifer (1980) showed that neonates can discriminate their mother's voice from a stranger's voice shortly after birth and it has been suggested that this ability stems from in utero foetal learning (Bigelow, 1977, cited in Field et al., 1984).

Sai and Bushnell (1988) verified whether 1-month-old infants were capable of recognising their mother's live face when presented in one of three orientations – *en face*, half-profile and profile. Results confirmed previous findings by Bushnell (1982) and Maurer and Salapatek (1976) that 1-month-olds can discriminate between their mother's face presented *en face* and that of an adult female stranger in the same pose. Furthermore, the results also established that 1-month-olds can discriminate between two faces in half-profile and recognise their mother's face. These findings emerged despite the experimenters' attempt to match for hair colour and face brightness as closely as possible, and control for olfactory cues. Controlling for olfactory cues proved to be successful as no preference for the mother's face was found in the profile condition.

In contrast, Melhuish (1982) reported an inability to discriminate between real faces on the basis of form or feature and observed successful discrimination only when the stimuli differed strongly in contrast. Greenberg and Blue (1977) suggested that the reason for these results may be the specific stimuli used for this particular experiment, the use of a single successive stimulus presentation rather than paired comparisons, and perhaps the use of too many comparison stimuli.

In conclusion, the demonstration of some flexibility in 1-month-olds' face recognition abilities indicates that the foundations for conceptual representation of the mother's face and the capacity to extract invariant information across a range of facial poses are being created.

6.3.2 Recognition of the mother's face by 3-month-olds

Using an adaptation of the infant control procedure (Horowitz, Paden, Bhana and Self, 1972) and the habituation to criterion paradigm, Barrera and Maurer (1981) studied 3-month-old infants' ability to recognise a photograph of their mother's smiling face presented alongside a stranger's smiling face. The visual preference test consisted of four trials during which the infant saw the face of a stranger (S) and the face of the mother (M) either in the order MSSM or SMMS. The preference test was followed by repeated presentations of the mother's face until the infant reached a habituation criterion. A recognition test followed during which the infant was presented with two trials with the stranger's face and two trials with the mother's face either in the order MSSM or SMMS. During the preference test, all infants looked longer at the mother's face but only girls did so significantly. During the recognition test, infants looked significantly longer at the novel face.

In the same way that Barrera and Maurer (1981) reported a shift of preference from the familiar face to the novel, Greenberg, Uzgiris and Hunt (1970) observed a preference for a familiar toy in 1- to 2 ½ -month-olds which shifted to a preference for the novel toy after repeated exposure to the familiar one. These results suggest that young infants' preference for an object is determined by their experience with that or similar objects.

6.3.3 Recognition of the mother's face by 5-month-olds

Bartrip et al. (2001) designed a set of experiments with a view to finding out at what age infants are able to discriminate their mother's face from a stranger's face on the basis of internal facial features alone, and whether or not the preference for the mother's face is due solely to the external features or whether it is a function of both internal and external features. Infants aged between 19 and 155 days were tested using three conditions: in the first condition both mother's and stranger's face were fully visible, in the second condition both mother's and stranger's face were rigged out with scarves, and in the third condition both women wore masks so that only the external features were visible.

One-month-olds displayed a significant preference for the mother's face in the internal condition. In the external condition on the other hand, it was not until the infants reached 4 months of age that a significant preference for the mother's face was displayed. These results suggested that the internal features of the mother's face are learned first (Bartrip et al., 2001).

Full face reached significance at 5 months of age with a preference for the stranger's face. The full face condition also revealed a gender difference in that, between the ages of 1 and 4 months, male infants expressed a greater preference for the mother's face than females.

However, Bartrip et al. (2001) emphasised that the pivotal change in the full face condition occurs before 3 months of age - at which stage the total looking time to mother and stranger becomes a matter of arbitrary choice between the two for at least a further 2 months.

Bartrip et al.'s (2001) findings that 5-week-old infants can recognise their mother's face from internal features alone, do not corroborate Pascalis et al.'s (1995) findings establishing that 4-day-old neonates could not perform this task. However, because 5-week-old infants have more visual experience than younger infants, different visual patterns were expected.

Studies of adult subjects with neurological impairments revealed that, despite problems with recognising familiar faces, some are still able to match photographs of unfamiliar faces (Warrington and James, 1967). Such evidence indicated that unfamiliar faces may be processed differently from familiar faces. More recent evidence (Rossion, 2001) showed that, in adults, discrimination of familiar and unfamiliar faces is accompanied by differential neural responses. Furthermore, other qualities than familiarity of a face may influence whether a face is discriminated from other faces. For example, after habituation to a face, 5-month-olds showed a novelty effect when the novel face was of a different sex and displayed different hair colour and hair style, but not when it was of same sex, hair colour and hair style (Dirks and Gibson, 1977).

6.3.4 Recognition of the mother's face by 6-month-olds

While most studies have looked at *when* infants are first able to recognise their mother's face (e.g. Bushnell et al., 1989; Field et al., 1984; Pascalis et al., 1995), few have looked at *how* infants recognise familiar faces, mainly because the methods used to study the neural bases of behaviour are impossible to use with young infants. The recording of event-related potentials (ERPs), however, is not subjected to the same limitations. Event-related potentials are a subset of the electroencephalogram (EEG) and reflect a momentary change in the electrical activity of a cluster of neurons that fire together in response to an isolated event (e.g. the presentation of a face). ERPs provide information about the timing of neurocognitive processes that occur while a person is responding to an event (as they are time-locked to the occurrence of a specific event), rather than supply information about the final outcome (e.g. the face was recognised or not).

ERP studies measuring infants' responses to faces showed that 6-month-old infants' ERPs do not discriminate between two faces presented with equal probability, even if familiarisation (short pre-exposure) with one of the two faces precedes the test (Nelson and Collins, 1991; Nelson and Salapatek, 1986). The ERPs were different for the two faces only if an oddball paradigm was used (i.e. one face was made more familiar by presenting it more frequently and increasing the probability of it being seen). A negative component was associated with the infrequently presented face (Courchesne, Ganz and Norcia, 1981; Karrer and Ackles, 1987) and thought to reveal greater allocation of attention to the more novel or unexpected face. When infants were familiarised with two faces prior to an oddball paradigm that also included novel faces, the infrequently presented novel face yielded a negative slow wave (subsequent to the negative component) associated with the detection of novelty, and the infrequently presented familiar face yielded a positive slow wave associated with the process of updating a waning memory. Finally, the frequently presented familiar face yielded a return to baseline associated with the recognition of a robust memory for that particular face. These results indicate that ERP measures may be helpful in studying the neural processes associated with infants' memory for faces.

De Haan and Nelson (1997) measured 6-month-old infants' ERPs to faces that varied in similarity to one another and in familiarity to the infant. Results showed that 6-month-olds' ERPs to their mothers' faces were different from those to strangers' faces, thus suggesting that infants recognised their mother's face. However, the neural processes associated with recognition varied with the degree of similarity between the faces. This pattern intimated that perceptual analysis and encoding of the stranger's face are likely to be more protracted when the stranger's face is similar to the familiar face. On the contrary, when the stranger's face and the familiar face are dissimilar, perceptual analysis and encoding may take place more quickly and activate memories associated with the familiar face. Greater ERP activity was observed at the right temporal scalp in both cases. This is consistent with the right hemisphere bias for face processing observed in adults and in infants from 4 to 9 months of age (de Schonen et al, 1986; de Schonen and Mathivet, 1989, 1990).

6.4 Methodological consideration: the still-face paradigm

A number of studies on the recognition of the mother's face by the infant used masks to create a condition in which internal features were not visible to the infant. However, in one study (Bartrip et al., 2001), this condition also produced the most distress in infants. This was probably due to this condition representing the most extreme form of the still-face effect, with the mask preventing display of any expression.

In 1- to 7-month-old infants, the still-face effect has been linked to a drop in infants' gazes, a complete stop in smiling (Gusella, Muir and Tronick, 1988; Tronick, Als, Adamson, Wise and Brazelton, 1978), increased grimacing and crying, and distress (e.g. Ellsworth, Muir and Hains, 1993; Field, Vega-Lahr, Scafidi and Goldstein, 1986; Stack and Muir, 1990; Weinberg and Tronick, 1996; Weinberg, Tronick, Cohn and Olson, 1999) not caused by fatigue or habituation. Tronick (1989) explains that the infant's stress response to the still-face procedure is caused by the adult's unresponsive behaviour to the infant's attempts to interact and expectations in a normal social situation.

Generally, infants have been found to respond more negatively to *emotional* separation created by the still-face condition than to *physical* separation from the parent (Field et al., 1986). Infants of depressed mothers have been found to react in a less negative manner to the still-face condition than children of non depressed mothers (Field, 1984).

The still-face condition comprises a list of several sources of adult stimulation, such as touch, vocal expression and dynamic action (Muir and Hains, 1993) and relatively minor changes in parental behaviour can impact how infants respond to the still-face episode. While Gusella et al. (1988) found that the still-face effect can be established whether or not mothers are allowed to touch their infants during the interactive periods, Stack and Muir (1992) on the other hand, demonstrated that active tactile stimulation during the procedure can help reduce the still-face effect. Gusella et al. (1988) reported that the mother's televised interactive face, without her voice, yielded more smiling and gazing than her interactive voice presented with a still-face (still image).

This body of evidence justified our decision to use a photographic representation of the mother's face in Experiment 5. It also warranted our decision to sit infants on their mother's lap during testing in order to avoid upsetting infants who might react to the unresponsive and static picture of their mother's face.

6.5 Methodological consideration: infant visual recognition memory

Early recognition of the mother's face is likely to rely on a form of memory called 'infant visual recognition memory' that emerges very early in life and correlates well with several cognitive abilities (e.g. language, cognition, representational play) in later childhood (Colombo, 1993; McCall and Carriger, 1993; Rose and Feldman, 1995; Bornstein, 1998), thus suggesting that there may be a continuity in the processes that mediate intellectual functioning across childhood.

Infant visual recognition memory has traditionally been measured by using the visual-paired comparison (VPC) task, introduced by Fantz in 1964, and adapted by Fagan (1970, 1973). After an initial familiarisation period, infants are presented with an arrangement of two stimuli: the familiar stimulus and a novel stimulus. Longer looking times towards the novel stimulus indicate recognition of the familiar stimulus as it is thought to arise when infants have completed the assimilation of the information contained in the familiar stimulus and are ready to turn their attention to the novel one (Pascalis and de Haan, 2003).

Several lines of evidence have demonstrated the existence of visual recognition memory during the first year of life. For instance, studies using Fantz's (1964) familiarisation technique observed recognition memory in 6-

month-old infants after a 2-minute interval (Cornell, 1974), a 2-week interval (Fagan, 1973), and a 1-minute interval (Diamond, 1995). A preference for novelty was also found with infants as young as 4 months of age after an interval of 10 seconds (but not after an interval of 15 seconds) (Diamond, 1995). These behavioural studies are supported by electrophysiological studies (ERP) that found evidence of recognition memory in infants aged 6 months (Nelson and Salapatek, 1986).

Visual recognition memory has been observed at even younger ages in studies using the infant control procedure (Martin, 1975; Slater, Morison and Rose, 1983; Pascalis and de Schonen, 1994; Pascalis, de Haan, Nelson and de Schonen, 1998) which offers longer looking times. Pascalis, de Haan, Nelson and de Schonen (1998) demonstrated 3- and 6-month-old infants' ability to remember a face over a retention interval of either 2 minutes or 24 hours after having been habituated to different poses. A subsequent electrophysiological study correlated results for a delay of 2 minutes. These data corroborated previous findings (Martin, 1975, cited in Pascalis and Bachevalier, 1999) and contrasted with Diamond's (1995) data. Rather than using objects, Pascalis et al. (1998) used faces. It may be that memory for faces develops sooner than memory for other objects (Pascalis et al., 1998).

Neonates were also found to show a novelty preference immediately after the familiarisation period (Slater et al., 1983; Pascalis and de Schonen, 1994) and after a 2-minute retention interval (Pascalis and de Schonen, 1994). These findings indicated that visual recognition memory can be observed in the first week of life with a visual preference test if the appropriate familiarisation time has been offered.

In Experiment 5 we tested recognition for the mother's face in infants aged between 1 and 9 months. We expected infants of the various age groups to display a differential preferential pattern as both novelty and familiarity preference have been observed in infants. A multitude of studies have supported the idea that neonates prefer to look at familiar stimuli (e.g. Piaget, 1952; DeCasper and Fifer, 1980; Meltzoff and Borton, 1979; Walton et al., 1992). However, there has been some evidence supporting the idea that, under certain circumstances, neonates can be habituated to the point that they will prefer the novel stimulus (e.g. Slater, Morison, Somers, Mattock, Brown and Taylor, 1990). For instance, Pascalis and de Schonen (1994) established that 3- to 6-day-old neonates habituate to a face after an average of 45 seconds of looking time, after which time they start showing a novelty preference.

Novelty preference has been observed in neonates straight after familiarisation (Slater et al., 1983) and after a 2-minute delay (Pascalis et al., 1998). Three- and 6-month-olds showed novelty preference after a delay of 2 minutes (Cornell, 1974; Pascalis et al., 1998) and a delay of 24 hours (Pascalis et al., 1998). Six-month-olds still showed a novelty preference after a delay of 2 weeks (Fagan, 1973), and 9-month-olds after a delay of 10 minutes (Diamond, 1995). Some studies, however, established that memory in infants could only be observed when the imposed delay was no more than a few seconds (e.g. Pancratz and Cohen, 1970; Cornell, 1974; Diamond, 1995).

Familiarity preference on the other hand, has been observed in neonates (Slater, 1995) who totalled a looking time of under 180 seconds during familiarisation. In contrast, neonates whose accumulated looking time exceeded 180 seconds displayed a novelty preference. With a visual preference task, the mother's face, a particularly familiar stimulus, has also been found to elicit a familiarity preference. This preference may be interpreted as an operant response on the infant's part to a visual cue that is linked to a gratifying result (Pascalis et al., 1995). It has been reported that stimuli that are involved in contingent learning paradigms often yield a familiarity effect (e.g. Rovee-Colier, 1990). Three and a half-, 4.5- and 6.5-month-old infants also showed a familiarity preference after limited exposure time to a stimulus. This preference shifted to a novelty preference after longer exposure times (Rose, Gottfried, Melloy-Carminar and Bridger, 1982, cited in Pascalis and de Haan, 2003). Conversely, Bahrick and colleagues (Bahrick et al., 1997; Bahrick and Pickens, 1995) observed a shift from novelty preference to familiarity preference in 3-month-olds using stimuli in motion.

6.6 Condition 1: 1- and 3-month-olds

Participants

Sixteen healthy, full-term 1-month-old infants (7 boys and 9 girls) and 16 healthy, full-term 3-month-old infants (8 boys and 8 girls) were recruited on the maternity ward of the Jessop Wing of the Royal Hallamshire Hospital of

Sheffield and tested at the University of Sheffield. All infants met the screening criteria of normal delivery, a birth weight between 2,600 and 4,600 g, and an Apgar score of at least 8 at 5 minutes.

One-month-old infants, at the time of testing, were aged between 29 and 40 days. Testing took place when the infant was in an awake and alert state. A further 14 1-month-old infants were selected but removed from the study for the following reasons: 10 infants had a strong position bias and 4 infants changed their state during testing.

Three-month-old infants, at the time of testing, were aged between 90 and 100 days. Testing took place when the infant was in an awake and alert state. A further 12 3-month-old infants were selected but removed from the study for the following reasons: 6 infants had a strong position bias, 4 infants changed their state during testing, and 2 infants because of an error on the part of the experimenter.

Informed consent was obtained from the parents of all infants on arrival at the Department of Psychology.

Stimuli

A colour photograph of the mother's face was contrasted with a colour picture of a female stranger (i.e. another infant's mother participating in the same study displaying similar hair colour and style). The pair of stimuli was presented twice to the infant.

Using a digital camera (Canon Powershot S50), the mother's face, wearing a neutral expression, was photographed on a white background. A white piece of fabric covered her clothes. Mothers' photographs were paired subjectively with strangers' photographs (see Figure 11).

Figure 11: A mother's face paired with a stranger's face, as used in Experiment 5.

The procedure used for the acquisition of mothers' and strangers' photographs was identical for all age groups.

Faces were depicted from the crown of the head to the jaw. External (i.e. hair) as well as internal (i.e. eyes, nose, etc) features were displayed. Photographs measured 17 cm in height and 14 cm in width.

Apparatus

Infants were tested in an anechoic room at the University of Sheffield. The stimuli were projected using a Sony LCD projector CPJ-D500 onto a screen, measuring 31 x 46 cm. The infant was seated on the mother's lap, facing the stimulus screen at a distance of 25 to 30 cm from the centre. The photographs were presented in pairs and were equidistant from the centre, separated by 8.5 cm.

Lighting in the room was minimal (i.e. a single desk lamp was switched on and placed out of the baby's field of vision) to ensure that the infant's attention would not be distracted from the projected pictures. A camera operated by the experimenter, mounted on top of the screen and linked to a VCR, recorded the infant's eye movements.

The apparatus was identical in condition 2.

Procedure

The infant was seated on his/her mother's lap facing a screen. Parents were asked not to talk to their baby during testing.

Once the infant was comfortable and settled, a red flickering light in the centre of the screen attracted the infant's attention and was immediately followed by two 10-second trials. Stimulus presentation was counterbalanced across infants and stimuli. When the child had accumulated 10 seconds of looking time for the first trial, the lateral position of the stimuli was counterbalanced for the second trial. If the infant looked away from the stimuli for 10 consecutive seconds or more, the trial was aborted (Turati et al., 2002).

The experimenter followed progression on a monitor screen during testing, therefore unaware of the stimuli presented.

All testing sessions were videotaped. Using Coleman's video analysing software Videolab (2001), videos were analysed frame by frame by the experimenter and an experienced observer. Both were blind to the lateral location of the stimuli. Pearson correlation between observers was high both for 1-month-olds ($r = .95$) and 3-month-olds ($r = .93$).

6.7 Condition 2: 6- and 9-month-olds

Participants

Eighteen healthy, full-term 6-month-old infants (10 boys and 8 girls) and 16 healthy, full-term 9-month-old infants (8 boys and 8 girls), were recruited through parent and baby groups in the local area and through posters in doctors' waiting rooms. All infants met the screening criteria of normal delivery, a birth weight between 2,600 and 4,600 g, and an Apgar score of at least 8 at 5 minutes.

Six-month-olds, at the time of testing, were aged between 165 and 196 days. Testing took place when the infant was in an awake and alert state. A further 2 6-month-old infants were selected but removed from the study because they changed their state during testing.

Nine-month-olds, at the time of testing, were aged between 260 and 284 days. Testing took place when the infant was in an awake and alert state. A further 2 9-month-old infants were selected but removed from the study because they changed their state during testing.

Informed consent was obtained from the parents of all infants on arrival at the Department of Psychology.

Procedure

Preliminary testing revealed that 6- and 9-month-old infants became fussy or turned away from the presentation after 5 seconds. Therefore, once the infant was comfortable and settled on his/her mother's lap facing the screen, a red flickering light in the centre of the screen attracted the infant's attention and was immediately followed by two 5-second trials. Stimulus presentation was counterbalanced across infants and stimuli. When the child had accumulated 5 seconds of looking time for the first trial, the lateral position of the stimuli was counterbalanced for the second trial. If the infant looked away from the stimuli for 5 consecutive seconds or more, the trial was aborted.

The experimenter followed progression on a monitor screen during testing, therefore unaware of the stimuli presented.

All testing sessions were videotaped. Using Coleman's video analysing software Videolab (2001), videos were analysed frame by frame by the experimenter and an experienced observer. Both were blind to the lateral location of the stimuli. Pearson correlation between observers was high both for 6-month-olds ($r = .84$) and 9-month-olds ($r = .93$).

6.8 ANOVA for all age groups

To facilitate a comparison across age groups, raw data were normalised by dividing the looking time for the mother's face by the total looking time for both faces to obtain the percentage of time spent looking at the mother's face.

A one-way ANOVA was performed where age (1, 3, 6 and 9 months) was the factor and length of looking time (in percentages) towards the mother's face was the dependent variable. An age effect was found ($F(3,62) = 2.94$, $p < 0.05$).

Because sample sizes were only slightly different and a test of homogeneity of variances revealed no differences, a Gabriel post-hoc test was performed (Field, 2000). Tests revealed that 1-month-olds looked significantly longer towards the mother's face stimulus compared to 3-month-olds ($p < 0.05$).

Looking times towards the mother's face and the stranger's face were compared within each age group using t-tests. Based on past findings (de Haan and Nelson, 1997; Sai and Bushnell, 1988; Bushnell, 1982; Barrera and Maurer, 1981; Maurer and Salapatek, 1976), we hypothesised that all age groups would display a preference for the mother's face and, therefore, used one-tailed t-tests.

Table 5 displays the length of time spent looking at each stimulus as a percentage of the total looking time. One-tailed t-tests by chance showed that 1-month-olds displayed a preference for the mother's face that was significant

($t(15) = 2.26$, $p < 0.05$), 3-month-olds showed no differences in looking times ($t(15) = 1.16$, $p > 0.05$), 6-month-olds showed no differences in looking times ($t(17) = 0.14$, $p > 0.05$) and 9-month-olds showed no differences in looking times ($t(15) = 0.38$, $p > 0.05$).

	1-month-olds (n=16)		3-month-olds (n=16)		6-month-olds (n=18)		9-month-olds (n=16)	
	MoF	Str	MoF	Str	MoF	Str	MoF	Str
% of total looking time (SD)	58.47 (13.84)	41.53 (16.97)	44.66 (14.29)	55.34 (19.43)	49.66 (9.60)	50.34 (13.84)	50.85 (13.55)	49.15 (9.17)
t-value	2.26		1.16		0.14		0.38	
p	0.02		0.13		0.44		0.35	

Table 5 – Experiment 5 : Percentage of looking time towards Mother's face (MoF) and Stranger's face (Str) with comparison by chance.

6.9 Discussion Experiment 5

A preference for the mother's face was observed for 1-month-olds. Thus, like Sai and Bushnell (1988), we found that 1-month-old infants were capable of discriminating an *en face* presentation of their mother's face (although the presentation was live in Sai and Bushnell's study).

In contrast with Barrera and Maurer (1981) who found that 3-month-old infants looked longer at their mother's face (however, only girls did so significantly), we observed no differences. Conversely, there was a tendency to look longer towards the stranger's face.

Because Barrera and Maurer's (1981) instructions required mothers to display a smile when photographed, this might have been instrumental in creating stimuli that were more emotionally charged than the ones used in Experiment 5, in which mothers were instructed to display a neutral expression. The observed tendency to prefer the stranger's face could also be explained by the fact that, with age, more of the infant's looking time tends to be allocated to the exploration of events and stimuli outside of the family unit.

Both 6- and 9-month-olds displayed a null-preference. Standard deviations were low so that results cannot be explained by variations within the observed population. However, rather than interpret this result as a failure to recognise the mother's face, like de Haan and Nelson (1997) we would like to evoke methodological reasons and suggest that the visual preference procedure is not suitable for measuring recognition at these ages. Thus, the level of physical resemblance between the photographs we used could have been instrumental in creating null-preference results. Indeed, de Haan and Nelson (1997) showed that 6-month-olds' ERPs associated with the recognition of their mother's faces varied with the degree of similarity between the mother's and the stranger's face. This pattern suggests that perceptual analysis and encoding of the stranger's face is likely to be more protracted when it is similar to the familiar face. In contrast, when the stranger's face and the familiar face are dissimilar, perceptual analysis and encoding may take place more quickly (and activate memories associated with the familiar face).

In Experiment 5 the mother's face was matched subjectively to the stranger's face. It is therefore possible that a similar process took place, thereby making the course of discrimination longer. However, we do not believe this to be the case as discrimination was observed in younger infants using the same procedure and, if anything, faster discrimination would be expected from older infants.

If we had used the same methodology as Barrera and Maurer (1981), perhaps we would have observed a preference for the mother's face in all four age groups.

On the whole, we observed no decline in looking times towards the mother's face with age, thus confirming results by Bartrip et al.,(2001). Such results do not support an interpretation of the data in terms of the still-face effect.

6.10 Conclusions Experiments 1 to 5

In Experiments 1 to 4 we suggested that a prototype might develop in the neonatal period, based on prenatal haptic knowledge and information within the first hours and days of life. A more solid experience-based face-specific prototype would emerge between 1 and 3 months of age. However, data implied that this prototype does not yet refer to a separate human face category.

Experiment 5 showed that 1-month-old infants are able to recognise their mother's face when contrasted with a stranger's face. This ability is consistent with neonates' ability to discriminate their mother's face (e.g. Field et al., 1984; Bushnell, 2001). At 3 months of age no preference was found. However, infants tended to look longer towards the stranger's face. As infants tend to demonstrate greater interest towards the outside world with age, perhaps this behaviour is instrumental in collecting information and knowledge about unfamiliar faces and enables them to develop a new prototype. This hypothesis is in line with de Haan et al. (2001) who found that, at about 3 months of age, infants are able to build a prototype from experienced exemplars of faces.

Smaller standard deviations were observed in Experiment 5 than in Experiments 1 to 4. This could indicate that the stimuli used in Experiment 5 were more engaging for young infants than those used in Experiments 1 to 4. This is in keeping with Quinn, Yahr, Kuhn, Slater and Pascalis (2002) who proposed that visual experience affects face processing skills in the first months of life. Indeed, infants who had mainly been cared for by a female caregiver preferred female over male faces, and the opposite was true of infants raised primarily by their fathers.

A number of contributing factors such as maturation of visual abilities, behaviour and face processing skills could explain why 3-, 6-, and 9-month-old infants did not display a preference for their mother's face. However, we hypothesise that it is a combination of all these factors which is responsible for the observed results. Furthermore, as suggested by de Haan and Nelson (1997), the visual preference technique may not be suitable for older infants and, therefore, may have been instrumental in creating results that do not corroborate past findings.

PART 2 : FOLLOW-UP OF PREMATURE CHILDREN

7. Introduction

A baby born before 37 weeks' gestational age is considered premature. Premature birth is associated with low birth weight and a higher incidence of brain injury, which can potentially lead to anomalies in visual functioning or visuomotor performances (Caputo, Goldstein and Taub, 1981) as well as motor and intellectual deficits (Perlman, 1998).

7.1 Vulnerability of the developing brain

Under normal circumstances, the third term of the gestational period coincides with a time of great activity for growth and differentiation of the foetus' brain inside the womb (François et al., 1998; Abernethy, Cooke and Foulder-Hughes, 2004). For the premature infant, however, this time is typically spent in special care units. The immaturity of the premature infant's brain makes it inherently more vulnerable to injury and accompanying perinatal risk factors, such as infections, metabolic complications, nutritional deficiencies, haemorrhagic or ischemic risks. The more premature the birth, the greater the likelihood that brain damage might occur. The conditions surrounding birth tend to be used as an indication of the child's future development (François et al., 1998).

The immature human brain undergoes organisational changes during foetal and postnatal development and is potentially vulnerable in locations that often lack sensitivity to injury later on in life (Johnston, 1995). For example, prior to 32 weeks of gestation, the developing white matter is particularly sensitive to damage from hypoxic and ischemic injury and metabolic insults. An illustration of this in the premature infant is the particular vulnerability of the germinal matrix (a site of neurogenesis and gliogenesis) to intracranial haemorrhage (Johnston, 1995). Furthermore, between the 26th and 34th week of gestational age, neuronal death and dendritic retraction are at their most intensive, giving rise to increased metabolic activity and, consequently, increased vulnerability to ischemic and haemorrhagic insults as well as cerebral circulatory disorders in cerebral areas involved in movement control (Mutch, Leyland and McGee, 1993). As a result, an interruption of these circuits could alter performance during development (Fazzi, Orcesi, Telesca, Ometto, Rondini and Lanzi, 1997). These observations support the idea that the developing brain displays a different organisation than the mature nervous system (Johnston, 1995) and are helpful in understanding patterns of injury in the developing brain.

7.2 Brain injury in premature infants

Neurological, cognitive and behavioural impairments observed in premature infants suggest that premature birth disrupts one or more components of cerebral neurodevelopment (Reiss, Kesler, Vohr, Duncan, Katz, Pajot, Schneider, Makuch and Ment, 2004).

The major neurological manifestations of brain injury in premature infants are spastic motor deficits, often accompanied by intellectual deficits.

The two principal brain lesions that cause these neurological manifestations are periventricular haemorrhagic infarction and periventricular leukomalacia (Perlman, 1998).

Periventricular haemorrhagic infarction refers to haemorrhagic necrosis of periventricular white matter that is usually large and asymmetric. The long-term correlates of periventricular haemorrhagic infarction are mainly spastic hemiparesis and intellectual deficits (Volpe, 1997; Perlman, 1998). These can be explained by the fact that, on one hand, motor nerve pathways transmitting signals from the cerebral cortex to the muscles transit through the periventricular areas and, on the other hand, new brain cells are formed in the periventricular areas and migrate to form the cerebral cortex. The lesion most often coexists with intraventricular haemorrhage (IVH) (Volpe, 1997). IVH is observed in varying degrees in about 50% of infants born with a weight under 1500 grams and/or born before 32 weeks of gestational age (Papile, Burstein and Burstein, 1978; Allen, Dransfield and Tito, 1984; Shankaran, Slovis, Bedard and Poland, 1982). A large proportion of the neurologic morbidity observed in premature infants is caused by IVH. Approximately 15% of all infants with IVH exhibit periventricular haemorrhagic infarction (Volpe, 1997).

Periventricular leukomalacia refers to necrosis of white matter resulting in the softening of tissues of the brain around the ventricles (Volpe, 1997). The outcome following periventricular leukomalacia tends to include moderate to severe cognitive and motor delays, often accompanied by visual impairments (e.g. de Vries et al., 1985).

7.3 Long-term development of premature infants

Because advances in perinatal and neonatal care allow the survival of an increasing number of premature infants (Sizun et al., 1998; Burguet et al., 2000; Hoekstra et al., 2004), there is a growing concern about the long term development of premature children as more of them enter the school system (Whitfield, Eckstein Gruneau and Holsti, 1997). Various studies intimate that, at school age, premature children tend to have a lower intellectual quotient (IQ) than age-matched control children and have more school-related problems (Voyer, 1986; Saigal, 1993 ; Sizun et al., 1998).

Premature birth comes with high rates of neurological risk factors (François et al., 1998) as a premature transition from intrauterine to extrauterine life is thought to disrupt foetal brain development (Peterson, Vohr, Staib, Cannistraci, Dolberg, Schneider, Katz, Westerveld, Sparrow, Anderson, Duncan, Makuch, Gore, Ment, 2000). The neurobehavioural outcome of premature infants has been reported to worsen with younger gestational age at birth and with lower birth weight (Hack, Friedman and Faranoff, 1996; McCormick, Workman-Daniels and Brooks-Gunn, 1996; Ábrahám, Tornóczky, Kosztolányi and Seress, 2004). Indeed, survivors of premature birth are susceptible to developing spastic motor deficits, known as 'cerebral palsy', as well as less noticeable developmental disabilities, involving vision, motility, cognition, behavioural problems and school disturbances (Volpe, 1997). The typical clinical profile of a premature child associates motor, visual and cognitive disabilities.

For instance, Yliherva, Olsen, Maki-Torkko, Koiranen and Jarvelin (2001) demonstrated that, at 8 years of age, low birth weight (LBW, i.e. less than 2500 g) children tend to experience more difficulties related to speech, language, learning and motor abilities than normal birth weight (i.e. 2500 g or more) children.

7.3.1 Long-term cognitive deficits

Although most neurological complications are diagnosed within the first year of life (François et al., 1998), in some cases, cognitive disabilities only become apparent when the child starts attending school (in the form of learning disabilities). Follow-up studies of very low birth weight (VLBW, i.e. 1500 g or less) children at school age have reported increased rates of behavioural and cognitive difficulties (e.g. Hoy, Bill and Sykes, 1988), even in the absence of neurological abnormalities in infancy or early childhood (Breslau, 2000). Low birth weight premature infants have been identified as a group at risk for attentional and cognitive problems in later childhood (Rose, Feldman and Jankowski, 2001).

Marlow et al. (1993) suggested that the presence of perceptual-motor problems at 6 years of age is the best predictor of school difficulties (i.e. poor performance in 2 or 3 subjects) at 8 years. Another study (Jongmans et al., 1998) demonstrated that differences between full-term and premature children could already be detected at the age of 6 years in reading ability. Furthermore, premature infants have often been reported to have specific language impairments that would not be predicted based on their average IQs (e.g. Saigal et al., 1991; Halsey et al., 1993). Sykes et al. (1997) claimed that even those premature children who had had uncomplicated neonatal courses often experienced serious cognitive and educational difficulties.

Saigal et al. (1991) found that, at the age of 8, extremely low birth weight (ELBW, i.e. 800 g or less) children had a mean WISC-R full-scale IQ of 91 compared with matched controls who had a mean full-scale IQ of 104. These results were corroborated by O'Brien, Roth, Stewart, Rifkin, Rushe and Wyatt (2004) who found comparable results for 8-year-old children born at less than 33 weeks of gestation. Whitfield, Eckstein Gruneau and Holsti (1997) demonstrated that, at 8 years of age, 60% of ELBW children displayed learning disabilities or a borderline IQ compared with only 18% in the control group.

Rose and Feldman (1995) demonstrated that, at 11 years of age, premature children scored, on average, about 10 points lower than their full-term counterparts for the WISC-R full-scale score. This difference between groups was coherent with findings at earlier ages (Rose, Feldman, McCarton and Wolfson, 1988; Rose, Feldman, Wallace and McCarton, 1991; Rose et al., 1992).

In Experiment 6 we looked at how premature children compared with their full-term counterparts as tested with a general intelligence test (WISC-III).

7.3.2 Long-term psychomotor deficits

In early childhood, premature individuals are at higher risk of developing psychomotor delays (Ross, 1995) than their full-term counterparts. For instance, during the first year of life, 40 to 80% of premature children show transitory anomalies linked to posture or to a lack of energy (tone) usually caused by minor neurological lesions.

When cerebral palsy occurs (i.e. in about 5-15% of survivors ; see Volpe, 1997; Selton, Andre and Hascoët, 2000), the type and severity of it is usually diagnosed during the first few years of life. However, a large proportion of children who do not suffer from cerebral palsy still show signs of clumsiness and have trouble concentrating and keeping focussed, all of which could compromise their schooling (Burguet et al., 2000).

For instance, Jongmans et al. (1998) demonstrated that a large proportion of children born prematurely performed poorly on tests of perceptual-motor ability. Similarly, at 5 years of age, children born prematurely were found to have a performance quotient (PQ – non verbal Wechsler scale of intelligence) below 2 standard deviations of the mean, three times more often than controls. PQ was at least one standard deviation below the verbal quotient (VQ – verbal Wechsler scale of intelligence) twice as often in premature children compared to their full-term counterparts (Burguet et al., 2000).

Marlow et al. (1993) suggested that any perceptual-motor delay on starting school represents a steady indicator of poor achievement a few years later, especially in mathematics. However, with time, it seems that socioeconomic factors become more predictive of a premature child's development. This is true for all premature births occurring after 28 weeks of gestational age and for babies with a birth weight of more than 750 grams (François et al., 1998).

7.3.3 Long-term visual deficits

Lesion studies and the observation of children born with cataracts have provided data on the effects of atypical visual experience and have linked early deprivation of visual experience (especially absence of patterned input) with impaired visual acuity, configural processing (Le Grand, Mondloch, Maurer and Brent, 2001) and general face processing in adulthood (Mondloch et al., 1998; Geldart, Mondloch, Maurer, de Schonen and Brent, 2002 ; Maurer, Lewis and Mondloch, 2005).

In contrast, babies born prematurely tend to benefit from extra visual experience compared to their full-term counterparts. Thus, follow-up studies of infants born prematurely could provide data on the effects of extra visual stimulation and perhaps show increased levels of performance in visual tasks which would continue into childhood.

However, one might question the quality of the extra visual experience the premature infant receives. Indeed, increased ambient light within the neonatal unit and phototherapy have been identified as adverse factors in retinal development (e.g. Powls, Botting, Cooke, Stephenson and Marlow, 1997) and premature birth has been linked with a number of perinatal insults suggesting that a large part of this population does not possess the necessary tools to benefit from extra visual stimulation. For instance, the premature infant born at 30 weeks post-conception with an immature visual system is near-sighted and can only discriminate highly contrasted large patterns presented at short distances (Grose and Harding, 1990).

Rather than being at an advantage, premature babies might, in actual fact, be at a disadvantage (de Haan, Bauer, Georgieff and Nelson, 2000) as low birth weight and prematurity have been associated with an increased incidence of ophthalmic disorders (e.g. Pennefather, Clarke, Strong, Cottrell, Dutton and Tin, 1999; Darlow, Clemett, Horwood and Mogridge, 1997; Ross, Lipper and Auld, 1991; Dowdeswell, Slater, Broomhall, Tripp, 1995).

For instance, Powls et al. (1997) indicated that VLBW children experience impairments such as reduced visual acuity and contrast sensitivity, refractive errors, strabismus and nystagmus. Powls et al. (1997) also found that children with reduced visual function on any measure are more likely to experience impaired motor skills. They suggested that, for VLBW children, abnormal contrast sensitivity is a significant predictor of low IQ.

Conversely, Burguet et al. (2000) found that children born between 25 and 33 weeks of gestation did not have a higher rate of strabismus, short-sightedness or long-sightedness.

Seigal (1994) and Foreman et al. (1997), however, found that, at 5 years of age they tended to have poorer visual acuity than controls, whereas visual-spatial processing was compromised both in infancy and at school age.

In Experiment 6 we investigated whether children born prematurely displayed long-term benefits from the extra visual stimulation or if the visual system's immaturity and the possible damage from perinatal insults caused long-term problems instead.

7.3.4 Memory deficits

A relationship between severity of brain haemorrhage and developmental deficit has been suggested (Papile, Munsick-Bruno and Schaefer, 1983; Shankaran, Slovis, Bedard and Poland, 1982) as more severe haemorrhages have been linked to high incidence of neurological impairments and mild haemorrhages have been linked to normal neurological functioning (Ross, Tesman, Auld and Nass, 1992). However, various studies found that mild haemorrhages can create specific lesions in the head of the caudate nucleus and destroy cells that normally would migrate to the amygdala and the thalamus (e.g. Allan and Volpe, 1986; Volpe, 1987).

For instance, in humans, Ross et al. (1992) found that 10-month-old premature infants were less likely to be correct in locating the placement of an object when its hiding place was changed, indifferently of IVH or not. They suggested that effects of prematurity, more so than the incidence of haemorrhage, are associated with the inability to locate a hidden object (Ross et al., 1992). Similarly, in infant and juvenile monkeys, damage to the caudate nucleus has been linked to impaired performance on tasks necessitating memory for location, while in infant monkeys damage to the amygdala and thalamus has been shown to impair visual attention and recognition memory (Ross et al., 1992).

Ross et al. (1992) proposed that, when a task taps into late maturing functions, premature infants may need more time than the normal age correction would suggest. For instance, de Haan et al. (2000) suggested that the more prolonged development of a function such as declarative memory makes it susceptible to be experience dependent, and, therefore, likely to be influenced by the healthy premature infant's atypical experience. They found that, at 19 months of age, premature infants had more difficulty remembering the order of actions in a sequence, both immediately after they saw the actions modelled and following a 15-minute delay, than full-term infants who were physiologically màture. In line with Den Ouden et al. (1991), these results indicated that low-risk premature infants need more than 2 years to come abreast with their full-term counterparts (de Haan et al., 2000).

De Haan et al. (2000) put forward the idea that experience plays a role in the development of memory systems, but that, in the case of premature infants, additional visual experience (relative to age-matched full-term controls) is not beneficial to performance and is in fact detrimental. Similar results have been observed with adults who suffered temporal-lobe damage and display difficulties reproducing ordered lists of events, as do adults with frontal lobe lesions (McDonough et al., 1995). In this way, it seems that damage to medial temporal and/or frontal lobes could affect performance on tasks demanding recall of order (de Haan et al., 2000).

In humans, brain growth is fastest around the time of term. Therefore, the brain is particularly vulnerable to malnutrition in its initial post-natal phase of development (de Haan et al., 2000). For many premature infants, however, the period between birth and term is one of relative malnutrition (Abernethy, Cooke and Foulder-Hughes, 2004). Indeed, during the third term of pregnancy, demands for neural growth are high and the placenta and human milk are the only sources of DHA (a dietary essential fatty acid fundamental for the normal development of the developing brain). Thus, the quality of diet in the first few weeks is an important factor influencing the premature infant's future cognitive development (Fazzi et al., 1997; Isaacs et al., 1998). Development of brain structures that underlie recall memory have been found to be altered following foetal deprivation (de Haan et al., 2000).

Premature and full-term infants also experience different sleep-wake cycles. As sleep is known to affect memory in adults (e.g. Plihal et al, 1999), it might also affect the development of memory circuits in infants.

In summary, various studies suggest that prematurity itself is a primary risk factor and that greater postnatal experience does not compensate for the atypical environment of the final weeks of gestation.

7.4 Declarative and nondeclarative memory

Human memory can be divided into two types (Manns, Stark and Squire, 2000) which involve different kinds of learning (Zola-Morgan and Squire, 1993). Declarative (or explicit, cognitive) memory refers to the conscious recollection of events and facts (Zola-Morgan and Squire, 1993; Manns et al., 2000) that can be brought to mind as an image or proposition (Johnson, 1997). It is composed of episodic and semantic memories and offers conscious recollection and flexible memory expression (Eichenbaum, 2000). Nondeclarative (or implicit, habit) memory refers to nonconscious learning abilities (Manns et al., 2000) expressed in skills (e.g. driving a car) or procedures (Johnson, 1997; Squire, 1986; Zola-Morgan and Squire, 1993; Squire and Zola, 1996), habits, simple forms of conditioning and priming (Manns et al., 2000).

Declarative and nondeclarative memory are supported by different brain systems (Zola-Morgan and Squire, 1993; Squire and Zola, 1996) and differ in their neural substrates. Declarative memory involves structures and connections in the medial temporal lobe and the midline diencephalon (i.e. the hippocampus and the surrounding entorhinal, perirhinal and parahippocampal cortices) (Zola-Morgan and Squire, 1993), whereas nondeclarative memory involves the neocortex and neostriatum (Packard et al., 1989; Wang et al., 1990), the extrastriate cortex (Squire et al., 1992) and the cerebellum (Thompson, 1986).

Rovee-Collier, Hayne and Colombo (2001) have intimated that declarative memory is very much dependent on context, i.e. the environment in which an event or stimulus is encountered, the emotional state of the individual, or elements relative to the visual stimuli associated with the encountered item. Brown and Aggleton (2001) and Eichenbaum, Otto and Cohen (1994) provided evidence for the hypothesis that the hippocampal system is necessary for the flexible expression of declarative memory across such changes in temporal or physical contexts. For instance, using a VPC task, Pascalis and Bachevalier (1995, cited in Robinson and Pascalis, 2004) demonstrated that monkeys that had suffered lesions of the hippocampal formation displayed chance performances in a changed context condition and novelty preference in a constant context condition. These results contrasted with recognition in all conditions for monkeys in the control group. Like Pascalis and Bachevalier (1995), in Experiment 6 we tested for contextual (relational) memory in premature and full-term children using a DNMS (delayed nonmatch-to-sample) task.

In the past, the general consensus was that, early in life, the immaturity of the hippocampal formation prevented contextual information to be integrated properly (e.g. Nadel and Zola-Morgan, 1984) and was therefore responsible for poor performances (compared to adult levels) on memory tasks during infancy. However, recent studies have supported the view that the human hippocampus is more mature at birth than was previously believed (Seress, 2001; Alvarado and Bachevalier, 2000). Consequently, Nelson (1995) proposed that, in primates, there is a nondeclarative, a pre-declarative and a declarative memory system that develop from infancy. Early on, the nondeclarative memory system is involved in visual expectations and conditioning (Rovee-Collier, 1993). The pre-declarative memory system is involved in infants' novelty preferences in paired comparison tasks with short delays and is dependent on the hippocampus (Nelson, 1995). It acts as an immature form of the declarative memory system due to the immaturity of cortical inputs to the hippocampus. At approximately 9 months of age, the declarative memory system develops, as the connections between the cortex and the hippocampus grow. Declarative memory is involved in recognition memory, inter-sensory coordination of information and the solving of new problems by making inferences from memory (Nelson, 1995; Eichenbaum, 2000).

Hayne et al. (2000) argued that, with age, infants demonstrate an increasing ability to recognise objects and events flexibly and independently across contexts. This ability is fundamental for appreciating continuity within changing environments and is an essential component of the declarative memory system in adulthood (Robinson and Pascalis, 2004; Rovee-Collier et al., 2001).

7.4.1 Recognition memory

Recognition memory is an example of declarative memory (Manns et al., 2000) and depends on the integrity of the medial temporal lobe and diencephalic structures (Reed and Squire, 1997; Manns and Squire, 1999). It includes both familiarity judgement and recollection (Nemanic, Alvarado and Bachevalier, 2004) and is defined as the ability to decide whether or not a stimulus has been encountered before (Bachevalier, Nemanic and Alvarado, 2003), thus measuring the extent of learning between the study and test phase of an experiment (Clutterbuck and Johnston, 2005). Recognition memory depends on the interaction between the visual cortical pathway and the limbic structures (Webster, Bachevalier and Ungerleider, 1994).

For instance, patients who have sustained lesions of the medial temporal lobe (e.g. Scoville and Milner, 1957) and patients with anoxic ischemia resulting in neuropathology mostly restricted to the hippocampal formation, show evidence of recognition memory impairments (Zola-Morgan, Squire and Amaral, 1986; Rempel-Clower, Zola, Squire and Amaral, 1996). As this is potentially true of prematurely born individuals, in Experiment 6 we compared premature and full-term children's performances using a selection of tasks.

The visual-paired comparison and delayed nonmatch-to-sample tasks have been used to investigate recognition memory in monkeys. Both tasks were impaired following perirhinal cortex damage. However, selective hippocampal lesions only affected the VPC task, revealing only moderate or no impairment on the DNMS task (Eichenbaum, 2000; Baxter and Murray, 2001, for review; Bachevalier et al., 2002). Thus, like Pascalis and Bachevalier (1999), Nemanic et al. (2004, p. 2021) proposed that the VPC and the DNMS tasks cannot be considered as "identical, interchangeable recognition memory probes." Nemanic et al. (2004) proposed that the VPC task involves incidental learning, thus favouring the creation of a conjunctive representation of the stimulus and its location and contexts (O'Reilly and Rudy, 2001). In contrast, intentional learning in the DNMS task favours the creation of a representation of the stimulus itself, not taking into account its spatial location or context. In Experiment 6 we looked at memory for spatial location using a DNMS task.

7.4.2 Lesions of the limbic system in premature children

Vachha and Adams (2004) proposed that, in the developing brain, the limbic structures - which include the hippocampus and the amygdala - are particularly vulnerable because of the proximity of limbic structures to the ventricles which, through mechanical compression effects of the dilated ventricles or via alterations of metabolic pathways, could generate neuropathological changes in these structures.

The structure of the amygdala is thought to be implicated in social cognition, involving adequate recognition and judgement of facial expressions (e.g. Kandel, Schwartz and Jessell, 2000; Nomura, Ohira, Haneda, Iidaka, Sadato, Okada and Yonekura, 2004), in particular fear (e.g. LaBar, LeDoux, Spencer and Phelps, 1995). This point was illustrated by Adolphs et al. (1994, 1995) who reported that an adult patient who had sustained bilateral calcification of the amygdala, was impaired in discriminating facial expressions, especially negative expressions such as fear. These findings were complemented by neuroimaging studies led by Whalen et al. (1998). They observed increased activation in the amygdala when fearful faces were presented, but decreased activation with happy faces. Using positron emission tomography (PET), Morris et al. (1996) observed that neuronal activity in the left amygdala is markedly greater with fearful faces than with happy faces. From these studies, it transpired that regions in and around the fusiform gyrus play a role in face recognition, whereas the amygdala plays an important role in the recognition of facial expressions.

The hippocampus is involved in long-term memory (e.g. Zola and Squire, 2000): lesions of the right hippocampus have been linked with spatial memory deficits while left lesions have been linked with verbal memory deficits (Kandel et al., 2000; Zola and Squire, 2000).

The hippocampus and basal ganglia are particularly susceptible to injury in premature infants (Abernethy et al., 2004). For instance, Fuller, Guthrie and Alvord (1983) demonstrated that hippocampal abnormalities were found in two-thirds of autopsies of premature infants. Isaacs et al. (1998) demonstrated that very premature children have deficits in declarative memory later in life that are associated with reductions in hippocampal volume.

Peterson et al. (2000) demonstrated that cortical grey matter was reduced in the amygdala as well as in the hippocampus of children born prematurely. This reduction was greater than expected from the overall reduction of the brain volume. These findings were corroborated by Isaacs et al. (2000) who found that adolescents with a gestational age under 30 weeks had significantly smaller hippocampal volumes bilaterally than age-matched controls (despite a similar head size). Memory deficits were also observed.

Researchers (Castellanos, Geidd, Eckburg, Marsh, Vaituzis, Kaysen, Hamburger and Rapoport, 1994; Hynd, Semrud-Clikeman, Lorys, Novey and Elopulos, 1990) found associations between the volumes of the caudate nuclei and the hippocampus and learning difficulties and attention deficit in school-age children born at term. Children born very prematurely showed differences in cerebellar, basal ganglia, total brain and grey matter volumes (e.g. Rushe, Rifkin, Stewart, Townsend, Roth and Murray, 2001; Abernethy, Palaniappan and Cooke, 2000). Abernethy et al. (2004) found that, in 7-year-old premature children, volumes of the caudate nuclei were significantly correlated with IQ. However, this relationship could simply indicate the correlation between brain size and IQ. The hippocampal volumes however, were not smaller than would be expected for this age.

Conversely, Peterson et al. (2000) found that, in 8-year-old premature children, regional cortical volumes and basal ganglia and hippocampal volumes were smaller in premature children than in their full-term counterparts.

In summary, cerebral structures that are involved in recognition memory have been found to be sensitive to ischemia. Therefore, memory problems can be expected in children who were born prematurely. For instance, Vargha-Khadem (1997) observed global anterograde amnesia after brain injury (ischemia) linked to premature birth. Magnetic resonance techniques revealed the presence of bilateral hippocampal pathology. However, levels for speech, language, literacy and factual knowledge were all within the low average to average range. Thus, these findings supported the view that episodic and semantic components of declarative memory are partly dissociable. Only episodic memory, however, seems to be fully dependent on the hippocampus.

7.5 Face processing in children

Early studies (Diamond and Carey, 1977; Carey and Diamond, 1977) found that developments in face recognition result from a specific, qualitative difference between children's and adults' face processing styles. Diamond and

Carey (1977) proposed that, prior to 10 years of age, children rely predominantly on featural processing for face recognition, whereas, after 10 years of age, children start relying on adult-like configural processing.

More recent studies, however, directly challenged this view and demonstrated that young children also show evidence of configural processing (e.g. Tanaka, Kay, Grimmell, Stansfield and Szechter, 1998; Carey and Diamond, 1994; Baenninger, 1994).

Freire and Lee (2001) suggested that both featural and configural discriminations improve with age, even though children find it easier to discriminate faces that vary according to features alone. These data supported the claim that there is a general improvement in face recognition rather than in a specific style of processing.

In line with Campbell et al. (1999), Taylor, Batty and Itier (2004) observed that the adult pattern of face processing is still not reached by the mid-teens, thus confirming that face processing follows a prolonged developmental path before becoming adult-like (e.g. Johnson et al., 1991; Maurer, 1983; Maurer and Barrera, 1981; Morton and Johnson, 1991).

In Experiment 6, we wished to verify whether premature children would present face processing abilities that differed from those of their full-term counterparts due to the extra visual stimulation they received at birth. Using a task based on the delayed match-to-sample (DMS) procedure, we observed whether both groups would display an inversion effect.

8. Experiment 6

Experiment 6 was designed to compare face processing development between infancy and childhood in premature and full-term individuals, and compare face processing, visual memory and facial expression recognition in full-term and premature children at school-age.

However, after having approached a small number of parents of premature infants on the neonatal intensive care unit of the Jessop Wing of the Royal Hallamshire Hospital of Sheffield, preliminary testing in such sensitive conditions proved very difficult. Therefore, we concentrated solely on a comparison of premature and full-term children's long-term development.

Participants

Studies that have explored the development of premature children around the age of 8 years have pointed to various neurobehavioural and neurocognitive problems (e.g. Yliherva et al., 2001; Vollmer et al., 2003; O'Brien, Roth, Stewart, Rifkin, Rushe and Wyatt, 2004; Reiss et al., 2004).

We tested children aged between 7 and 10 years. The aim was to verify whether children born prematurely tend to catch up with their full-term counterparts, rather than to establish the exact age at which this might take place.

There is some debate in the literature about what constitutes an ideal control group in a study with premature children. One option (Jongmans et al., 1998) is to select controls using variables relevant at the time of birth (e.g. full-term birth, similar date of birth, cared for in the same hospital, of the same gender and ethnic origin, etc.), while another approach is to select children at the time of follow up, using variables related to home background, school experience, etc.

The sample we tested was constituted from a cohort of premature and term children who had been followed up by Sheffield Children's Hospital from birth. Premature infants had been matched with full-term controls born at a similar date, cared for in the same hospital, and of the same ethnic origin. Children were tested annually by the hospital for growth and general health.

Sixteen premature children (10 girls and 6 boys) and 16 control children (7 girls and 9 boys) were tested.

The children in the premature group were born at least 3 weeks premature, i.e. at less than 37 weeks' gestational age (M= 31.06 weeks of gestation, SD= 3.23), with a birth weight between 850 and 2500 g (M= 1544 g, SD= 451). Their mean age was 9 years and 3 months (SD= 9 months). Like O'Brien et al. (2004), we did not perform correction for prematurity at any age.

The children from the control group were all born full-term, with a birth weight between 3000 and 4590 g (M= 3699 g, SD= 530). Their mean age was 9 years and 7 months (SD= 13 months).

No difference was observed between the mean ages of premature and full-term children ($t(31)= 1.19, p> 0.05$).

General prodecure

A letter was sent to all parents whose addresses had been supplied to us by our contacts at Sheffield Children's Hospital. Parents who were interested in participating in the study could either telephone us directly or telephone our contacts at the hospital for more information. Informed consent was obtained from parents.

All tests were performed in one session (except for 5 of the youngest children who were tested over 2 sessions) at the University of Sheffield. Children of both groups were tested using a battery of visual tests that covered face processing (the inversion effect and discrimination of emotions) and object processing (relational memory). Children's intellectual quotients (IQ) were tested using the Wechsler Intelligence Scale for Children (WISC-III UK edition, 1992).

Testing started with the WISC-III test, followed by the facial expression labelling test, the face recognition test and the relational memory test. Results for the WISC-III test were sent to parents the week following their child's appointment.

8.1 Description of tests

8.1.1 Facial expression labelling test

Ekman and Friesen (1971) reported that six facial expressions (i.e. happiness, sadness, anger, fear, surprise and disgust) are readily recognised across different cultures. The facial expression labelling test gives a measure of the participant's ability to identify these emotions.

Studies indicated that, at all ages, happiness is processed more accurately and faster than other facial expressions (Walden and Field, 1982; Gross and Ballif, 1991; Montirosso et al., unpublished). Young children are poor at discriminating anger and disgust expressions while older children are relatively poor at discriminating sadness and surprise (Reichenbach and Master, 1983; Gross and Ballif, 1991).

Researchers have suggested that the use of dynamic faces improves recognition of facial expressions compared to use of static two-dimensional photographs (De Sonneville et al, 2002; Herba and Phillips, 2004).

Thus, children were presented with a short film of a human face (black and white, depicted from the crown of the head to the jaw) changing from a neutral facial expression to one of 6 emotions, i.e. happiness, sadness, anger, fear, surprise or disgust (see Figure 12). The films were presented on a computer screen in a quiet room at The University of Sheffield. The child had to tell the experimenter which emotion he/she thought was being portrayed.

Children were presented with 16 exemplars of 6 emotions through 4 sets of faces. Accuracy (expressed in percentages) was recorded.

Based on past studies (see section 7.4.2), we hypothesised that premature children would not perform as well as their full-term counterparts.

Figure 12 : 'Anger', as used in the facial expression labelling test.

8.1.2 Face recognition test

The face recognition test measures the inversion effect and is based on a delayed match-to-sample (DMS) task. This programme allowed us to verify whether premature children performed as well as their full-term counterparts on a face recognition task and whether both groups displayed an inversion effect.

Thirty black and white photographs of upright and inverted human faces (depicted from the crown of the head to the jaw) were used. Performance on human face stimuli was contrasted with performance on thirty upright and inverted *en face* car stimuli (see Figure 13).

Figure 13: An illustration of the familiarisation phase and test phase, as used in the face recognition test.

Familiarisation with a face stimulus (upright or inverted) for a period of 1 second was followed by the test phase during which the child was presented with two pictures (upright or inverted): the habituated face and a novel face. Familiarisation with a car stimulus (upright or inverted) for a period of 1 second was followed by the test phase during which the child was presented with two pictures (upright or inverted): the habituated car and a novel car.

In the test phase, the child pressed either key ‘Z’ or key ‘M’ as fast as possible to indicate which picture he/she had previously seen. Accuracy and reaction times were recorded.

We hypothesised that premature children would display lower levels of accuracy, as low birth weight and prematurity have been associated with an increased incidence of ophthalmic disorders (e.g. Pennefather et al., 1999; Darlow et al., 1997; Ross et al, 1991; Dowdeswell et al., 1995) which could put them at a disadvantage (e.g. de Haan et al., 2000).

8.1.3 Relational memory test

A delayed nonmatch-to-sample (DNMS) task was presented. Children were familiarised with a configuration of 3 objects for 5 seconds. In the recognition phase children were presented with the habituated configuration and a novel configuration. Children had to point towards the novel configuration (see Figure 14). This test was presented on a computer screen in a quiet room.

Figure 14: An illustration of the familiarisation phase and the test phase, as used in the relational memory test.

Despite findings supporting the idea that, in monkeys, damage to the amygdala and thalamus are associated with impaired recognition memory (Ross et al., 1992), we hypothesised that no differences would be observed between the two groups because of the relatively low level of difficulty of the task.

	Full-scale	Verbal scale	Performance scale
Full-term (n=16)	117.88	123.44	107.06
SD	14.48	13.68	14.88
Premature (n=16)	107.31	111.94	101.06
SD	12.76	10.14	14.93
t-value	2.54	2.69	1.52
p	0.02	0.02	0.15

Table 6 – Mean scores on all three WISC-III scales with standard deviations (SD), with comparison by chance.

8.2.2 Facial expression labelling test

We considered all correct answers. An average of 56.94% of correct answers was scored by the premature group, while an average score of 64.09% was observed for the full-term group.

Correct answers were analysed in a one-way ANOVA with birth (premature, full-term) as the independent factor and facial expression (fear, anger, happiness, sadness, disgust, surprise) as the dependent variable. No significant effects were found (see table 7).

	Fear	Anger	Happiness	Sadness	Disgust	Surprise
Premature (SD)	5.8 (4.2)	10.1 (2.2)	15.4 (1.1)	9.1 (3.2)	6.3 (3.8)	13.7 (1.8)
Full-term (SD)	8.3 (4.9)	10.4 (2.2)	15.3 (1.6)	10.7 (3.3)	7.4 (4.1)	14.2 (1.5)
F-value	2.36	0.16	0.02	2.03	0.64	0.69
df						
Between groups	1	1	1	1	1	1
Within groups	30	30	30	30	30	30
p	0.13	0.69	0.89	0.16	0.43	0.41

Table 7 – Facial expression labelling test : average number of correct answers per expression, per group. Anova showing F-value, degrees of freedom between and within groups and p-value.

Both groups displayed good discrimination for 'happiness' and 'surprise'. In both groups, 'fear' and 'disgust' were most often mistaken for 'surprise' and 'anger', respectively. These results were in line with past studies (Walden and Field, 1982; Reichenbach and Master, 1983; Gross and Ballif, 1991; Montirosso et al., unpublished).

To a lesser extent, 'anger' was mistaken for 'disgust', while 'sadness' was most often mistaken for 'disgust' and 'fear'.

Pearson correlations were calculated for all expressions. The correlation between 'happiness' and 'surprise' ($r = 0.42$) was the only one to be significant at the 0.05 level.

8.2.3 Face recognition test

Average percentages of correct answers were higher for upright compared to inverted stimuli : premature children presented an average score of 89.17% for upright human faces compared to 81.67% for inverted human faces. Full-term children presented an average score of 88.33% for upright human faces compared to 80.83% for inverted human faces (see table 8).

Results were analysed for each stimulus (upright and inverted human face, upright and inverted car) using two-tailed t-tests. No differences were observed between groups (see table 8).

	HF Upright	HF Inverted	Car Upright	Car Inverted
Premature (SD)	89.17 (2.49)	81.67 (2.47)	82.08 (3.58)	81.25 (3.28)
Full-term (SD)	88.33 (3.36)	80.83 (3.03)	82.50 (2.64)	84.58 (2.41)
t-value	0.19	0.21	0.13	0.77
df	15	15	15	15
p	0.85	0.84	0.89	0.45

Table 8 – Average percentages of correct answers on upright and inverted human face (HF) and car (Car) stimuli, and results for two-tailed t-tests for the face recognition test.

Reaction times (in milliseconds) for correct answers were analysed using two-tailed t-tests. Full-term children displayed faster reaction times than premature children for all but one stimuli and were significantly faster when discriminating inverted car stimuli (see table 9).

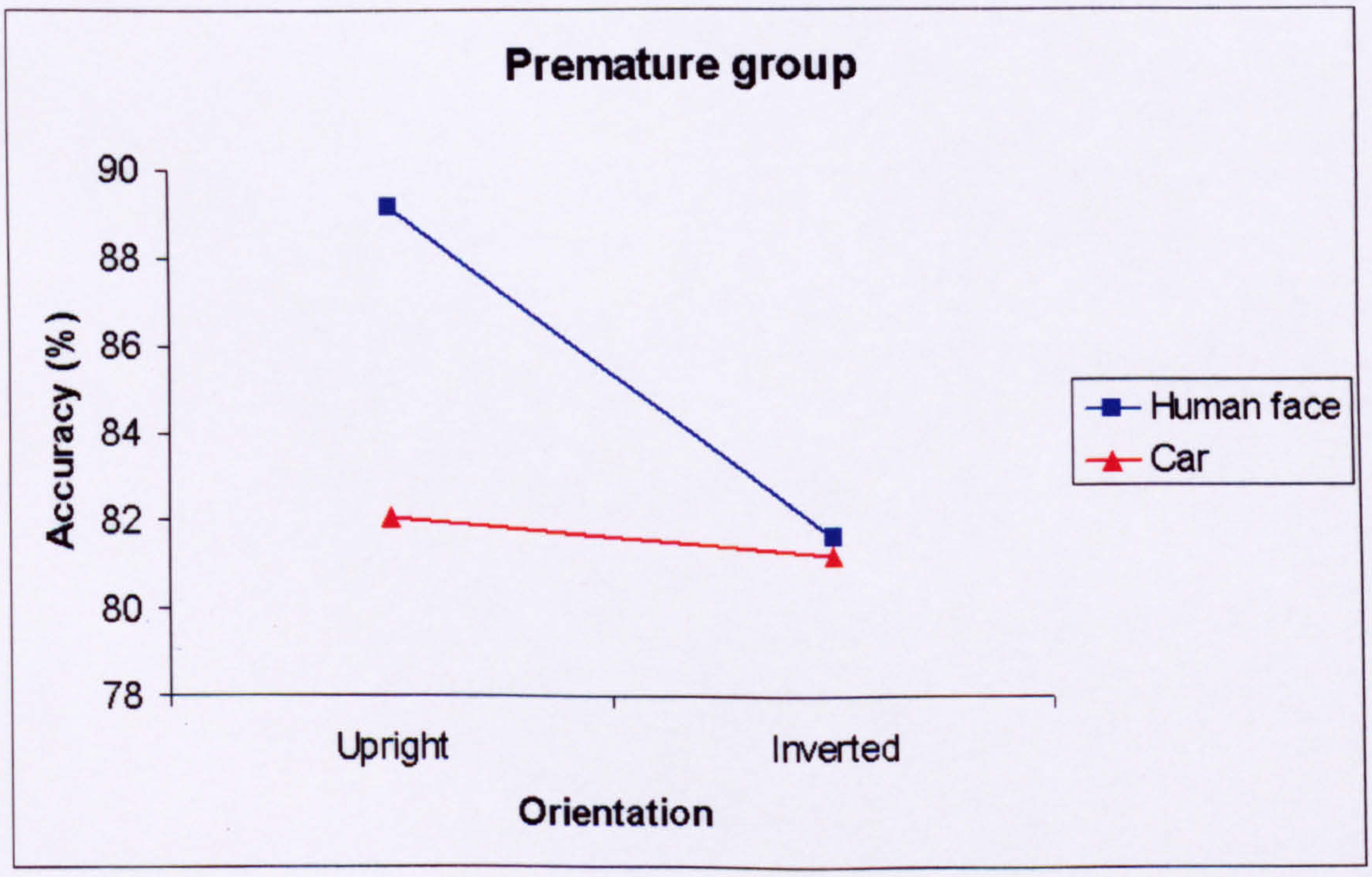
	HF upright	HF inverted	Car upright	Car inverted
Premature (SD)	871 (292)	956 (355)	854 (331)	931 (359)
Full-term (SD)	837 (295)	908 (328)	869 (264)	869 (310)
t-value	1.08	1.24	0.45	1.69
df	185	156	168	167
p	0.28	0.22	0.65	0.09

Table 9 – Mean reaction times (ms) for correct answers for each stimulus of the face recognition test and results for two-tailed t-tests.

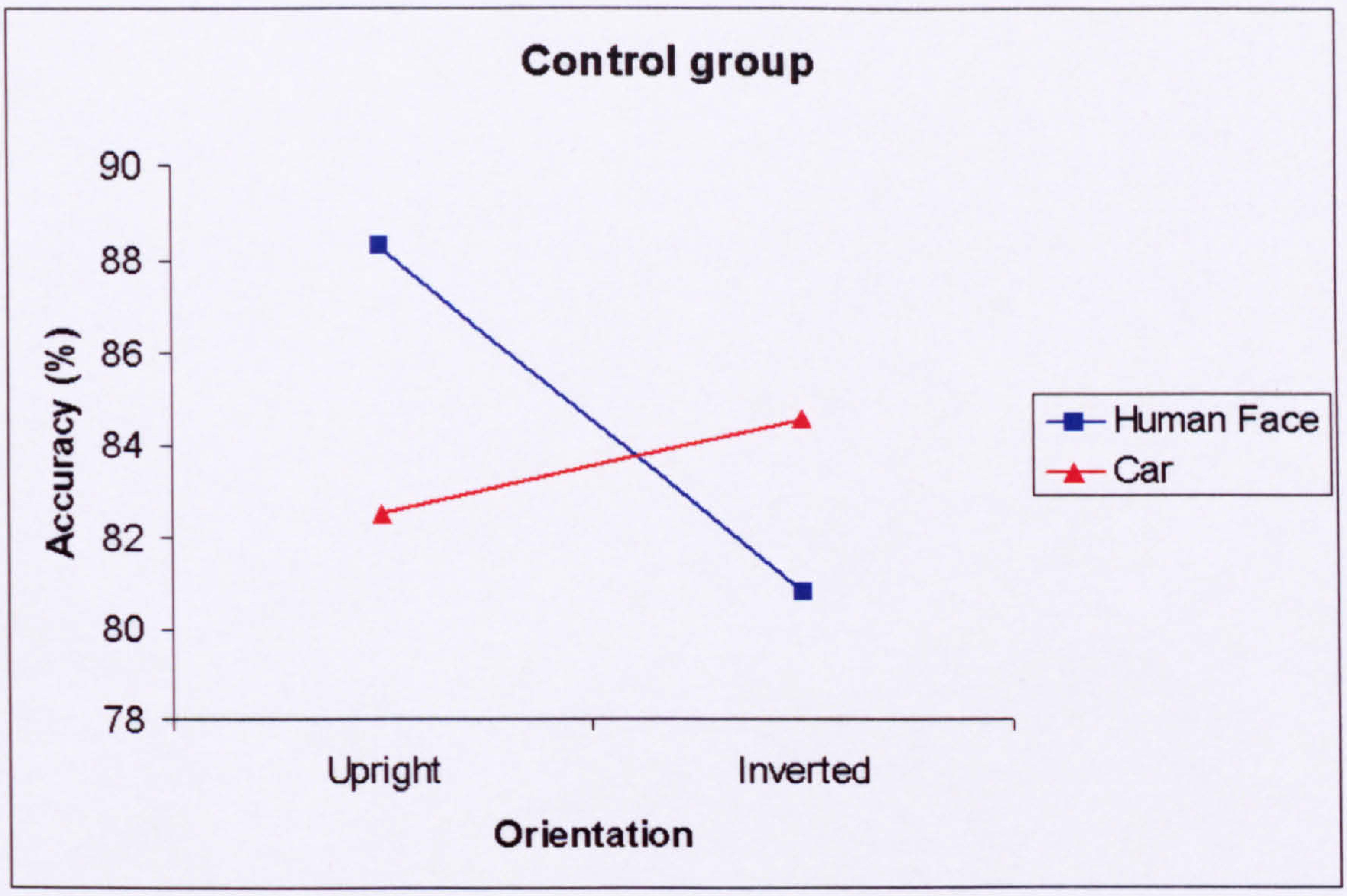
T-tests were also performed within groups to verify whether both groups showed an inversion effect on accuracy of discrimination of the stimuli. An inversion effect was observed for premature children who performed significantly better on upright ($t(15) = 3.00$, $p < 0.05$) compared to inverted human faces (see table 10, graphs 1 and 2).

	Hf Up / HF Inv Premature	HF Up / HF Inv Controls	Car Up / Car Inv Premature	Car Up / Car Inv Controls
t-value	3.00	1.74	0.23	0.59
df	15	15	15	15
p	0.01	0.10	0.82	0.56

Table 10 – Results of the two-tailed t-tests, with comparison by chance for accuracy of discrimination within groups for the face recognition test.



Graph 1 – Face recognition test: percentage of correct answers for upright and inverted human face and car stimuli for the premature group.

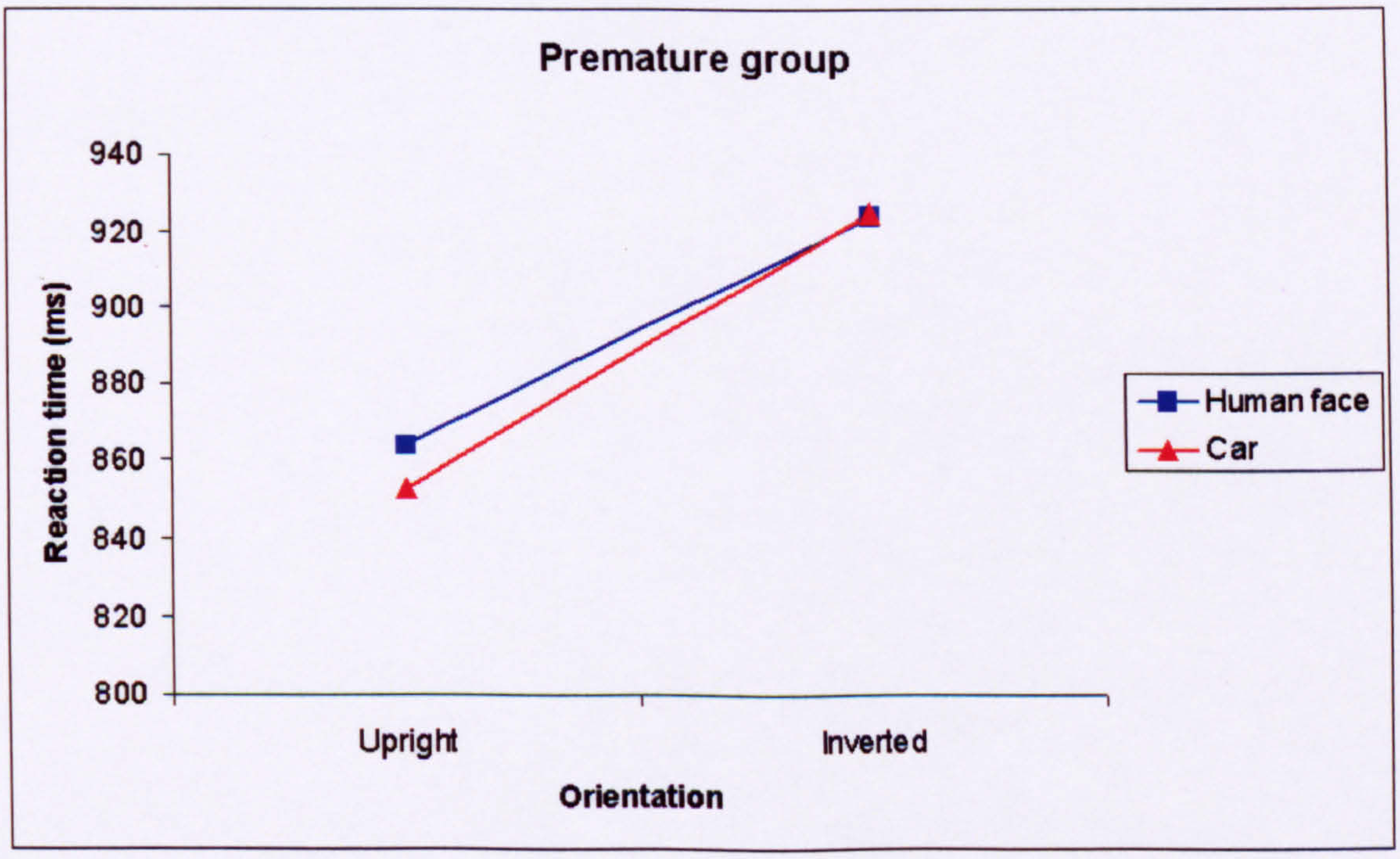


Graph 2 – Face recognition test: percentage of correct answers for upright and inverted human face and car stimuli for the control group.

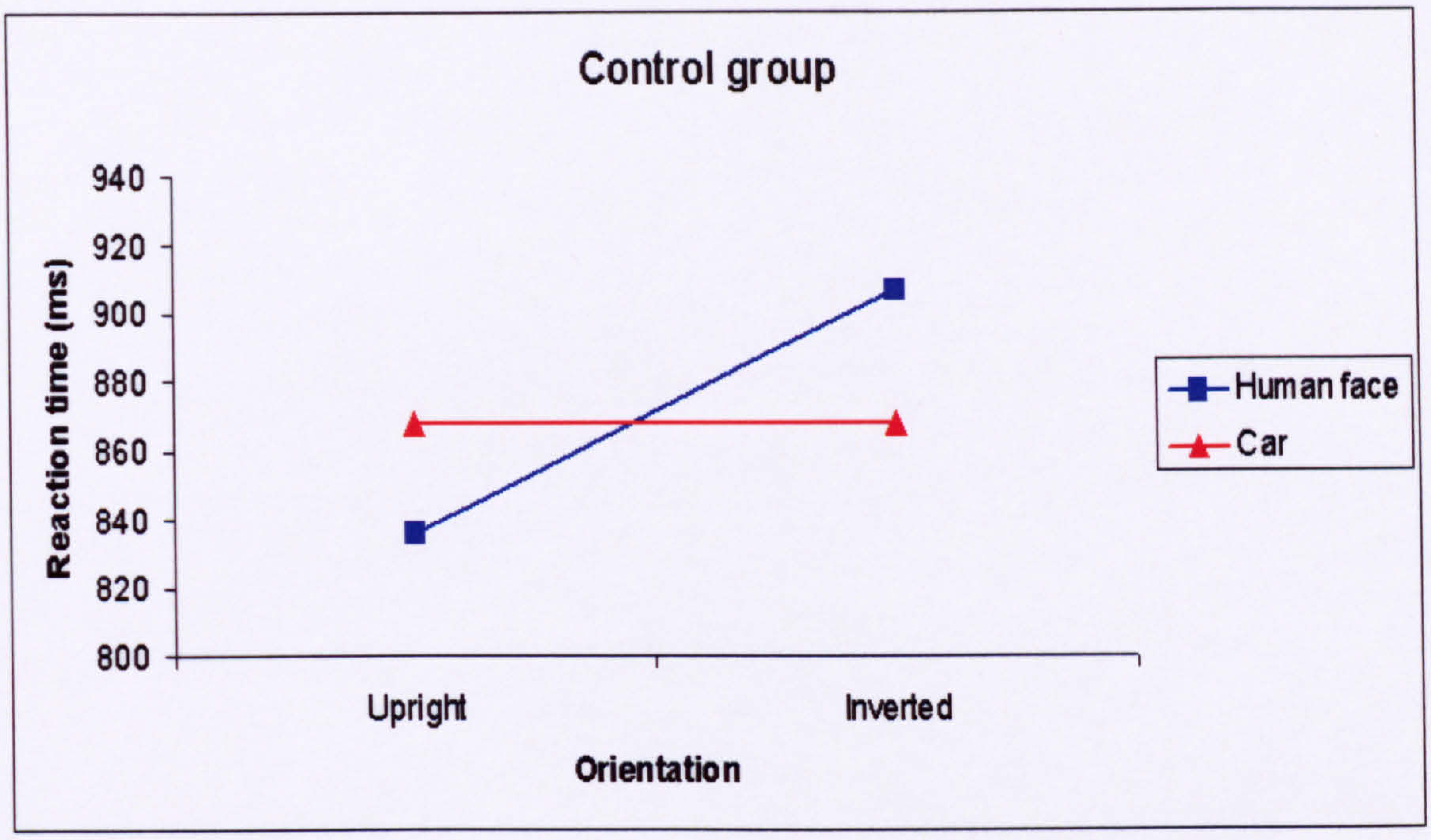
T-tests performed within groups on the reaction times of correct answers revealed that full-term children displayed significantly shorter reaction times for the upright human faces compared to the inverted human faces (see table 11, graphs 3 and 4).

	HFUp/HFInv Premature	HFUp/HFInv Controls	CarUp/CarInv Premature	CarUp/CarInv Controls
t-value	1.69	2.01	1.83	0.06
df	197	156	192	167
p	0.09	0.047	0.07	0.95

Table 11 – Face recognition test : two-tailed t-tests for reaction times within groups (premature and control) for upright and inverted stimuli.



Graph 3 – Face recognition test : average reaction times (ms) for upright and inverted human face and car stimuli for the premature group.



Graph 4 – Face recognition test : average reaction times (ms) for upright and inverted human face and car stimuli for the control group.

8.2.4 Relational Memory Test

Controls obtained a mean average score of 92.81% of correct answers (SD= 7.06), whereas premature children obtained 91.56% (SD= 7.46). A t-test revealed no differences in accuracy between the control and premature groups ($t(15)= 0.41$, $p> 0.05$).

	Full-term	Premature
Accuracy in % (SD)	92.81 (7.06)	91.56 (7.46)

Table 11 – Relational memory test : average percentages of correct answers for full-term and premature groups.

8.3 Discussion Experiment 6

Impairments observed in premature infants suggest that premature birth disrupts cerebral neurodevelopment (Reiss et al., 2004) and, at school age, premature children have been found to have a lower IQ than their full-term counterparts (Voyer, 1986; Saigal, 1993 ; Sizun et al., 1998).

Experiment 6 investigated whether similar differences would be observed in the population of school-aged premature and full-term children we tested.

Statistical tests performed on the WISC-III intelligence test indicated that, as a group, premature children did not perform as well as full-term children. Full-term children scored significantly higher than premature children on the full-scale and verbal indexes. The full-scale score varied because of the verbal score alone. Within the interpretative frame of the WISC-III test, however, both groups scored at 'average' level or above. Thus, no deficiencies were observed with this test in either groups. A bias may have been created by the fact that all premature children who participated were in good health and did not present major handicaps. In contrast, at the time of testing, a couple of full-term children were experiencing school-related problems.

Low birth weight and prematurity have been associated with an increased incidence of ophthalmic disorders in infancy (e.g. Pennefather et al., 1999; Darlow et al., 1997; Ross et al., 1991; Dowdeswell et al., 1995). Therefore, Experiment 6 compared premature and full-term children's face processing abilities at school-age.

Both groups performed well on a face recognition task involving upright and inverted faces and cars. Only the premature group, however, displayed significantly greater accuracy with upright faces than inverted faces, thus showing an inversion effect. Although the control group did show greater accuracy with upright faces than inverted faces, this effect was not significant, possibly because of the relative easiness of the task.

In the developing brain, the limbic structures are particularly vulnerable (Vachha and Adams, 2004). The structure of the amygdala is thought to be implicated in the recognition of facial expressions (e.g. Kandel et al., 2000; Nomura et al., 2004).

Experiment 6 investigated whether premature children displayed lower performances than full-term children in a task measuring the ability to recognise facial emotions.

The facial expression labelling test revealed that premature and full-term children displayed comparable abilities in the discrimination of facial emotions.

These results are in line with Montirosso et al. (unpublished) who found that, in a normal population, performance on facial expression recognition was explained by chronological age and experience rather than the individual's cognitive ability.

However, both premature and control groups displayed low measures of accuracy (56.94% and 64.06%, respectively), which suggests that the facial expression labelling test may have been too long and perhaps too difficult for this age group.

Because cerebral structures involved in recognition memory have been found to be sensitive to ischemia, memory problems can be expected in prematurely born children (e.g. Vargha-Khadem, 1997). In particular, individuals with anoxic ischemia resulting in neuropathology of the hippocampal formation, show evidence of recognition memory impairments (Zola-Morgan et al., 1986; Rempel-Clower et al., 1996). As this is potentially true of prematurely born children, Experiment 6 investigated premature and full-term children's performances on a relational memory task. This task revealed no differences between groups.

In summary, results intimated that, despite displaying levels within the normal range of intelligence, premature children aged between 7 and 10 years of age performed less well than full-term children on an intelligence test, thus indicating that perinatal conditions may have affected performances in middle childhood. However, tests also revealed that premature children performed as well as their full-term counterparts in the discrimination of facial emotions, thus demonstrating no long-term visual deficits. Furthermore, in contrast with full-term children, premature children displayed an inversion effect, thereby showing an adult-like face processing system.

8.4 Conclusions Experiment 6

In Experiment 6, we investigated face processing and visual memory abilities in school-aged children born prematurely. We wished to examine whether premature children would present better face processing abilities than those of their full-term counterparts due to the extra visual stimulation associated with premature birth, or if the visual system's immaturity at birth and the possible damage generated by perinatal insults caused long-term problems instead.

Results did not lend support to either hypotheses. Instead, they seemed to indicate that, by the time premature children reach middle childhood, any problems that may have been caused by premature birth have been overridden by experience. However, our sample of premature children consisted of 16 healthy individuals with no severe handicaps related to premature birth and was therefore not entirely representative. Thus, no general conclusions can be drawn from our data with regard to the long-term development of premature infants.

CONCLUDING REMARKS

Part one of this thesis was dedicated to the analysis of visual preferences of neonates and 1- and 3-month-olds.

In Experiments 1 to 4 we used a visual preference task to verify whether young infants prefer the human face stimulus when paired with other stimuli.

Results confirmed that neonates prefer a photographic representation of the human face at birth depending on the comparison stimulus. Indeed, a preference for the human face stimulus was found when presented alongside a Fourier transform, an inverted human face, and a monkey face. No preference was observed when the human face stimulus was paired with a car stimulus.

We hypothesised that this preference involved a form of early prototype based on structure, facedness, orientation, and level of contrast. In line with de Haan et al. (2001), results also seemed to indicate that this prototype is not yet fully mature.

One-month-olds showed no preference in any of the four conditions while 3-month-olds showed a preference for the human face when paired with a Fourier transform or a car stimulus.

De Haan et al. (2001) proposed that, at about 3 months of age, a prototype is built from experienced exemplars. However, our results indicated that a face-specific prototype may already be developed within a few weeks of birth and that, by 3 months of age, this prototype may be responsible for infants' ability to discriminate faces from non faces and schematic face-like patterns.

Data also implied that this prototype does not yet refer to a separate human face category. Indeed, no preference was observed between the human face and the monkey face, thereby indicating that both stimuli were perceived as equally attractive.

If, however, like Quinn and Eimas (1998), we assume that infants form a global category of humans that includes other animals (e.g. horses and fish) and serves as a reference point (Carey, 1985; Rosch, 1975), results suggest that this global category could also include monkey faces. This interpretation supports the idea that, like neonates, 1- and 3-month-old infants can discriminate human and monkey faces. This hypothesis goes against the existence of two separate prototypes.

Results supported the idea that face processing is being tuned to a human template during the first year of life (Pascalis et al., 2002). Pascalis et al. (2002) proposed that, after 6 months of age, the face prototype becomes specific to the faces that the infant tends to encounter frequently. To verify this claim, future work could include the testing of 6- and 9-month-old infants.

The control stimuli used in Experiments 1 to 4 presented interpretative limitations. Thus, this final chapter would not be complete without a word of warning as to the conclusions we drew from the data we presented in this thesis.

Experiment 1 used a paired presentation of a human face and a Fourier transform of another human face to verify that the structure of the human face is an important factor in the observation of visual preferences in neonates and young infants. However, because the Fourier transform is effectively a 'cloud' of high and low contrast, it does not allow for any definite conclusions to be drawn. As an alternative, we could have used a control stimulus that was a photographic representation of the human face presented in a muddled jigsaw puzzle fashion. Any preferences that would have been observed using these stimuli would have been more meaningful. Indeed, in this case, longer looking times towards the face stimulus could have been interpreted as a significant preference for the particular structure of the human face.

Experiment 2 presented an upright human face paired with another inverted human face to verify whether orientation is an important factor in the observation of visual preferences early in life. Unfortunately, by choosing to use photographs of two different individuals for the upright and the inverted stimulus, we created a situation where it was not clear which element of the stimulus was responsible for the observed preference. Indeed, factors such as gender and brightness of the stimulus could have been responsible for or participated in the particular preferences we observed. A paired presentation of the same photograph oriented in the upright and inverted position would have avoided these problems and produced results which would have been less ambiguous.

Regarding prototype formation (e.g. Valentine, 1991; de Haan et al., 2001) and the increase of the specificity of the face recognition system to human faces with age and experience (Nelson, 2001), Experiment 3 used a human face paired with a monkey face to verify whether a preference would be observed for the human face (hereby showing that because of the lack of experience young infants have with faces, they have an advantage in recognising facial identity, regardless of species). However, the monkey face stimuli we used lacked in contrast levels compared to the human face stimuli. This could have been the reason why neonates showed a preference for the human face. Indeed, their immature visual system might not have been able to process the monkey face stimuli as well as the more clearly contrasted human face stimuli because of low acuity and accommodation. In order to verify this, an additional experiment could have been designed using line drawings of human and monkey faces.

Experiment 4 presented neonates and 1- and 3-month-old infants with a paired presentation of a human face stimulus and an *en face* car stimulus. This stimulus did not work as we had expected it to work. Indeed, results suggested that the infants' immature visual system might have processed the car stimulus as a variation of the *config* stimulus. However, another element that might have played an even bigger part in the null-preference we observed in neonates and 1-month-olds might have been the greater contrast levels presented by the car stimulus compared to the human face stimulus. We did not take this element sufficiently into account when interpreting the data.

With the help of a visual preference task, Experiment 5 tested the recognition of the mother's face in 1- to 9-month-old infants in the hope of producing data that would show the development of face processing of a particularly familiar face (i.e. the mother's face) in the first year of life. We did not test neonates in this experiment because of practical reasons.

Findings concerning the recognition of the mother's face by neonates and older infants corroborate the view that the system operating in neonates and older infants is not the same (e.g. de Schonen et al., 1986; Pascalis et al., 1995).

In Experiment 5, a preference for the mother's face was observed for 1-month-olds only. These results corroborate previous findings with 1-month-olds (e.g. Sai and Bushnell, 1988).

In contrast with Barrera and Maurer (1981), however, we did not observe a visual preference at 3 months of age. Perhaps, future work using the same methodology as Barrera and Maurer (1981) could produce similar results.

Both 6- and 9-month-olds displayed a null-preference. Like de Haan and Nelson (1997) we evoked methodological reasons and suggested that the visual preference technique is not suitable for measuring recognition at these ages. Perhaps a more engaging and dynamic task would have been more appropriate and produced significant results. For instance, instead of using static images, movement could be introduced in the task. Indeed, to maintain 6- and 9-month-olds' attention long enough to observe a preference, a simple computer programme could be designed which would allow to present the mother's and the stranger's face going up and down on the screen at a regular pace. Thus, as the mother's face would be going up, the stranger's face would be going down, and vice versa.

Furthermore, in keeping with Quinn et al.'s (2002) findings, future studies could investigate whether a preference for the father's face can be observed when presented alongside a stranger's face. If visual experience affects face processing skills in the first months of life, a preference for the father's face might only be observed for infants raised primarily by their fathers.

Part two of this thesis investigated face processing and visual memory abilities in children born prematurely. We could not test newborn premature infants for practical reasons. Unfortunately, because of this, the link with part one of this work was somewhat lost.

Experiment 6 investigated whether school-aged children born prematurely displayed long-term benefits from the extra visual stimulation they received at birth or whether damage from perinatal insults might have caused long-term problems instead. However, no ophthalmic tests were performed. Instead, we hoped to verify the benefits from or damage caused by extra visual stimulation by confirming whether their face processing abilities had been altered in any way compared to their full-term counterparts by looking at the face inversion effect (FIE) and relational visual memory.

Experiment 6 also looked at possible damage to the limbic system caused by premature birth. We hoped to achieve this by verifying whether premature and full-term children would present similar abilities in a facial expression labelling task.

Three tasks were thus developed: the facial expression labelling test, the face recognition test and the relational memory test.

The tests were first used with the youngest children of our sample. Unfortunately, for this reason we did not realise until we started testing older children that the relational memory test was not suitable for them as the difficulty level was too low. The test was thus used with all ages even though we suspected that no differences would be observed between the two groups.

Results of Experiment 6 indicated that, in this particular population, experience had prevailed over potential problems caused by premature birth. However, the premature children we tested were a particularly healthy group with no severe deficits caused by premature birth. For instance, despite the fact that premature birth is associated with low birth weight which, in turn, has been linked to anomalies in visual functioning (Caputo et al., 1981), only one premature child wore glasses. Therefore, results should be interpreted with care and no general conclusions should be drawn with regard to the long-term development of premature infants.

Future work could include a comparative study with younger children to support the view that premature birth is associated with visual, motor and intellectual deficits (Caputo et al., 1981; Perlman, 1998) which can cause later problems.

Furthermore, including a greater number of children with more severe conditions surrounding birth may also give a more accurate description of premature infants' long-term development.

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