EXPERIENTIAL INFLUENCES ON THE DEVELOPMENT OF FACE PERCEPTION

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This thesis examined the role of experience in the development of face perception. In Experiments 1-4, I examined the role of experience in the development of the perception of attractiveness by testing whether facial features that influence adults' ratings similarly influence babies too young to have been affected by cultural conditioning. In Experiment 1, adults rated faces with larger eyes as more attractive than faces with smaller eyes, and 5-month-olds looked longer at faces with larger eyes. In Experiments 2-4, adults rated faces with features at a medium or low height (large forehead, small chin) as more attractive than faces with high features (small forehead, large chin), whereas 5-month-olds looked equally long at those faces. In Experiment 5, there was no effect of the features' height in 3-year-olds, except those with more exposure to peers, who rated low features as more pretty than high features. The results suggest that the adult preference for larger eyes begins during infancy but that preferences for features at an average or low height emerge later, only after additional experience with faces and/or cultural learning.

To see whether early visual experience is critical for the development of adult skills in face processing, in Experiments 6 and 7 I compared normal adults and children to patients deprived of visual input during early infancy because of bilateral congenital cataracts. Patients performed abnormally in tasks requiring matching facial identity, holistic processing, and the differentiation of faces based on local and configural processing. Patients performed normally in tasks requiring the processing of large, local features under longer exposures: lip reading, matching facial expression and gaze direction. They were also normal on a task requiring efficient configural processing of shapes. Results from the normal groups indicate that skills in face processing are not fully developed by age 6, but are adultlike at 10 years. Combined, the results suggest that early exposure to faces sets up the cortical circuits that become specialized for face processing, and that those circuits are shaped by years of experience differentiating among faces.

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I express my gratitude to family and friends—all who gave love and encouragement over many years, especially during the most challenging times. I dedicate the thesis to my mother

perchè questo non sarebbe stato possibile senza di te.

Table of Contents

Table of Contents Continued

List of Figures

List of Tables

Table Page

CHAPTER 1

INTRODUCTION

Human adults' perception of human faces encompasses a wide variety of skills that occur in day-to-day living and that are fundamental to social interaction. Adults recognize people's faces and various aspects of faces guide their interactions—for example, faces' attractiveness, direction of gaze, and expression of emotion. Adults use two strategies to efficiently and accurately identify people and their signals: in local processing, adults parse and analyse individual facial features (e.g., shape of the eyes, mouth, or chin); in configural processing, adults analyse the spatial relationships among the features, including the spacing between the feature(s) and the faces' outer contour (e.g., spacing between the eyes, spacing between the mouth and the chin). Although adults can use either strategy for a given task, configural processing is more useful than local processing when people are viewed from afar and their facial details are difficult to resolve, or when they pass by or turn away quickly and there is little time to analyse the features individually.

A wealth of research has centered on human adults' capabilities in face processing and the mechanisms underlying them. Adults are considered "experts" in face processing because they can easily recognize thousands of individual faces, even when the faces belong to people who have not been seen for many years or when they belong to unfamiliar people to whom adults have had only brief exposure (Bahrick, Bahrick, & Wittlinger, 1975). Furthermore, adults can recognize faces on the basis of local characteristics and/or configural cues even under conditions in which the faces are highly similar in their features and in the spacing of those features (see Sergent, 1984 for a review). They can also easily recognize many facial signals, such as emotional expression and direction of gaze, and they can decode a person's speech just by reading his/her lips (see Bruce & Young, 1986, for a review). Neurophysiological studies in normal adults and comparisons between normal adults and adult patients with brain damage have shown that specific regions of the temporal cortex in the right hemisphere are important for some aspects of face processing (e.g., de Renzi, 1986; Sergent, Ohta, & Macdonald, 1992), and have led to theories that adult face processing engages distinct cortical systems (Bruce & Young, 1986).

A separate group of studies has examined adults' perception of the attractiveness of faces. Adults share similar opinions regarding which photographs of faces in a set are more attractive (e.g., Bernstein, Lin, & McClellan, 1982; Maret & Harling, 1985), and their judgments of attractiveness are affected similarly by variations in facial characteristics such as the size of the internal features (e.g., Cunningham et al., 1995; McArthur & Apatow, 1983-1984) and their position (e.g., Grammer & Thornhill, 1994; Langlois & Roggman, 1990). For example, adults judge as more attractive faces containing larger eyes and faces with a larger forehead. Adults also rate as more attractive faces containing a constellation of features that resemble infants' faces (e.g., larger eyes, larger forehead, smaller nose), faces with features of average size that are positioned in average locations, and faces that are bilaterally symmetrical. The similarity in the effects of facial morphology on perceptions of beauty for adults from diverse cultural regions (e.g., McArthur & Berry, 1987) has led to theories of a biological/evolutionary basis for human aesthetic preferences (e.g., Grammer & Thornhill, 1994; Jones, 1995; Thornhill & Gangestad, 1999).

While much of our knowledge of human face perception comes from studies of adults, there has been growing interest in exploring the developmental course of face perception. Developmental research allows an analysis of the relationship between brain processes and face perception by comparing the capabilities of children with immature brains to those of adults with more sophisticated neural systems. It also allows an examination of the role of experience in the normal development of face perception. One body of research has examined face perception from early childhood through to middle childhood, a period during which many face processing skills improve steadily until reaching adult levels (see Chung & Thomson, 1995, for a review). For example, while young children are proficient in recognizing famous people's faces, it is not until about 10 years of age that they typically show adultlike expertise in recognizing unfamiliar faces to which they were briefly exposed (e.g., Carey & Diamond, 1980; Flin, 1980). Improvements in face recognition during middle childhood may reflect an improved ability to ignore local cues and to encode faces on the basis of the spatial relationships among the features (e.g., Carey & Diamond, 1994; Diamond & Carey, 1977), and according to some authors (Carey, 1996), may depend on many years of experience differentiating among human faces.

A larger body of research has examined face perception during infancy, a period during which many changes in the brain occur and during which many face-processing capabilities emerge (reviewed in Johnson, 1990; Maurer, 1985). Babies only a few days old perceive some aspects of faces: newborns look longer at face-like patterns than some non-face objects (e.g., Mondloch et al., 1999); they recognize their mothers, or at least recognize their external features (e.g., hair colour or shape) (e.g., Bushnell, Sai, & Mullin, 1989); and, they look longer at faces rated as attractive by adults than at faces rated as unattractive (Slater et al., 1998). Such early capabilities in face perception can be assumed not to depend on cultural conditioning because newborns have had no cultural input. While early skills might be related to babies' memory for faces to which they have been exposed (Bushnell et al., 1989; Pascalis et al., 1995), they probably depend minimally on the cortex because anatomical and behavioural evidence indicates that the cortex exerts little control over the young infants' visual behaviours for the first few weeks of life (Atkinson et al., 1988; Bronson, 1974; Maurer & Lewis, 1979). According to Johnson and Morton (1991), face processing capabilities present during the first weeks of life are controlled by a primitive, subcortical mechanism, which they term *Conspec,* that functions to direct young infants' attention to the faces of their conspecifics. The authors also argue that a primitive memory mechanism that stores specific views of faces mediates the young infants' recognition of their mothers (i.e., the hairdo).

Beginning at three to four months of age, babies exhibit many more skills in face processing: they recognize individual faces based on the internal features alone (e.g., de Schonen & Mathivet, 1990); they recognize a face posing with different head orientations, even after a 24-hour delay (e.g., Pascalis, Matheny, de Schonen, & Nelson, 1994); and they differentiate some facial expressions (e.g., Barrera & Maurer, 1981) and directions of gaze (e.g., Vecera & Johnson, 1995). By three months of age, babies can form a mental prototype of a face and will treat it as more familiar than the individual faces from which it was formed, as do adults (e.g., de Haan, Johnson, Maurer, & Perrett, submitted). By four months, the right hemisphere appears to be specialized for configural processing, as it is in adults: 4- to 9-month-old infants distinguish between faces varying in the spatial relationships among their internal features (i.e., with eyes of different size or orientation) more efficiently in the left visual field (which is transmitted first to the right hemisphere), whereas they distinguish between faces on the basis of an individual feature (i.e., eye shape) more efficiently in the right visual field (i.e., left hemisphere) (Deruelle & de Schonen, 1998).

Recent theories by Johnson and Morton (1991; Morton & Johnson, 1991) and by de Schonen and her colleagues (de Schonen, Deruelle, Mancini, & Pascalis, 1993; de Schonen & Mathivet, 1989) suggest that the skills in face processing that emerge at about three to four months of age, and their subsequent development into the adult specialization for face processing, depend on young infants' early experiences with faces. Johnson and Morton (1991) propose that the Conspec mechanism causes a newborn to orient toward face-like patterns, and hence, to expose an emerging cortical mechanism to many examples of faces. From this experience with faces, the learning mechanism, which the authors term Conlern, causes the cortical changes that enable the infant to encode and differentiate between faces in terms of their identity, direction of gaze, and emotional expression.

de Schonen and Mathivet (1989) argue that newborns' visual constraints limit the information available to the developing cortical mechanism and lead it to become specialized for configural processing. Specifically, because young infants have poor visual acuity and contrast sensitivity that limit their perception to large elements of high contrast (e.g., Banks & Salapatek, 1981; Mayer et al., 1995), de Schonen (de Schonen et al., 1993; de Schonen & Mathivet, 1989) argues that the emerging cortical mechanism is influenced more by the larger features in faces and the spacing between them than by the small, facial details. Such biased input may cause the cortical mechanism to become specialized for encoding and differentiating between faces on the basis of the spatial relationships among large features.

In this dissertation, I examined the perception of faces in humans spanning the years from early infancy to adulthood to gain insight about the influence of early visual experience on the subsequent specialization for face processing. One set of questions centered on whether visual input from birth is critical for the normal development of face processing: does the development of face processing proceed normally despite visual deprivation during early infancy and delayed visual experience? Are different aspects of adult face processing shaped similarly by visual input during the first weeks of life or are some aspects not influenced by experience? A second set of questions centered on the role of experience in the development of adult aesthetic preferences. More specifically, does visual experience with faces during infancy and childhood shape adult aesthetic preferences? Does development of some aspects of adult aesthetic preferences begin only after infancy and/or childhood, only after significant experience with faces and/or extensive cultural and social learning? To address these issues, I studied experiential influences on the development of face perception *indirectly* in two ways.

In the first part of the thesis, I examined the role of experience in the development of the perception of faces' attractiveness. I did so by examining young babies' behavioural preferences for faces in which I had manipulated the internal features, and then comparing babies' behavioural preferences to the aesthetic preferences of adults. The purpose of my research was to explore the facial characteristic(s) that influence infants too young to have been affected by cultural conditioning or extensive experience with faces, and to assess whether such characteristics influence adults similarly. If babies and adults respond similarly to the variations in individual facial characteristics, the findings would suggest that those characteristics contribute to the development of aesthetic preferences before extensive cultural learning. If instead the facial characteristics begin to have an adultlike influence sometime after early infancy, the findings would suggest a role for more extensive cultural input, social learning, and/or additional experience with human faces. As an extension to this research, I also measured young children's aesthetic preferences. The study of children followed from the main findings that manipulations of one facial characteristic did not influence the reactions of adults and babies in a similar way. By testing children, I traced the period in development when the variable begins to exert its adultlike influence, and hence, gained insight about the influence of experience/social norms on the development of the perception of beauty.

In the second part of the thesis, I examined the role of early visual experience in the development of adult face-processing capabilities. I did so by comparing face processing skills in normal children and adults with a history of normal visual experience to those of patients treated for bilateral congenital cataracts that had deprived them of patterned visual input during infancy. The patients, aged 10 to 38 years, had been treated for a dense and central opacity in the lens of both eyes that prevented patterned stimulation from reaching the retina. They were treated by surgical removal of the natural lens and fitting of the eye with an optical correction that gave them nearly normal visual input (see Maurer, Lewis, & Brent, 1989). The cohort I tested was treated after visual deprivation from birth lasting anywhere from two months to two years of age, and so it provided an opportunity to examine the development of face processing in the absence of visual experience during early infancy. Because the patients had been deprived of all patterned visual input, and not just of faces, it was an indirect test of recent theories (Johnson & Morton, 1991; de Schonen & Mathivet, 1989) that the development of face processing depends on young infants' experiences with faces. By the time of my testing, patients had had 10 to 37 years of delayed visual input following treatment. The purpose of my research was to explore whether face processing skills that emerge during infancy and later become perfected depend on visual experience during the first few months of life or whether they can be learned from delayed experience. If patients with a history of early visual deprivation performed abnormally, the findings would suggest that the development of those capabilities depends on early visual input. If not, the findings would suggest that such face processing skills can develop normally despite early visual deprivation. As an extension to this research, I included a test of the processing of geometric shapes. The results allowed me to make inferences about whether early visual experience is necessary for the normal development of object processing skills in general or whether it plays a special role in the development of human face processing.

In Chapter 2, I present the research aimed at understanding experiential influences on the development of the perception of attractiveness. Specifically, I examined adults' ratings of attractiveness and 5-month-old infants' looking times and/or facial expressions to faces that had been manipulated with respect to the size of their eyes or the height of their internal features. These variables were chosen for manipulation because each on their own had been previously shown to influence adults' aesthetic judgments (e.g., Cunningham, 1986; McArthur & Apatow, 1983-1984) and because there was reason to believe that young infants might be sensitive to the same manipulations. Five-month-olds were tested because they are known to have a functioning visual cortex (e.g., Atkinson et al., 1988; see also Johnson, 1990 for a review) and to be sensitive to changes in faces' eyes, nose and mouth (Caron, Caron, Caldwell, & Weiss, 1973). Although by five months of age infants have been exposed to a number of human faces, some of which they have learned to recognize (Bushnell et al., 1989; Pascalis et al., 1995), they have had minimal exposure to cultural standards of beauty, and so they afford an opportunity to examine the effect of variations of the facial features before extensive cultural input.

The approach I used to examine experiential influences on the development of aesthetic preferences built on previous studies showing that young infants look longer at natural photographs of faces rated as attractive by adults than at faces rated as unattractive (Langlois et al., 1987; Samuels & Ewy, 1985). Since my research began, one study has found this to be true even in infants just a few days old (Slater et al., 1998). Visual preferences for attractive faces during early infancy may be the basis for the later development of the perception of beauty. Hence, adults' perceptions of beauty may not depend solely on cultural learning or significant experience with faces. That interpretation is supported by cross-cultural studies showing that adults of different races residing in diverse cultural regions share similar opinions on which faces in a set are more attractive (e.g., Bernstein et al., 1982; Cunningham et al., 1995). My research adds to the current literature by exploring whether particular characteristics of faces that contribute to adult aesthetic preferences are rooted in visual preferences during early infancy, prior to extensive cultural input.

Since my research began, Langlois and her colleagues (Rubenstein, Kalakanis, & Langlois, 1999) used a similar approach to document that facial averageness has similar effects in infants and adults. They took photographs of individual Caucasian faces, and then created the average of the individual faces. When each individual face was paired with the averaged composite, Caucasian 6-month-olds looked longer at the averaged face, and Caucasian adults rated it as more attractive. The findings suggest that facial averageness contributes to the development of aesthetic preferences, perhaps because from early infancy we form mental prototypes of faces and then respond to faces that are similar to the prototype as familiar and appealing (Langlois & Roggman, 1990). In the research reported in Chapter 2, I assessed whether other known influences on adult aesthetic preferences—eye size and the height of the faces' internal features—are rooted in early visual preferences.

In Chapter 2, I also examined 3-year-olds' ratings of the "prettiness" of faces varying in the height of their internal features because adults and 5-month-olds had reacted differently to that manipulation and I hoped to track the beginning of the adultlike influence of the features' height. This is the first study to examine the effect of manipulating one aspect of faces on the perception of beauty in young children. In addition, by examining the aesthetic ratings in groups of 3-year-olds classified as being "more exposed" or "less exposed" to similar-aged peers, it is the first to explore whether children's aesthetic preferences are related to the amount of exposure they have to peers' faces, and hence, whether this type of experience during childhood contributes to adults' perception of facial beauty.

In the research reported in Chapter 3, I examined the role of early visual experience in the development of face processing by studying patients with a history of visual deprivation during early infancy and normal groups of 6-year-olds, 10-year-olds and adults. To do so, I created two batteries of tasks designed to measure different skills in face processing. One battery required participants to match faces based on: (1) identity despite changes in facial expression; (2) identity despite changes in head orientation; (3) facial expression despite changes in identity; (4) speech sound (lip reading) despite changes in identity; and, (5) direction of gaze despite changes in head orientation and identity. This battery was adapted from one that distinguished children with congenital brain damage from age-matched controls (Mancini, de Schonen, Deruelle, & Massoulier, 1994). Deficits were related to the site and hemisphere of damage, as would be expected from evidence that different components of face processing are controlled by separate cortical systems (e.g., Bruce & Young, 1986). The tasks in this battery also tested the types of skills that Johnson and Morton (1991) and de Schonen and Mathivet (1989) have suggested develop as a consequence of visual experience with faces during the first weeks of life. The primary goal was to evaluate whether face processing skills are affected adversely by visual deprivation during early infancy, as would be predicted by these theories. A second goal was to examine whether distinct aspects of face processing are differentially affected by early visual deprivation, just as they are differentially affected by early brain damage.

The second battery of tasks was designed to examine the effect of early visual deprivation on the development of the specialized strategies underlying face perception. Specifically, I tested patients' capabilities to match faces primarily on the basis of an individual feature (local processing) or on the basis of the spatial relationships among the internal features (configural processing). I also tested the ability to perceive human faces holistically—a strategy that causes normal adults to perceive a facial Gestalt or "whole", and that can interfere with local processing. For comparison, I also measured capabilities to match geometric figures on the basis of small, individual elements, the spatial relationships among those elements, and on the basis of their overall shape (Gestalt). These tasks were adapted from ones used in studies of normal and brain-damaged adults and children (e.g., Delis, Robertson, & Efron, 1986; Hole, 1994) and in studies of hemispheric specialization in normal infants (Deruelle & de Schonen, 1995; 1998). Previous findings suggest that cortical regions located in the right hemisphere are specialized for configural processing of visual patterns and that cortical regions in the left hemisphere are specialized for local processing. Although I did not study lateralization directly, my study evaluated whether configural processing is particularly affected by early visual deprivation, as predicted by de Schonen and Mathivet (1989). Holistic processing of visual patterns is an additional strategy that appears to involve cortical mechanisms in the right hemisphere (e.g., Allison et al., 1994; Kanwisher, McDermott, & Chun, 1997), and so I examined whether it too is affected by early visual deprivation.

This is the first study of the effects of early visual deprivation on higher levels of visual processing. Previous studies of sensory processing in children treated for bilateral congenital cataracts have revealed deficits in sensory visual abilities that are immature at birth (e.g., contrast sensitivity, visual acuity, peripheral vision) but not in visual abilities that are relatively mature at birth (e.g., the discrimination of colour and large shapes) (e.g., Maurer et al., 1989). In addition, for some visual functions, deficits are worse following longer than shorter periods of early deprivation. These findings suggest an important role for early visual experience in the development of sensory vision, and are complemented by studies of cats and monkeys showing an adverse effect of early visual deprivation by eyelid suture on the development of sensory visual functions that are immature at birth and that develop over many months, including visual acuity, contrast sensitivity, and peripheral vision (e.g., Boothe, 1981; Mitchell & Murphy, 1984). My study addresses whether the higher-level function of face perception, which is immature at birth and which develops postnatally, is also adversely affected by early visual deprivation.

Organization of Thesis

Chapter 2 describes my research on the perception of faces' attractiveness. The chapter begins with a review of the literature suggesting that adults' perception of beauty does not depend entirely on cultural influences—because there are similarities in aesthetic judgments in adults from diverse cultures and because there are similarities in adults' and young infants' preferences for faces. In Section 2, I review research showing an effect of faces' eye size on adults' aesthetic judgments and research showing infants' early sensitivity to faces' internal features, including the size of the eyes. I then describe Experiment 1 in which I investigated the influence of eye size on adults' aesthetic ratings of faces and 5-month-olds' looking times. In Section 3, I review the literature on adults' perception of the attractiveness of faces varying in the height of their internal features and a separate literature on infants' sensitivity to faces varying in the positioning of the internal features. I then report Experiments 2 and 3 in which I investigated the effects of the height of faces' internal features on adults' aesthetic ratings and 5-month-olds' looking times. To determine whether infants' preferences were indexed similarly by their looking times and their facial expressions, in Experiment 4 I included measurements of infants' facial expressions to faces varying in the features' height. Because the results of Experiments 2 to 4 showed differences between adults and infants, and so as to explore when the features' height begins to exert an adultlike influence on reactions to faces, in Section 4, I describe Experiment 5 in which I examined the effect of the height of the features on 3-year-olds' ratings of prettiness. The final section draws conclusions about the influences on adult aesthetic preferences that are present during infancy and the contribution of postnatal cultural influences, social learning, and visual experience with faces.

In Chapter 3, I examine the role of early visual experience in the development of face processing by studying face-processing capabilities in patients who were deprived of visual experience during the first few months of life because of bilateral congenital cataracts. The chapter begins with a review of the literature on face processing during infancy, childhood and adulthood, and recent theories that have emphasized an important role for early visual experience in their development. In Section 2, I begin by describing the characteristics of the patient sample and normal participants, the testing sites, and the general apparatus used for the study. I then describe the tasks used in Experiment 6 to measure various components of face processing—the ability to perceive facial identity, facial expression, and direction of gaze, and the ability to read lips. In Experiment 7, I begin by reviewing studies showing that adults use two strategies to efficiently recognize faces—local and configural processing—that are controlled by independent cortical systems. I also review the evidence that adults use holistic processing of faces to the detriment of local processing. I then describe the tasks designed to measure the ability to identify faces using local cues (the shape of an individual feature), configural cues (the spacing between the internal features), and holistic cues. In Experiment 7 I also review evidence that adults use similar strategies to process geometric figures, and I describe the tasks designed to measure those strategies. In the discussion, I summarize the findings of Experiments 6 and 7 and draw conclusions about the role of visual experience during early infancy in shaping the development of adult face processing. Moreover, I consider whether early visual input has a special influence on the development of face processing or whether it is necessary for the development of all object processing. The last section of Chapter 3 also considers whether the pattern of results for patients might be influenced by something other than, or in addition to, their early visual deprivation.

In Chapter 4, I summarize and integrate the findings of my studies, and draw conclusions about experiential influences on the development of face perception. I also suggest possible directions for future research.

CHAPTER 2

EXPERIENTIAL INFLUENCES ON THE DEVELOPMENT OF THE PERCEPTION OF FACES' ATTRACTIVENESS

In Chapter 2, I describe the experiments that compared 5-month-olds' looking times and adults' aesthetic ratings as they viewed faces varying in the size of their eyes (Experiment 1) and the height of their internal features (Experiments 2 to 4) to see if these facial characteristics affect babies and adults in the same direction. If so, the findings would suggest that their influence on adults' perception of beauty does not originate from cultural input. Based on the finding that the height of the internal features influenced adults and babies differently, I also examined 3-year-olds' judgments of the prettiness of faces varying in the features' height (Experiment 5) in order to trace the age at which the adultlike influence of the height of the features emerges. The chapter begins with a review of the literature on adults' judgments of faces' beauty and infants' looking times to "attractive" faces. It closes with a discussion of my findings with adults, infants, and children as they relate to the hypothesis that some aspects of adult aesthetic preferences develop from preferences that were present before extensive cultural conditioning or social learning.

2.1. BACKGROUND LITERATURE

One type of evidence that suggests that adults' perceptions of beauty are affected by factors in addition to cultural input comes from studies that have compared the perception of faces' attractiveness in adults and children from different races and cultures. When shown pictures of faces, adults and children of different races show similarities in their aesthetic judgments: White- and Black-American adults rate similarly the attractiveness of faces depicting White and Black individuals (Bernstein et al., 1982), and 6- and 10-year-old Caucasian-, Black-, and Mexican-American children rate similarly the attractiveness of faces representing children of their own and different ethnic groups (Langlois & Stephan, 1977). However, the participants in these studies were residents of the U.S., and consequently, had been exposed to American standards of beauty. As a result, any similarities in aesthetic judgments across raters of different race might have been guided by exposure to the same cultural norms.

Stronger support for the notion that human aesthetic preferences are influenced by factors in addition to culture comes from studies showing similarities in aesthetic judgments among adults residing in diverse cultural regions. Oriental adults living in Japan or Korea and Caucasian adults living in the U.S. agree on which faces in a set are more attractive (Bernstein et al., 1982; Maret & Harling, 1985). They also agree about the characteristics of faces that make them more attractive, including having larger eyes (Cunningham et al., 1995; Perrett, May, & Yoshikawa, 1994), a larger forehead and a smaller chin (McArthur & Berry, 1987), or having a constellation of internal features that make the face appear juvenile or "babyish"—larger eyes, a larger forehead and a smaller nose (McArthur & Berry, 1987). Based on Darwin's (1871) sexual selection theory, several authors (Buss, 1994; Johnston & Franklin, 1993; Jones, 1995; Symons, 1979) have suggested that adults' aesthetic preferences for features representing babyishness evolved because they maximized reproductive success. The typical size and placement of the internal features in young adults' faces are more similar to those in babies than in elderly adults (Enlow, 1982). Thus, women who possess babyish faces are more likely to be young and fertile compared to older women with less babyish features. Over evolutionary history, men who were attracted to, and mated with, women with more babyish features would have maximized their fitness compared to men who did not respond to such features.

Adults from different cultures also agree that "average-looking" faces are attractive (Grammer & Thornhill, 1994; Langlois & Roggman, 1990; Perrett et al., 1994; Rhodes & Tremewan, 1996; Thornhill & Gangestad, 1993). In those studies, an averaged composite of a face was produced by computer digitizing the luminance levels in each part of individual faces, and then averaging the values across a series of faces. As more and more faces were averaged together, the size and shape of each feature approached mean values and the feature moved toward an average position (see Langlois & Roggman, 1990 and Langlois, Roggman, & Musselman, 1994). Both Caucasian adults and Japanese adults rate averaged faces made from Caucasian or Japanese faces as more attractive than most of the individual faces that make up the composite. On the basis of concept learning theory (Rosch, 1978), Langlois and Roggman (1990; see also Langlois et al., 1994) suggest that after exposure to many faces in their environment, adults form a mental prototype of a face and respond to faces that resemble the prototype, such as an averaged face, as though they were familiar and appealing. The appeal of an averaged face of a different race presumably arises because it is more similar to the prototype than faces of that race that deviate from its average.

An averaged composite of a face is more bilaterally symmetrical than the individual faces making up the composite, and that variable also influences adults' aesthetic judgments of faces (Grammer & Thornhill, 1994; Thornhill & Gangestad, 1993; Zebrowitz et al., 1996; but see Langlois et al., 1994). Based on previous findings that parasitic infection causes body asymmetry (e.g., Møller, 1990; Polak, 1993), and that asymmetry is correlated with low rates of reproduction in males (e.g., Thornhill, 1992; Thornhill & Gangestad, 1994), Thornhill and his colleagues (e.g., Grammer & Thornhill, 1994; Thornhill & Gangestad, 1993) suggest that human aesthetic preferences for faces containing average and/or symmetrical features evolved because they enhanced reproductive success. Individuals who possess body features that are close to average and/or perfect symmetry are likely to have good immune systems that allowed them to resist pathogenic attack that would have altered their morphology during development (Watson & Thornhill, 1994), and their good genes would be passed on to future generations. Over evolutionary history, individuals would have maximized their reproductive success by being attracted to, and choosing, mates with such average and/or symmetrical features compared to individuals who did not respond to these features that signal good gene quality.

A different type of evidence that suggests that adults' perceptions of faces' attractiveness are influenced by factors in addition to culture comes from studies of the perception of "attractive" and "unattractive" faces in babies too young to have been affected by cultural influences. In these studies, the baby is shown two faces at a time, and where the baby looks is determined by judging which of the two stimuli falls over the center of the pupil (Kessen, Haith, & Salapatek, 1970). When the baby fixates one face more than the other, he/she demonstrates discrimination and preference (see Fantz, 1964 and Fantz, Fagan, & Miranda, 1975). When tested with this spontaneous visual preference technique, infants look longer at a face previously rated as attractive by adults than at a face rated as unattractive (Langlois, Ritter, Roggman, & Vaughn, 1991; Langlois et al., 1987; Samuels et al., 1994; Samuels & Ewy, 1985; Slater et al., 1998).

In the first study to report the phenomenon, Samuels and Ewy (1985) showed 3- and 6-month-olds pairs of black-and-white photographs of Caucasian male and female faces that were matched on sex, hair colour, hairstyle, and facial expression, but which differed in attractiveness, as previously rated by adult judges. Babies at both ages looked longer at the attractive faces than at the unattractive faces. This effect has been replicated in studies by Langlois and her colleagues, who tested 3- and 8-month-olds with colour photographs of Caucasian men and women, African-American women, and babies (Langlois et al., 1987; Langlois et al., 1991). More recently it has also been shown in babies only a few days old, who were tested with colour photographs of Caucasian women (Slater et al., 1998). Taken together, the findings suggest that there is a visual preference present early in life that may contribute to the development of adults' perception of beauty.

Other studies have examined whether facial characteristics that have been known to influence adult aesthetic preferences also influence infants' visual preferences. Adults rate photographs of faces whose internal features are more symmetrical about a vertical axis as more attractive than faces with less symmetrical features (e.g., Grammer & Thornhill, 1994; Thornhill & Gangestad, 1993), but symmetry does not influence infants' looking preferences: 4- to 9-month-olds looked equally long at photographs of faces manipulated so that they contained perfectly symmetrical features and at natural versions of the same faces with nonsymmetrical features (Samuels et al., 1994). In contrast, facial averageness does influence adults and 6-month-old babies in the same way. Rubenstein, Kalakanis and Langlois (1999) took photographs of individual Caucasian faces, and then created a composite that was the average of the group of faces. When each individual face was paired with the averaged composite, Caucasian 6-month-olds looked longer at the averaged face, and Caucasian adults rated it as more attractive. In another test, the 6-month-olds treated the averaged facial composite as more familiar than the actual faces they had just seen. From these findings, Langlois and her colleagues suggest that young babies, like adults, extract a mental prototype from the faces to which they are exposed, and then respond to faces that resemble the prototype, such as an averaged composite, as though it were familiar and attractive (also see Langlois & Roggman, 1990). Although facial averageness is influential by six months of age, it is not likely to contribute to newborns' visual preferences for attractive faces (Slater et al., 1998) because the ability to extract face prototypes appears to develop between one and three months of age (de Haan et al., submitted). Taken together, the findings suggest that even late in infancy, facial symmetry is not a determinant of faces' attractiveness, but by six months of age—and almost certainly not at birth—facial averageness has become an influence on the development of the perception of beauty.

The purpose of my research was to explore other facial characteristics that influence adults' judgments of beauty and to examine the development of each influence to see whether it is present before extensive cultural conditioning. In the research reported in this chapter, I manipulated one aspect of faces—the size of the eyes or the height of the faces' internal features—and then examined the effect of the manipulation on adults' ratings of attractiveness and 5-month-olds' looking times and/or facial expressions.

The characteristics of eye size and the height of the internal features were chosen for study primarily because previous studies have shown that each independently influences adults' aesthetic ratings of faces (e.g., McArthur & Berry, 1987), and because the size of a pattern's elements and the position of a face's features influence babies' visual preferences (e.g., Fantz et al., 1975; Maurer, 1985; Maurer & Salapatek, 1976). (See Sections 2.2a and 2.3a in this chapter.) Also, given young infants' poor visual acuity and contrast sensitivity (Banks & Salapatek, 1981; Mayer et al., 1995), I suspected that larger facial features would be more likely to influence babies' reactions than small details. As in previous studies with adults and infants, I tested a large number of subjects in order to have sufficient statistical power to detect a possibly small effect of the manipulation of a single characteristic (see Rubenstein et al., 1999 and McArthur & Apatow, 1983-1984 for comparable sample sizes used in studies of infants and adults, respectively).

Five-month-old infants were tested because they are known to have a functioning visual cortex (e.g., Atkinson et al., 1988; see also Johnson, 1990, for a review) and to be sensitive to changes in the faces' internal features, including the eyes, nose and mouth (Caron et al., 1973). Also, by five months, infants can perceive the similarity between a three-dimensional object and a photographic representation, and between a photograph and a schematic representation (DeLoache, Strauss, & Maynard, 1979). This should make them old enough to demonstrate with the photographs and drawings of faces I used what they are sensitive to in real faces. Although even before five months of age infants have been exposed to a large number of human faces, some of which they have learned to recognize (Bushnell et al., 1989; de Haan et al., submitted; Pascalis et al., 1995; Rubenstein et al., 1999), they have had little exposure to cultural standards of beauty, and so it was possible to examine the effects of eye size and the height of the internal features before extensive cultural and/or social learning.

The methods for measuring looking preferences in infants were similar to those used in previous studies that examined infants' preferences for various stimuli, including "attractive" faces (e.g., Fantz et al., 1975; Langlois et al., 1987; Slater, Rose, & Morison, 1984). Typically the baby is shown two stimuli side-by-side on a projection screen and observers record how long the baby looks at each stimulus using the corneal reflection technique (Kessen et al., 1970). While most previous studies have used a fixed presentation time (e.g., 10 seconds) (e.g., Langlois et al., 1987), in my studies, each trial began when the baby first fixated one of the faces, as judged by one of two observers, and continued until each observer had independently measured 10 seconds of looking at the faces (Slater et al., 1984). This method may be more sensitive for measuring visual preferences than using trials of fixed duration because infants are given more opportunity to compare and choose between the faces, and because it gives equal weighting in the analysis to infants with long and short looking times (Humphrey & Humphrey, 1989).

Because many young infants have a side bias—a tendency to look at one side of the visual field longer than the other side regardless of the stimuli present, I used procedures similar to those used in previous studies to control for its effect on looking times (e.g., Langlois et al., 1987). Each pair of faces was shown first in one random left-to-right position and, following a non-facial stimulus, in the reversed position. So that babies with excessive side bias would not mask visual preferences, the data from infants who looked at the same side across trials more than 80 percent of the time were excluded and replaced. In addition, a looking preference for each face was calculated based on the average of the two trials with the left-to-right reversal. However, analyses were also based on the first presentation of each pair of faces in order to examine babies' first impressions of the faces, as was done with adults, and to determine whether the first trial with each pair of faces is more sensitive for picking up babies' visual preferences.

In one other study of infants' visual preferences (see Section 2.3, Experiment 4), I showed a single face in the center of the projection screen during each trial and measured looking times using an infant-controlled procedure that times the duration of the infant's first fixation (Horowitz, Paden, Bhana, & Self, 1972). The trials began when two observers judged that the baby fixated the face, and they did not end until both observers judged that the baby had looked away. Using one face per trial avoided the problem of side bias on looking times, and it allowed me to examine infants' looking under conditions that resemble more closely those that occur during real interactions. It also allowed measurements of both babies' looking time and facial expressions while viewing each of the faces. In some procedures, infants have been found to vary their facial expression, but not their looking time, during variations in face-to-face interaction with adults (Hains & Muir, 1996; Langlois, Roggman, & Rieser-Danner, 1990).

In each experiment, facial stimuli were presented in the same way for adults and infants so that the conditions for obtaining their preferences would be as similar as possible. In the sequential procedure, adults rated the faces one at a time using a unidimensional 5-point Likert scale of attractiveness (from very unattractive to very attractive). This procedure, which has been used to test perceptions of attractiveness in adults (e.g., Langlois et al., 1987), is probably closest to how adults would judge the attractiveness of a particular face in the real world. In the paired-choice format, adults rated the relative attractiveness of two faces on a bipolar 5-point scale (face on left much more attractive; face on right much more attractive). Although less natural, the paired format may force adults to make more discriminating aesthetic judgments.

2.2 THE EFFECTS OF THE FACES' EYE SIZE ON ADULTS' AESTHETIC RATINGS AND 5-MONTH-OLDS' LOOKING TIMES

A. Background & Purpose

Adults rate drawings or photographs of faces with larger eyes as more attractive than faces with smaller eyes, and this is true across faces of different age (i.e., infants, adults), sex, and race (Horvath, Szmigelsky, & Fenton, 1987; Keating, 1985; McArthur & Apatow, 1983-1984; McArthur & Berry, 1987; Sternglanz, Gray, & Murakimi, 1977). Adults also rate infants' faces and adult females' faces with a constellation of features labelled as "babyish", including larger eyes, along with a larger forehead, smaller chin, and smaller nose, as more attractive than faces with less babyish features (Berry & McArthur, 1985; Cunningham, 1986; Hildebrandt & Fitzgerald, 1979; Keating, 1985; Maier, Holmes, Slaymaker, & Reich, 1984; McArthur & Apatow, 1983-1984; McArthur & Berry, 1987; Sternglanz et al., 1977). In addition, they rate adult females' faces containing a constellation of "expressive" features, including larger pupils, raised eyelids, raised eyebrows and wider mouth, as more attractive than faces with less expressive features (Cunningham, 1986; Cunningham et al., 1995). Adults' aesthetic preferences for faces with larger eyes might be related to more general preferences for babyish faces—in this case for faces with larger eye height and width in relation to a smaller head frame—and for expressive faces—in this case for faces with wider pupils and larger eye height (as occurs with the raised eyelids of expressive faces).

Just as eye size influences adults' perceptions of attractiveness, either on its own or in combination with other variables, it may also influence young babies' visual preferences. Even newborns are sensitive to the size of a pattern's elements (Fantz et al., 1975), and to the amount of visible energy it contains (Banks & Salapatek, 1981; Kleiner & Banks, 1987), a characteristic that varies with element size. Beginning at two months of age, babies often look at the internal features of faces, especially the eyes, and frequently scan between the eyes (Hainline, 1978; Haith, Bergman, & Moore, 1977; Maurer & Salapatek, 1976). By two to three months, they also notice differences in the internal features: they look longer at the mother than at a stranger, even when identical scarves cover the hair (de Schonen, Gil de Diaz, & Mathivet, 1986; de Schonen & Mathivet, 1990; Morton, 1993); they look longer at a novel face than at a face to which they have been habituated, even when both are wearing scarves (Bushnell, 1982); and following habituation to a face, they react to some changes of facial expression (Barrera & Maurer, 1981; Muir & Hains, 1993; Nelson, 1987). They also notice changes in the eyes: they look longer at a schematic face that includes eyes than at one with the eyes deleted (Maurer, 1985), they vocalize more often to faces wearing glasses onto which eyes have been pasted than to faces with the eyes absent (Bloom, 1974; 1975), and they look longer at faces with the eyes open rather than closed (Ames & Barnes, cited in Maurer, 1985). By three to four months, they discriminate between faces with gaze en face versus averted (Hains & Muir, 1996; Hood, Willen, & Driver, 1998; Murray & Trevarthen, 1985; Vecera & Johnson, 1995), and at least by five months, they discriminate between faces differing in the size of their eyes (Deruelle & de Schonen, 1998). Thus, young infants look at the eyes, and notice many changes in them, including their size. These findings led us to ask whether infants' visual preferences for "attractive" faces might be influenced, at least in part, by their preferences for larger eyes.

In an unpublished study, Carney (1995) tested the effect of eye size on both adults' ratings of attractiveness and 5-month-olds' looking times. She created black-and-white drawings of female faces that were identical except for the size of their eyes: one version of each face had its eyes enlarged by three standard deviations from the population mean; the second version had its eyes reduced by three standard deviations. Infants' distributions of looking times were recorded as they viewed pairs of faces consisting of two versions of a face with larger and smaller eyes. The infants did not show any visual preferences: they looked equally long at the two alternatives. In contrast, whether viewing the schematic faces one at a time or in contrasting pairs, adults rated the versions with larger eyes as more attractive.

Although these results did not support the hypothesis that eye size affects babies' visual fixations on faces, the 5-month-olds in Carney's (1995) study may have processed the black-and-white drawings differently from the way they process real faces. One-month-olds scan almost exclusively the external contours of real faces (Haith et al., 1977; Maurer & Salapatek, 1976) but scan more frequently the interior of schematic faces (Maurer, 1983), a finding that suggests that young infants may extract different kinds of information from real and schematic stimuli. While babies by five months of age can perceive the similarity between an object and its photograph, and between images of objects depicted in photographs and drawings (DeLoache et al., 1979), they may have had difficulty perceiving the similarity between faces in the real world and the less realistic drawings. Previous studies reporting a relationship between infants' looking times and adults' aesthetic ratings used more realistic images, either black-and-white (Samuels & Ewy, 1985) or colour photographs of faces (Langlois et al., 1987; Langlois et al., 1991; Samuels et al., 1994). Therefore, I suspected that infants' visual preferences for faces varying in eye size would be more likely to be revealed with more realistic, colour photographs of faces.

B. Experiment 1

The purpose of Experiment 1 was to measure adults' ratings of relative attractiveness and 5-month-olds' distribution of looking times as they viewed pairs of colour photographs consisting of two versions of a face with smaller and larger eyes. As in most previous studies with adults (e.g., Carney, 1995; Cunningham, 1986), I manipulated simultaneously the length and height of all aspects of the eye, including the iris and pupil, and I limited the stimuli to female faces. I varied eye size by two standard deviations from the population mean for faces rather than by three standard deviations as was done previously with black-and-white drawings of faces (Carney, 1995) because of preliminary results that adults found larger manipulations unrealistic and unattractive (See Stimuli).

Method

Subjects

Adults. Adult subjects were 32 (16 male) undergraduate students (M age: 20 years; range: 18 to 27 years) participating for points in a psychology course at McMaster University. Twenty-five adults were Caucasian and seven were Asian.

Infants. Infant subjects were 40 (20 male) full-term 20-to 22-week-olds (M age: 21.5 weeks). Fifty-one infants were recruited from a pool of mothers who had volunteered their babies at birth for later study. The infants had no known abnormalities at birth, a gestational age of 38 to 42 weeks at birth, and a birthweight of at least 2500 grams. All 51 infants were tested, but 11 infants were excluded from the analyses because of low inter-observer reliability (i.e., Pearson correlation between the two observers' measurements of visual fixations < 0.80; n = 6), fussiness (n = 3), procedural error (n = 1), or excessive side bias (n = 1; looking to the same side ≥ 80% of the time).

Stimuli

Photographing faces. I took photographs of the faces of 97 Caucasian females, aged 17 to 29 years. All faces were photographed outside the testing area so that they would not be familiar to adult raters from the university. Models posed with a neutral expression, wore a black cape to cover clothing, and removed paraphernalia from the head region (e.g., glasses, earrings). Flash units, positioned to the left and right of the face, with reflecting umbrellas were used to diffuse the light and minimize shadows. See Appendix 1 for details of the method of photographing faces.

Selecting photographed faces. I selected 15 faces from the pool of 97 photographs for manipulation of eye size based on the following criteria: neutral expression; little or no make-up; no hair covering the face; aged 17 to 23 (M age: 21); and mean attractiveness rating close to average from 30 pilot adults (M rating on a 5-point scale: 3.1; range: 2.8 to 3.3), with minimal variability among the raters (M variance: 0.73; range: 0.49 to 0.93). I chose to manipulate faces with average ratings because I expected that they would yield greater variation in ratings after making the eyes larger and smaller than if I had begun with faces rated at the extreme values of attractiveness. Appendix 2 describes the preliminary experiment in which I collected adults' aesthetic ratings of the 97 natural photographs.

Manipulating eye size. The 15 colour slides were sent to a photography laboratory to be converted into colour-digitized images (256 x 256 pixels) and stored on Photo CD. The graphics images were then downloaded onto a Macintosh LC 475 and viewed on a 15" colour Apple Multiple Scan monitor (Model M2978) using Adobe Photoshop 2.5 software. Photoshop was also used to create two versions of each of 10 faces, one with smaller eyes and another with larger eyes, with the sizes set at two standard standard deviations above and below the population mean. Faces with larger and smaller eyes had ratios of eye width (i.e., distance from inner to outer corner) to face width (i.e., distance between the cheekbones at their widest points) of .27 and .21, and ratios of eye height (i.e., distance from top lid to bottom) to face height (i.e., distance from hairline to chin) of .08 and .05, respectively. Eye width was set at the value for the width of the eye two standard deviations above or below the population mean for adult faces (Farkas, 1981) divided by the width of the face of the population mean. Eye height was set at the value for the height of the eye two standard deviations above or below the mean divided by the face height of the population mean. Changes in eye width and eye height were produced by enlarging or reducing the eyes, a process that also caused proportional changes in the area of the iris and pupil.

The 20 computerized images (i.e., 2 versions of each of 10 faces) were imaged from the computer onto colour slide film using a Digital Palette Film Recorder (Polaroid, Model CI3000) and Imageprint software, and then were sent to a photography laboratory for development into 20 colour slides.

It is interesting to note that I initially altered the eye size in the 15 original photographs to three standard deviations above and below the population mean. Pilot adults who viewed these 30 images (2 versions x 15 faces) found the majority of them to be unattractive, and many of the raters reported that the faces with larger eyes looked unnatural. See Appendix 3 for details of the pilot experiment on adults' ratings of attractiveness of the 30 faces varying in eye size by three standard deviations. A separate group of adults rated the faces for the likelihood that they had been manipulated or tampered with by the experimenter: they judged it highly likely that the faces with larger eyes had been manipulated, and more likely than the faces with smaller eyes. Refer to Appendix 4 for the experiment on adults' ratings of 'tampering with' the 30 faces varying in eye size. To make the faces appear more realistic, I decided to re-manipulate some of the original photographs with eye size varying by only ± 2 standard deviations from the population mean.

Selecting final stimuli. The 20 colour slides were rated for attractiveness by 30 pilot adults who did not participate in the final study. Adults viewed the two versions of the 10 faces sequentially in a random order, and rated their attractiveness using a 5-point scale (1=very unattractive; 5=very attractive). The four faces selected as final stimuli were those from the set of 10 for which changes in eye size most strongly affected adults' aesthetic ratings with minimal variability among the raters. The means for the four faces chosen for the final study were: (1) 3.5 and 2.5; (2) 3.0 and 2.5; (3) 3.1 and 2.3; and (4) 3.2 and 2.4. See Appendix 5 for details of the preliminary experiment on adults' ratings of attractiveness of the 20 faces.

Presenting final stimuli. All faces were shown as slides projected onto a rear-projection screen (64 cm wide x 28 cm high), and in pairings consisting of a face with larger eyes and a second version with smaller eyes. Each face was approximately lifesize (12 cm wide x 16 cm high) and formed an image of 9 x 12 visual degrees when viewed from 75 cm (for adults) and 15 x 20 visual degrees when viewed from 45 cm (for infants). The inner edges of the two faces were 5.5 cm apart (7 visual degrees when viewed from 45 cm). This spacing was the minimum necessary to distinguish reliably a baby's visual fixations on the two faces yet ensure that as the baby viewed the outer edge of one face, at least the nearer edge of the other face would be visible peripherally (Lewis & Maurer, 1992). Figure 1 illustrates the four pairs of colour photographs of faces, reduced in size. For comparison, Figure 2 shows the four pairs of black-and-white drawings of faces varying in eye size used by Carney (1995).

Figure 1.

The four photographs of female faces varying in eye size used in Experiment 1 on the influence of eye size. Faces were presented paired, approximately lifesize, and in colour.

1

2

3

4

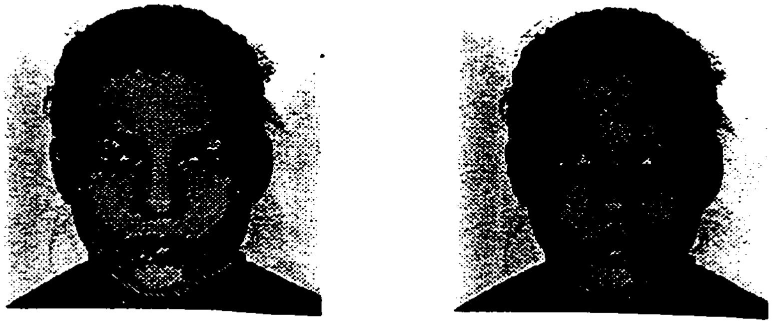


Figure 2.

The four black-and-white drawings of female faces varying in eye size used in the experiment by Carney (1995). Faces were presented paired and approximately lifesize.

To maintain infants' attention to the screen, non-facial stimuli (see Appendix 6) were shown for five seconds after every trial with a pair of faces. The non-facial stimuli contained characteristics that are known to attract babies' looking, such as patterning, curved edges, and high contrast (Fantz et al., 1975), and had been effective in maintaining 5-month-olds' interest in faces in a previous study from our laboratory (i.e., looking times to faces that followed a pattern were longer than to faces that followed another face; Henderson, 1993).

Design

To control for any effects of side bias on infants' looking times, each pair of faces was presented first in one random left-to-right position and, following a non-facial stimulus, in the reversed position. I created eight different random orders, with the constraints that (1) across orders, each of the four face examples appeared equally often in each trial position and (2) within each order, the version of a face with larger eyes appeared first on the left half the time. Each non-facial stimulus occurred in the same positions for all subjects. Thus, each subject received 15 trials (i.e., 4 pairings of faces and 4 left-to-right reversals, separated by 7 patterns).

Apparatus

Babies sat on a platform facing the screen onto which the faces were projected from a Kodak carousel projector. Their view of the room was blocked by a black frame surrounding the screen and black curtains hanging beside them. Small peepholes on each side of the frame allowed two observers to stand behind the screen and watch the infant's eyes. The observers recorded their independent judgments of the infant's fixations via joysticks connected to a Commodore PET (2001 Series) computer. Adult raters used a remote control device to advance the slides.

Procedure

I began by explaining the procedure and obtaining informed consent from the adult participant or infant's parent.

For Adults. Adults were tested individually while standing 75 cm from the screen. Adults filled in a rating sheet on the relative attractiveness of the faces within each pair, using a 5-point scale: Face on left much more attractive (-2); Face on left somewhat more attractive (-1); The faces are equal (0); Face on right somewhat more attractive (+1); Face on right much more attractive (+2). They used a remote control device to advance the projector after each rating. So as to obtain their first impressions of faces, I asked adults not to move backwards through the series. Adults viewed the same sequences as the infants, including the left-right reversals and non-facial stimuli, but they did not rate the non-facial stimuli. When they finished, adults completed a form asking for their age, sex, and race, and were debriefed about the manipulation. Appendix 7 shows one of the rating sheets used by adults to record their relative attractiveness judgments (a), and the demographic questionnaire completed by adults after testing with faces (b).

For Infants. The baby sat in an infant seat positioned so that the infant's eyes were 45 cm from the projection screen. Parents stood out of the infant's sight and were asked to remain quiet during testing. The procedure began with a presentation of a blank slide. Then the baby saw a sequence of one pairing of faces followed by one non-facial pattern until he/she saw all eight pairings of faces. For trials with faces, two observers recorded fixations independently by pressing one of two buttons on the joystick when they judged the baby to look at the face on the left or right side, respectively. Their judgments were based on the reflection of the stimuli over the center of the baby's pupil. Because the observers detected the light reflection from the facial stimulus and could not resolve the faces' details, they were unaware of which side contained the version with larger eyes. A trial began when the baby first fixated one of the faces, as judged by either observer, and continued until each observer had measured 10 seconds of looking time (Slater et al., 1984). After each trial with faces, a non-facial stimulus was shown for five seconds. The intertrial interval was three seconds.

Data Analysis

For Adults. The data for adults consisted of their ratings of relative attractiveness of eight pairings of faces (4 pairs of faces + left-to-right reversals). I included adults' ratings from only the first trial for each of the four pairings and ignored their ratings from the left-to-right reversal. I did so in order to be more likely to capture adults' first impressions of faces and because I suspected that adults' ratings of the left-to-right reversals might be influenced by their desire to be consistent across trials. I had adults view the left-to-right reversals anyway in case they did influence adults and so as to make the procedure the same as that for infants.

Adults' mean ratings of each of the four pairings of faces were subjected to separate one-sample t-tests (two-tailed) to determine whether the rating for each pairing differed from 0, or equal attractiveness for the smaller and larger versions. I used separate t-tests because an ANOVA on adults' ratings of relative attractiveness for the two versions in each of the four facial pairings, with one within-subjects factor (face example), was significant, $\underline{F}$ (3,93) = 4.83, $\underline{p} < .01$. In a second analysis, I averaged the ratings across the four faces for each adult to yield one overall rating for relative attractiveness and then subjected these scores to a one-sample t-test.

For Infants. The data from infants consisted of the proportion of time spent looking at each member of eight pairings of faces, as judged by each of the two observers. The Pearson correlation between the proportions measured by the two observers across the eight trials ranged from 0.8 to 1.0 (mean $\underline{r} = 0.93$). By averaging the proportions across the two observers and across the left-to-right reversals I created four scores for each baby: proportion of looking to versions with larger eyes in four female faces.

An ANOVA on the four mean proportion scores, with one within-subjects factor (face example), was not significant, $\underline{F}$ (3,117) = 0.392, $\underline{p} > .10$. Therefore, I averaged the proportions across the four faces for each baby to create one score: mean proportion of looking to version with larger eyes. This proportion score was subjected to a one-sample t-test (two-tailed) to determine whether it differed significantly from a chance value of 0.50. In a second set of analyses more similar to those used with adults, I determined babies' proportion score from only the first presentation of the two versions of each of the four female faces.

Results

For Adults. Adults rated the versions of faces 1 and 3 with larger eyes as more attractive than their counterparts with smaller eyes (ts [31] = 3.22 and 3.13, ps < .01), but the effect was not significant in face examples 2 and 4 (ts [31] = 0.5 and 0.45, ps > .10). When adults' ratings were averaged across the four faces, there was also a significant effect, with the versions with larger eyes rated as more attractive, $t(31) = 2.31$, $p < .05$. As shown in **Table 1**, 63 percent of the adults demonstrated this preference in their averaged rating, and many more adults rated the version with larger eyes as more attractive when viewing face examples 1 and 3 than when viewing examples 2 and 4. **Figure 3** (right side) shows adults' mean relative attractiveness ratings of the four pairings of colour photographs of faces. For comparison, Figure 3 (left side) shows adults' mean ratings of relative attractiveness of the four pairings of black-and-white schematic faces used by Carney (1995).

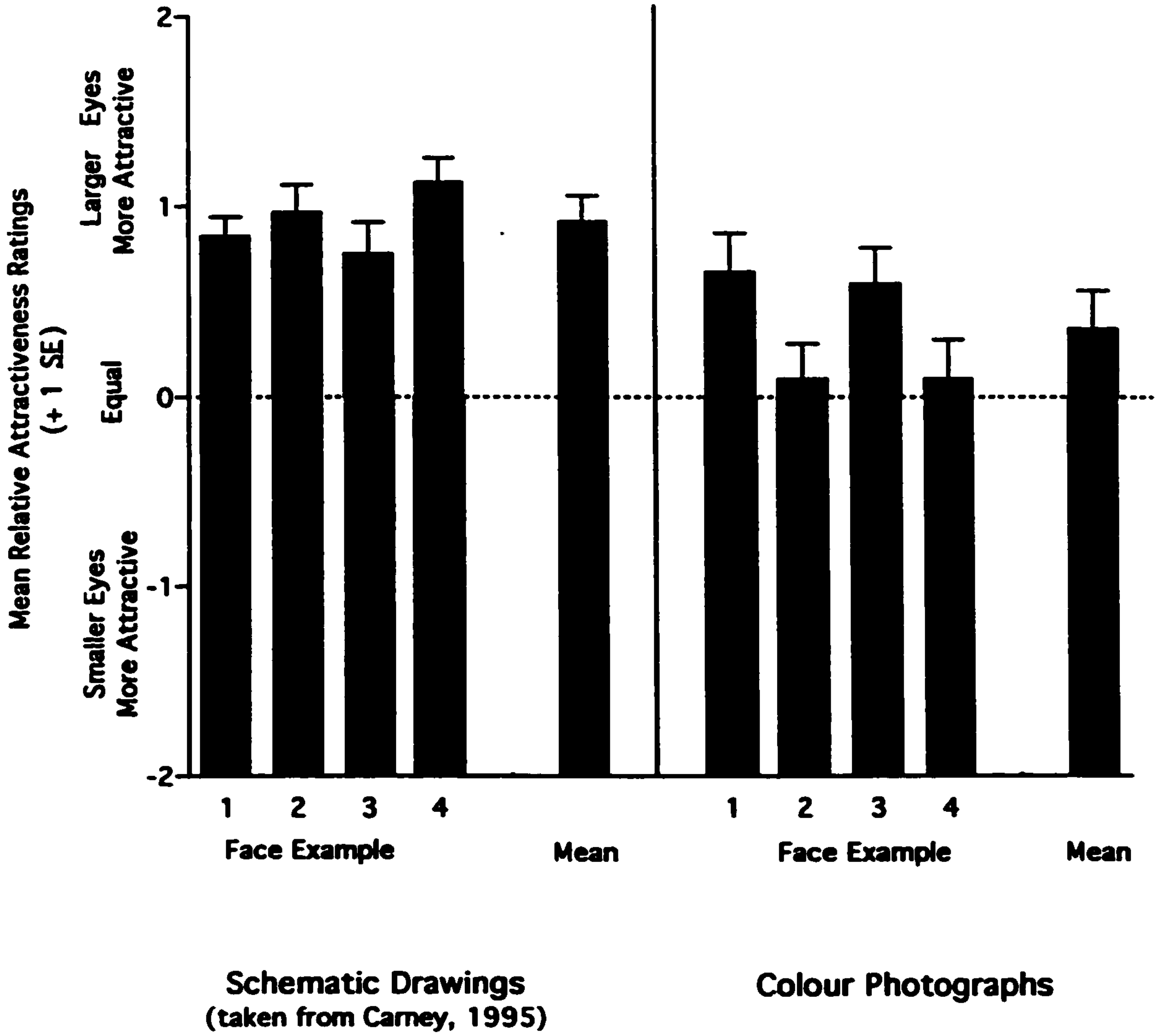
Table 1.

The percentage of adults who rated as more attractive each of the four colour photographs of female faces with larger eyes, smaller eyes, and neither version. In italics, the percentage of 5-month-olds who looked at for longer duration, the face with larger eyes, smaller eyes, and neither version For infants, percentage was based on data averaged across both trials, and in parentheses, from only the first presentation with face pairs. The mean represents the percentages of subjects who demonstrated the preference in an averaged score collapsed across the four face examples.

	Percentage of Adults Rating as More Attractive *Percentage of 5-Month-Olds Looking at for Longer Duration*		
Face Example	Larger Eyes	Smaller Eyes	Neither
1	72	25	3
	63	*33*	*4*
	(63)	*(37)*	*(0)*
2	47	34	19
	45	*48*	*7*
	(58)	*(38)*	*(4)*
3	66	25	9
	53	*43*	*4*
	(53)	*(47)*	*(0)*
4	47	41	12
	65	*35*	*0*
	(55)	*(43)*	*(2)*
mean	63	34	3
	60	*35*	*5*
	(65)	*(33)*	*(2)*

Figure 3.

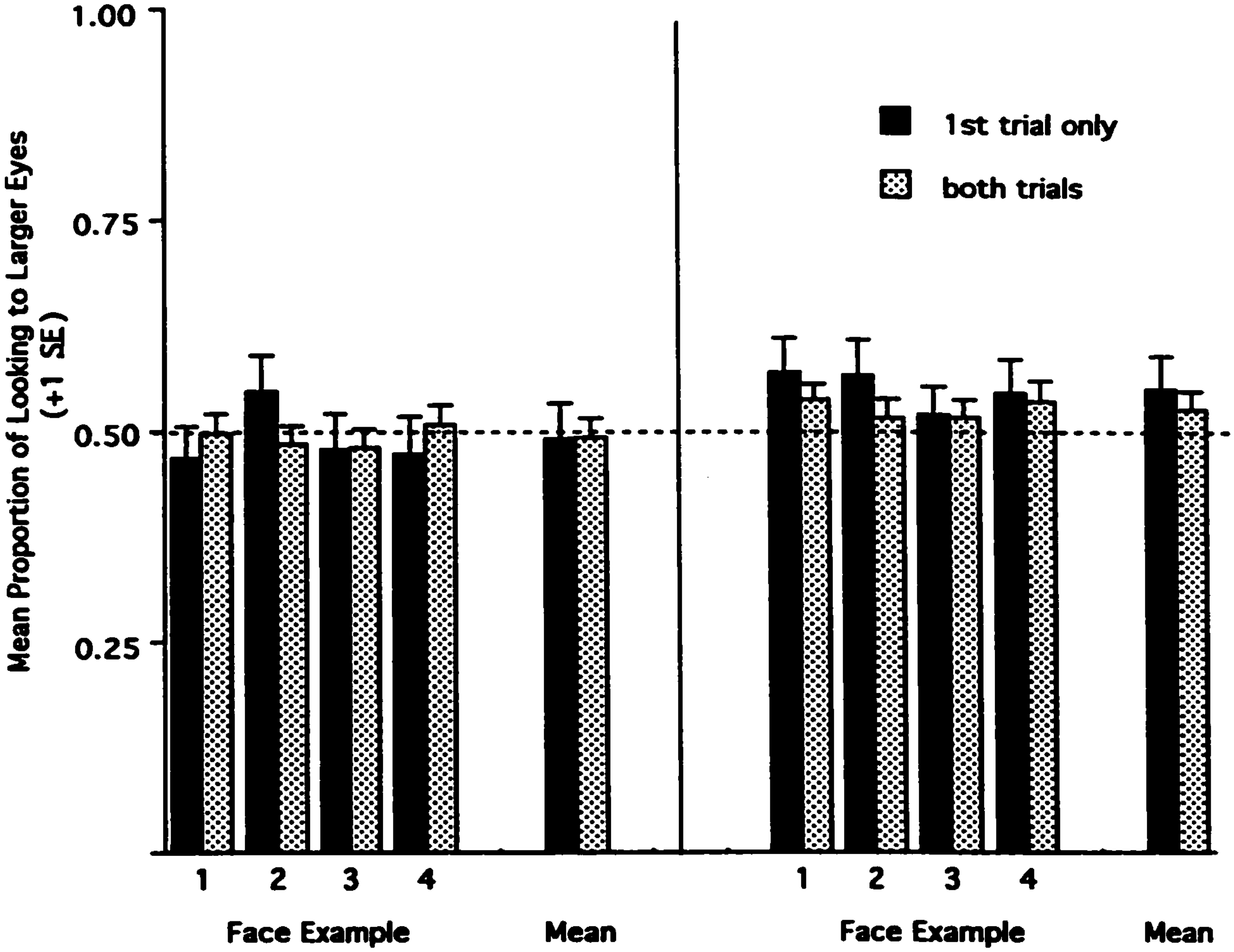
Adults' mean ratings of relative attractiveness (+1 SE) of the four pairings of faces varying in eye size in Experiment 1 that used colour photographs (right side) and in the previous experiment by Carney (1995) that used black-and-white drawings (left side). The photographs used in Experiment 1 are illustrated in Figure 1. Carney's (1995) drawings are shown in Figure 2.


Mean Relative Attractiveness Ratings (+ 1 SE)
Larger Eyes More Attractive
Equal
Smaller Eyes More Attractive
2
1
0
-1
-2
1
2
3
4
Face Example
Mean
1
2
3
4
Face Example
Mean
Schematic Drawings
(taken from Carney, 1995)
Colour Photographs

For Infants. A one-sample t-test indicated that babies' mean proportion score differed significantly from a chance value of 0.50, $\underline{t}$ (39) = 2.22, $\underline{p} < .05$. As shown in **Figure 4** (right side), babies looked longer at the colour photographs of faces with larger eyes than at the faces with smaller eyes. The results from the first presentation of each of the four pairings were similar: babies looked significantly longer at the versions with larger eyes, $\underline{t}$ (39) = 2.17, $\underline{p} < .05$. As shown in Table 1 (in italics), most of the infants looked longer at the versions with larger eyes. An unpaired t-test comparing 5-month-olds' mean proportion of looking to the photographed faces with larger eyes from this experiment and in Carney's (1995) study with black-and-white drawings indicated that the proportions were significantly greater for photographs than for drawings (means = .53 and .49, respectively), $\underline{t}$ (78) = 2.09, $\underline{p} < .05$. For comparison, Figure 4 (left side) shows infants' proportion scores for the drawings in Carney's study.

Figure 4.

Five-month-olds' mean proportion of looking time (+1 SE) to the four faces with larger eyes. Proportions are shown for Experiment 1 that used colour photographs (right side), and for Carney's (1995) study that tested babies with black-and-white drawings (left side). The patterned bars show results from both trials with each face pairing; the black bars, for the first trial with each pairing.



Schematic Drawings
(taken from Carney, 1995)

Colour Photographs

Discussion

In Experiment 1, adults rated the colour photographs of female faces as more attractive when they contained larger eyes. In addition, 5-month-olds looked longer at the photographed faces with larger eyes than at the faces with smaller eyes. This is the first study to demonstrate that eye size is one facial characteristic that influences adults and young infants in the same direction. The findings support the hypothesis that there are influences on the development of aesthetic preferences in addition to cultural learning.

The finding that adults rated as more attractive colour photographs of female faces with larger eyes is consistent with the previous study from our laboratory that manipulated eye size in black-and-white drawings of female faces (see Figure 3 for a comparison to Carney, 1995) and with published studies that used black-and-white schematic faces and coloured photographs (e.g., Cunningham, 1986; McArthur & Apatow, 1983-1984). It is also consistent with the literature on aesthetic preferences for babyish faces and for expressive faces (Cunningham, 1986; Cunningham et al., 1995; Hildebrandt & Fitzgerald, 1979; Maier et al., 1984; McArthur & Apatow, 1983-1984), both of which contain large eyes. According to some authors (e.g., Buss, 1994; Symons, 1979), aesthetic preferences for young-looking faces may have evolved because they signal women's reproductive success, and potential partners maximized their fitness by mating with such females. Cunningham (1986) has suggested that expressive features in faces may signal friendliness, interest and responsivity, and human aesthetic preferences for them may have evolved to attract individuals to mates who can be approached safely and/or that such preferences may have developed from learning to associate large eyes with positive emotions.

Like adults, young babies' preferences for larger eyes may reflect an evolved preference for "babyish" or "expressive" faces (Cunningham, 1986; McArthur & Apatow, 1983-1984). Babies' preferences for larger eyes may reflect a more general preference for patterns with elements of larger physical size, an optimal amount of contour and/or more energy at low spatial frequencies to which young babies are most sensitive (e.g., Banks & Salapatek, 1981; Fantz et al., 1975). However, the 5-month-olds responded to larger eyes when viewing my colour photographs but not when viewing black-and-white drawings of faces in Carney's (1995) study, even though the size and amount of contour were *greater* in the drawings. This comparison suggests that, at least by five months of age, babies' preference is not based merely on physical size or contour but rather on their experience with faces in the real world, which is easier to generalize to the coloured photographs than to the line drawings. The different results from the two experiments suggest that the many previous studies with line drawings of faces (reviewed in Johnson & Morton, 1991 and Maurer, 1985) may underestimate young babies' capabilities in everyday human face perception.

Aesthetic preferences for larger eyes might originate from visual preferences for faces containing highly expressive features to which young babies are exposed often. Adults typically respond to babies during face-to-face interaction with wide-eyed expressions of interest and positive affect (e.g., Hains & Muir, 1996), and so it is possible that young babies come to recognize features as they look during such interactions, including the larger eye height produced by raised eyelids, the raised eyebrows, and the widened mouth. It is unlikely that the 5-month-olds used another eye cue associated with expressive faces—larger pupils—because the contrast was low between the pupil and the brown iris in all of the photographed faces. In any event, viewing expressive faces in the real world might cause babies to look longer at novel faces with larger eyes, perhaps in the same way that previous experience with faces causes them to look longer at their mother's face than at the face of a female stranger even when they see her wearing a novel hair scarf (de Schonen et al., 1986; Morton, 1993), and to look longer at a schematic positive-contrast face than at its negative-contrast version (Dannemiller & Stephens, 1988).

Although Experiment 1 shows that it is possible to isolate one variable, eye size, that influences both adults' and infants' reactions to faces, it also shows that eye size, at least on its own, has only a subtle effect. Figure 4 (right side) indicates that differences in eye size produced only small shifts in 5-month-olds' looking times. Interestingly, a comparison of the two bars in Figure 4 (right side) suggests that the preference, though slight, was stronger during the first presentation of the pair of faces than when the data were averaged across the two trials with the left-to-right reversal. I speculate that babies look longer at their preferred version of a face during its first presentation, and then, as a result of becoming bored or habituated to that face, they either show random looking during the second presentation or they look longer at the other (now relatively novel) version of the face. Thus, a single paired trial may be more sensitive for picking up subtle visual preferences for one face over another.

Variations in eye size also had only a small effect on adults' ratings of attractiveness. Those changes produced small shifts in adults' ratings, and the effect was not significant in two of the four pairings of faces (Figure 3, right side). One possibility is that the optimal eye size is above the mean but less extreme. The small size of the effect may also be related to the way I created facial images. The larger and smaller eyes were made from a set of faces that in their natural form had been rated by adults as only "average" in attractiveness. Because adults' aesthetic judgments are influenced strongly by characteristics in addition to the size of the eyes (e.g., Cunningham, 1986; Langlois & Roggman, 1990; McArthur & Apatow, 1983-1984), their preferences for faces with larger eyes may not have been strong because those other characteristics were not particularly appealing. As would be expected, adults' ratings of attractiveness in my experiment are similar to those reported in other experiments that manipulated black-and-white drawings of faces along one dimension (i.e., see McArthur & Apatow, 1983-1984 and McArthur & Berry, 1987 for manipulations of the height of faces' internal features), but are lower than those reported in experiments using black-and-white drawings of faces in which many features in addition to eye size were manipulated (e.g., McArthur & Apatow, 1983-1984; McArthur & Berry, 1987) and in other studies using nonadulterated colour photographs of faces (e.g., Cunningham et al., 1995; Langlois et al., 1987).

Interestingly, the effect of eye size on adults was not as strong as in Carney's (1995) study with drawings (compare left and right sides of Figure 3) and it was shown by a smaller percentage of subjects (i.e., 63% vs. 97%, respectively). This pattern is consistent with the known tolerance of adults for distortion in schematic drawings (i.e., caricatures; Benson & Perrett, 1991). When viewing drawings of faces in Carney's (1995) study, adults appeared to have based their judgments of relative attractiveness on differences in eye size and ignored whether the drawings looked distorted. But when viewing the more realistic photographs in Experiment 1, adults reacted not only to the size of the eyes but also to whether they looked natural. In the pilot experiment with unusually large eyes that were three standard deviations above the mean (as in Carney, 1995), adults saw the face as unnatural and unattractive. In the main experiment, when the eyes were set two standard deviations above the mean, adults found them more attractive than smaller eyes, but, perhaps because those eyes also deviated from the norm, the preference was smaller than for line drawings.

In any event, the finding that adults rate faces with larger eyes as more attractive than faces with smaller eyes and that 5-month-olds look longer at faces with larger eyes is consistent with the many reports that young infants look longer at faces rated more attractive by adults than at faces rated less attractive (Langlois et al., 1991; Langlois et al., 1987; Samuels et al., 1994; Samuels & Ewy, 1985). Like previous findings on facial averageness (Rubenstein et al., 1999), my findings indicate that there are some characteristics of faces that influence the development of adults' perception of beauty before extensive cultural input.

Unlike eye size (Experiment 1) and facial averageness (Rubenstein et al., 1999), the height of the faces' internal features might not influence reactions to faces in an adult way from early infancy. In our laboratory, when adults and 5-month-olds saw black-and-white drawings of faces presented individually that were identical except that the internal features were at a low height (large forehead, small chin), a high height (small forehead, large chin), or at a medium height, adults rated faces with their features at the medium height as most attractive and faces with their features at the high height as least attractive, but babies looked equally long at faces with their features at various heights (Henderson, Maurer, & Geldart, 1994). These results suggest that the features' height influences the reactions of adults but not young infants, at least when they are tested with black-and-white drawings presented one at a time. In the next section, I describe my studies that examined the effect of the height of the faces' internal features on adults' aesthetic ratings and 5-month-olds' behavioural preferences. One purpose was to test the generality of the original findings with realistic, colour photographs. A second purpose was to use a paired-comparison procedure—in which two versions of a face with its features at different heights are presented—to see if it might reveal infants' visual preferences.

2.3. THE EFFECTS OF THE HEIGHT OF FACES' INTERNAL FEATURES ON ADULTS' AESTHETIC RATINGS AND 5-MONTH-OLDS' LOOKING TIMES AND FACIAL EXPRESSIONS

A. Background and Purpose

Previous studies have shown that the height of the internal features influences adults' judgments of faces' attractiveness, although there is inconsistency across studies in the pattern of influence (Henderson, 1993; Henderson et al., 1994; McArthur & Apatow, 1983-1984; McArthur & Berry, 1987; Sternglanz et al., 1977). Caucasian adults rated black-and-white drawings of infants' faces with their features at a lower height as more attractive than infants' faces with their features at a higher height (Sternglanz et al., 1977). In their ratings of Caucasian adult faces, Korean adults rated faces with features at a medium height as most attractive and faces with features at a high height as least attractive (McArthur & Berry, 1987), while Caucasian adults' ratings varied with the sex of the face—they rated female faces with lower features as more attractive than female faces with higher features, and they rated male faces with higher features as more attractive than male faces with lower features (McArthur & Apatow, 1983-1984). Thus, when the height of the internal features was manipulated in adults' faces, the results varied with the sex of the face and the background of the rater.

In our laboratory, Henderson (1993) had (mostly) Caucasian adults view black-and-white drawings of adults' faces that consisted of three versions with features at low, medium, and high height in each of three male and three female faces. Adults rated both male and female faces with their features at the medium or low heights as more attractive than faces with their features at the high height, and they rated faces with low and medium heights as no different in attractiveness. In a follow-up study, using a larger number of subjects and counterbalancing the order in which they viewed the two sexes of face, Henderson et al. (1994) also found that adults rated male and female faces with their features at the medium height as more attractive than faces with their features at the low height. These findings are similar to those previously reported for Caucasian adults, at least in their ratings of female faces (McArthur & Apatow, 1983-1984), and for Korean adults in their ratings of male and female faces (McArthur & Berry, 1987).

Adults' higher ratings of attractiveness for faces with their features at a low height than for faces with their features at a high height is consistent with other studies showing that adults rate infants' faces with larger foreheads as more cute than faces with smaller foreheads, adult female faces with smaller chins as more attractive than faces with larger chins, and both infant and adult female faces with a number of "babyish" features, including a larger forehead and smaller chin, as more attractive than faces with less babyish features (Berry & McArthur, 1985; Cunningham, 1986; Hildebrandt & Fitzgerald, 1979; Keating, 1985; Maier et al., 1984; McArthur & Apatow, 1983-1984; McArthur & Berry, 1987; Sternglanz et al., 1977). Such preferences for faces with their features at a lower height might reflect a more general preference for facial babyishness.

Adults' higher ratings of attractiveness for faces with their features at a medium height than for faces with their features at either low or high heights is consistent with the finding that adults rate an 'averaged' composite face as more attractive than the individual faces that make up the composite (e.g., Langlois & Roggman, 1990). The composite is derived from averaging a group of individual faces, and as more and more individual faces are included in the averaging, the features begin to assume an average size and position (Langlois et al., 1994). Faces with their features at the medium height—like those used in the Henderson et al. (1994) study—were not created by averaging, but the features are in approximately the same positions as in a composite face because they were placed at the population mean. Thus, adults' preferences for faces with their features at a medium height might reflect a general preference for facial averageness.

There are reasons to suspect that infants might also be sensitive to the height of the faces' internal features. Beginning at two months of age, babies begin to scan mainly the internal features of faces (e.g., Maurer & Salapatek, 1976), and by three months, they can remember something about those features (e.g., de Schonen et al., 1986). From an early age, babies can also discriminate among schematic faces on the basis of the positions of their internal features. In some comparisons, even newborns differentiate between a line drawing of a natural face and a drawing in which all of the features are inverted or in a scrambled position (Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Maurer & Young, 1983; Mondloch et al., 1999; Morton & Johnson, 1991; Valenza, Simion, Macchi Cassia, & Umilta, 1996; but see Easterbrook, Kisilevsky, Hains, & Muir, 1999). By five months of age, if not earlier, babies respond to the deletion or repositioning of individual features, including the eyes and nose/mouth (Caron et al., 1973; Maurer, 1985). Finally, while young infants' poor visual acuity limits their perception of fine detail (e.g., Mayer et al., 1995), they are nonetheless sensitive to the size of a pattern's elements (Fantz et al., 1975), and by two months if not earlier, to their distribution (i.e., phase spectra) (Atkinson, Braddick, & Wattam-Bell, 1986; Dannemiller & Stephens, 1988; Kleiner, 1987; Kleiner & Banks, 1987; Mondloch et al., 1999). These findings led us to ask whether infants' visual preferences for attractive faces might be related to preferences for faces varying in the size of the forehead, the size of the chin, and/or the positioning of the internal features relative to the frame.

Henderson (1993) tested the influence of the height of the internal features on 5-month-olds' looking times. She showed infants the same sequence of 18 schematic faces that had revealed strong effects in adults' aesthetic ratings, and she measured their looking preferences by an infant-controlled procedure that timed the duration of first fixation on each of the faces. The infants looked equally long at faces with features at the three heights. However, the results for infants might have been affected by fatigue. The infants looked longer at faces shown in the first half of the series than in the second half, presumably because the procedure was so long that they tired of the faces across trials. This was of special concern because the order of the faces was not counterbalanced, and it turned out to deviate systematically from randomness, with some versions positioned earlier in the series than others (i.e., faces with low or medium features presented earlier than faces with high features). These deviations from randomness, coupled with the infants' habituation, could have masked the influence of the features' height on babies' looking times because otherwise preferred stimuli may have been presented late in the series.

In a follow-up study, Henderson et al. (1994) re-examined the issue using a design that allowed the data from infants to be analysed after a shorter procedure. The 5-month-olds viewed sequentially faces of one sex, and after a break, they viewed faces of the other sex. As before, the height of the internal features did not influence infants' looking times. This result held true whether the analysis was based on looking times across the whole procedure or from only the first half of the procedure when it was more likely to capture babies' preferences before they became bored. However, the features' height did have a mild effect on infants' facial expressions: they expressed slightly but significantly more positive affect in reaction to male or female schematic faces with their features at the high height than to faces with their features at the low height. Thus, at least as reflected by changes in their facial expression, the babies discriminated among faces varying in the height of their internal features and they showed a mild preference for faces with high features over faces with low features. This preference contrasted with adults' ratings of the faces with high features as *least* attractive.

The finding that 5-month-olds showed sensitivity to variations among faces by differential facial expressions but not by differential looking time is similar to findings on infants' reactions to perturbations of adult behaviour (e.g., eye contact, smiling, talking) during face-to-face interactions (e.g., Hains & Muir, 1996). In the Henderson et al. (1994) study, the 5-month-olds altered their facial expressions in the presence of static images of faces posing with neutral facial expression. The infants may have smiled at the static faces with high features because these faces caused a positive affective reaction and/or because they tried to initiate or maintain some form of communication with them. Unexpectedly, however, infants' affective preference for high features was in the opposite direction from adults' aesthetic ratings. That result is unlike those from previous studies reporting that infants look longer at faces rated as more attractive by adults (e.g., Langlois et al., 1987). Such discrepancies led us to ask whether there might have been limitations in the method of collecting looking preferences and/or the facial stimuli used to test infants' preferences.

First, babies may have looked equally long at all three versions of the faces because each face was presented individually, and they find any face interesting to look at. Langlois et al. (1987) have speculated that young infants may be more likely to show differential looking when they are forced to choose between two faces. All previous studies showing that infants look longer at faces rated attractive by adults (e.g., Langlois et al., 1987), including my study on the influence of eye size (Experiment 1), used a paired-comparison design that gives babies an opportunity to make a choice between faces. I suspected that a more sensitive test of infants' looking preferences for feature height would involve presenting two different versions of a face (i.e., low vs. high height, low vs. medium height, and medium vs. high height) and recording how the infant chooses to distribute his/her looking between the two versions. Therefore, in Experiments 2 and 3 I used a paired-comparison technique. In Experiment 4, I measured both infants' duration of first fixation and their facial expressions as they viewed each of the faces presented one at a time in the center of the visual field.

Second, the 5-month-olds' visual and/or affective preferences might have been obscured because they processed the black-and-white drawings that were used in Henderson's (1993; Henderson et al., 1994) studies differently from the way they process real faces. In Experiment 1 on the study of eye size, 5-month-olds looked longer at faces with larger eyes when they viewed colour photographs. The effects were not significant in a previous study from our laboratory (Carney, 1995) that used black-and-white drawings. Similarly, all previous studies reporting infants' visual preferences for faces rated attractive by adults used photographic images of faces (e.g., Langlois et al., 1987). Therefore, in Experiments 3 and 4, I used coloured photographs of faces varying in the features' height. (In Experiment 2, I used the black-and-white schematic drawings from the Henderson et al. [1994] study.)

In all three experiments, adults rated the attractiveness of the same faces that were shown to infants. In Experiments 2 and 3, adults rated the relative attractiveness of each pair of drawings and photographs of faces varying in the height of the internal features. In Experiment 4, they rated the attractiveness of single photographs of faces presented sequentially.

B. Experiments

Experiment 2

The purpose of Experiment 2 was to measure adults' ratings of relative attractiveness and 5-month-olds' distribution of looking times as they viewed pairs of black-and-white drawings of male and female faces varying in the height of their internal features. As in Experiment 1 on the influence of eye size, babies viewed each face pairing until they had accumulated 10 seconds of looking time and the measure of preference was the proportion of that time spent looking at each member of the pair. Adults rated the relative attractiveness of the faces within each pair.

Method

Design

To make the procedure as short as possible for infants, each subject saw each of the three types of pairing (i.e., low with high; medium with high; low with medium) in one of the three male faces and in one of the three female faces, with a different face used for each type of pairing and with the face chosen counterbalanced across subjects. Each pair of faces was presented first in one random left-right position and following a non-facial stimulus, in the reversed position. Each non-facial stimulus occurred in the same positions for all subjects. Thus, there were 11 trials for each sex of face (i.e., 6 pairings of faces separated by 5 patterns). Half of the subjects saw all the pairing of female faces first and half saw male pairs first, followed by a break before testing with the other sex.

Even with a break, infants might become habituated to faces across trials. Therefore, I checked for order effects, and when I found them, based the main analysis on data from only the first half of the procedure. I tested a larger number of subjects in Experiment 2 than in Experiment 1 so as to have sufficient statistical power to detect a possibly small effect in data taken from only the first half of the trials.

Subjects

Adults. Seventy-two (36 male) undergraduate students (M age: 21 years; range: 19 to 29 years) participated for points in a psychology course. Sixty-one adults were Caucasian, 10 were Asian, and one was Black.

Infants. Infant subjects were 72 (36 male) full-term 20- to 22-week-olds (M age: 21 weeks). An additional 26 infants were tested but excluded from analyses because of low inter-observer reliability (i.e., Pearson correlation between two observers' measurements of visual fixations < 0.80; $n = 8$), side bias ($n = 7$; looking to the same side $\geq 80\%$ of the time), fussiness ($n = 5$), equipment failure ($n = 4$), or procedural error ($n = 2$).

Stimuli

The stimuli were 18 black-and-white drawings of faces that had been used by Henderson (1993; Henderson et al., 1994). Henderson (1993) used Mac-a-Mug software to create three versions of each of six schematic faces (3 male; 3 female): a face with its features at a low height, with a large forehead and small chin; a face with its features at a high height, with a small forehead and large chin; and a face with its features at a medium height, with an average-sized forehead and chin. These faces are illustrated in **Figure 5**. Faces with features at the low, medium, and high height had ratios of forehead to chin length of 2.4, 1.4, and 0.87, respectively. The ratio that determined the location of the low features was set by the value of forehead length two standard deviations above the population mean for adult faces (Farkas, 1981) divided by chin length two standard deviations below the mean. Conversely, the location of the high features was set by the forehead length two standard deviations below the mean divided by chin length two standard deviations above the mean. The ratio for medium height was the value of forehead length to chin length of the population means. Criteria turned out to be the same for male and female faces. The six faces were those in an original set of 21 for which pilot testing had indicated that changes in the features' height most strongly affected adults' ratings of attractiveness (using a 5-point Likert scale: 1 = very unattractive; 5 = very attractive) with minimal variability among 16 raters (Henderson, 1993).

All faces were shown as slides projected onto a rear-projection screen (64 cm wide x 28 cm high), and in pairings consisting of a face with its features at two different heights, e.g. a face with its features at the low height paired with the same face with its features at the high height. Each face was near lifesize (12 cm wide x 16 cm high) and formed an image of 9 x 12 visual degrees when viewed from 75 cm (for adults) and 15 x 20 visual degrees when viewed from 45 cm (for infants). The inner edges of the two faces were 5.5 cm apart (7 visual degrees from 45 cm). Slides containing a single non-facial stimulus (e.g., checkerboard, bulls'-eye; see Appendix 6) were shown for five seconds after every trial with a pair of faces.

Figure 5.

The three versions of faces varying in the height of their internal features in each of three male and three female schematic faces used in Experiment 2. The stimuli were taken from Henderson (1993; Henderson et al., 1994) and presented in pairings consisting of two versions of a face with its features at two different heights. All faces were shown approximately lifesize.









Apparatus and Procedure

The apparatus and procedures for adults and infants were the same as those in Experiment 1 on the influence of eye size except as noted below.

For Adults. Adults rated the relative attractiveness of three pairings of one sex, and then saw two blank slides before they gave ratings of the three pairings of the other sex.

For Infants. Two observers recorded a baby's looking times to faces as the baby viewed a sequence of one pairing of faces followed by a 5-second presentation of one pattern until he/she had seen all pairings of one sex. After a 5-minute break in a different room, the baby's looking times were recorded as he/she viewed the pairings of the other sex.

Data Analysis

For Adults. The data for adults consisted of their ratings of relative attractiveness of six pairings of schematic faces, and their left-to-right reversals. So as to be more likely to capture adults' first impressions of faces, I included adults' ratings of relative attractiveness from only the first trial with each pairing and calculated six scores for each subject: mean rating of high paired with low, high paired with medium, medium paired with low in male faces and in female faces. To find out if these scores could be collapsed across sex of face and/or order, I calculated an ANOVA with one between-subjects factor (order) and two within-subjects factors (sex of face and type of pairing). Because the ANOVA showed no effects of order or sex of face, nor any significant interaction (all ps > .10), I collapsed the ratings into three scores representing the three types of pairing. The three mean scores were subjected to one-sample t-tests (two-tailed) to determine whether the ratings differed significantly from 0, i.e., equal attractiveness.

For Infants. The data for infants consisted of the proportion of time spent looking at each member of six pairings of schematic faces and their left-to-right reversal, as judged by each of the two observers. The Pearson correlation between the proportions measured by the two observers across the 12 trials ranged from 0.80 to 1.0 (mean $\underline{r} = 0.93$). By averaging the proportions across the two observers and across the left-to-right reversals I created six scores for each baby: proportion of looking to low when paired with high, proportion to low when paired with medium, and proportion to medium when paired with high features in male faces and in female faces. An ANOVA on the six mean proportion scores, with one between-subjects factor (order) and two within-subjects factors (sex of face and type of pairing), showed no effects of order or sex of face, nor any significant interactions (all $\underline{p}$s $> .10$). Consequently, I collapsed the proportions into three scores representing the three types of pairings and subjected the three scores to one-sample t-tests (two-tailed) to determine whether they differed significantly from a chance value of 0.50.

I also re-analysed infants' looking times from the first presentation of each of the three pairings and ignored data from the left-to-right reversal. This was to capture infants' first impressions of faces and to make the analysis more similar to that used with adults, and because the results of Experiment 1 on the influence of eye size revealed stronger visual preferences during the first presentations of a pair of faces. These three new proportion scores were then subjected to one-sample t-tests (two-tailed). Note that although these analyses did not make use of the left-to-right reversals and therefore did not control for the effects of side-bias on looking times, infants who had a strong side bias were not part of the final sample (discussed in Section 2.1).

Results

Adults. Adults rated faces with their features at the low or medium height as significantly more attractive than faces with features at the high height (both ps < .001), and they rated faces with their features at the medium height as significantly more attractive than faces with features at the low height, $p < .01$. **Figure 6** (left side) shows adults' mean relative attractiveness ratings for faces varying in the height of the internal features.

Infants. The infants' mean looking times did not differ significantly from a chance distribution whether they were shown pairs of faces with their features at the low and high heights, the medium and high heights, or the low and medium heights (all ps > .10).

Babies' looking times from the first presentation of each of the three pairings did not differ significantly from a chance distribution when they were shown pairs of faces with their features at the medium and high heights, $p > .10$, or at the medium and low heights, $p > .05$. However, babies looked significantly longer at faces with their features at the high height than at faces with their features at the low height, $t(71) = 2.95$, $p < .01$. **Figure 7** (left side) shows the distribution of infants' looking time for each type of pairing of schematic faces averaged across the two trials with the left-to-right reversal (patterned bars) and from the first presentations only (black bars). It indicates the proportion of the 10-second presentation that infants spent looking at the member of the pair that is marked with an asterisk.

Figure 6.

Adults' mean ratings of relative attractiveness (+1 SE) of each of the three types of pairing of schematic drawings of faces from Experiment 2 (left side) and of coloured photographs of faces from Experiment 3 (right side): versions of a face with features at the low and high heights (Low vs. High); at the medium and high heights (Medium vs. High); and at the medium and low heights (Medium vs. Low). An asterisk depicts the version rated as more attractive.

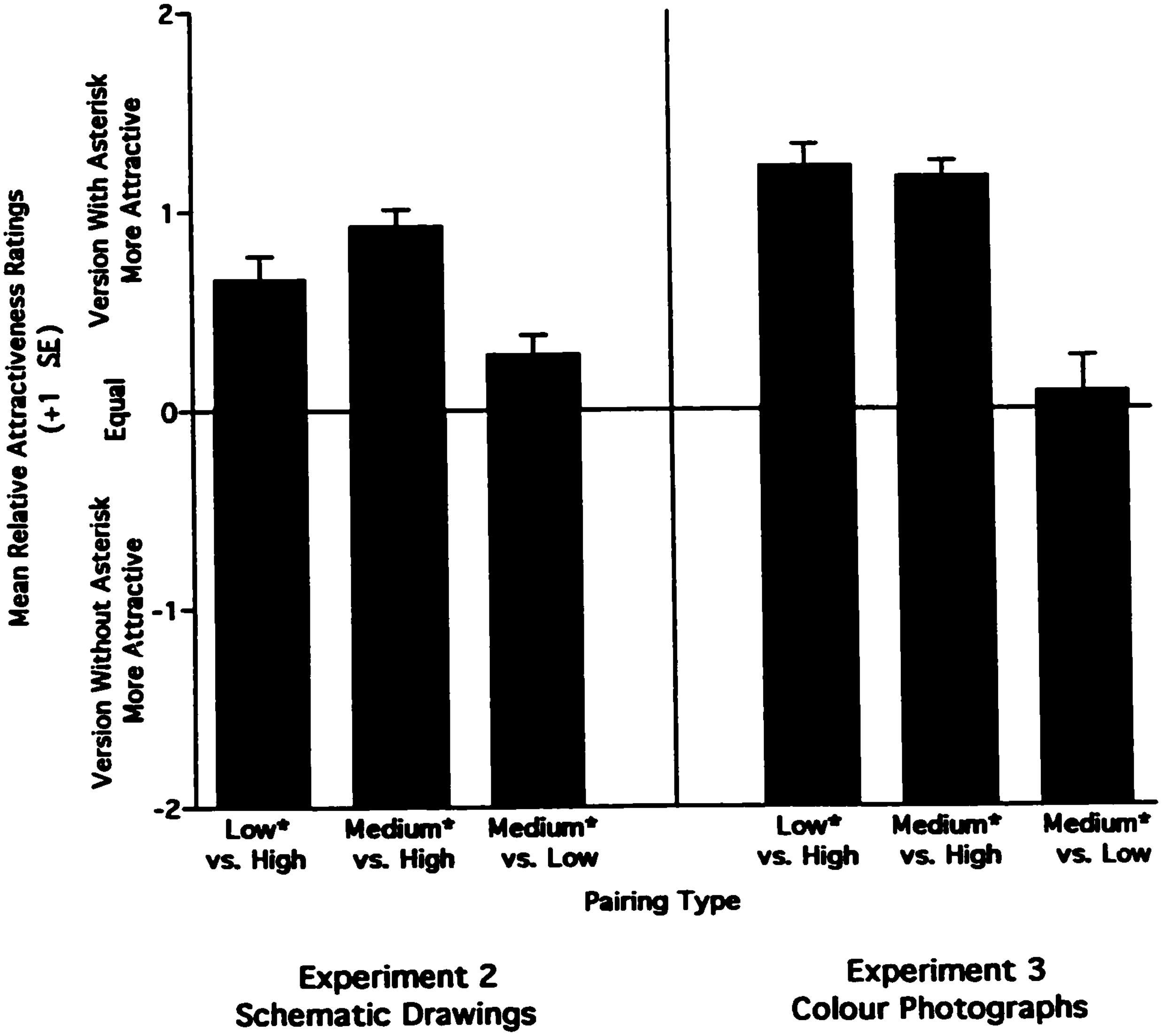
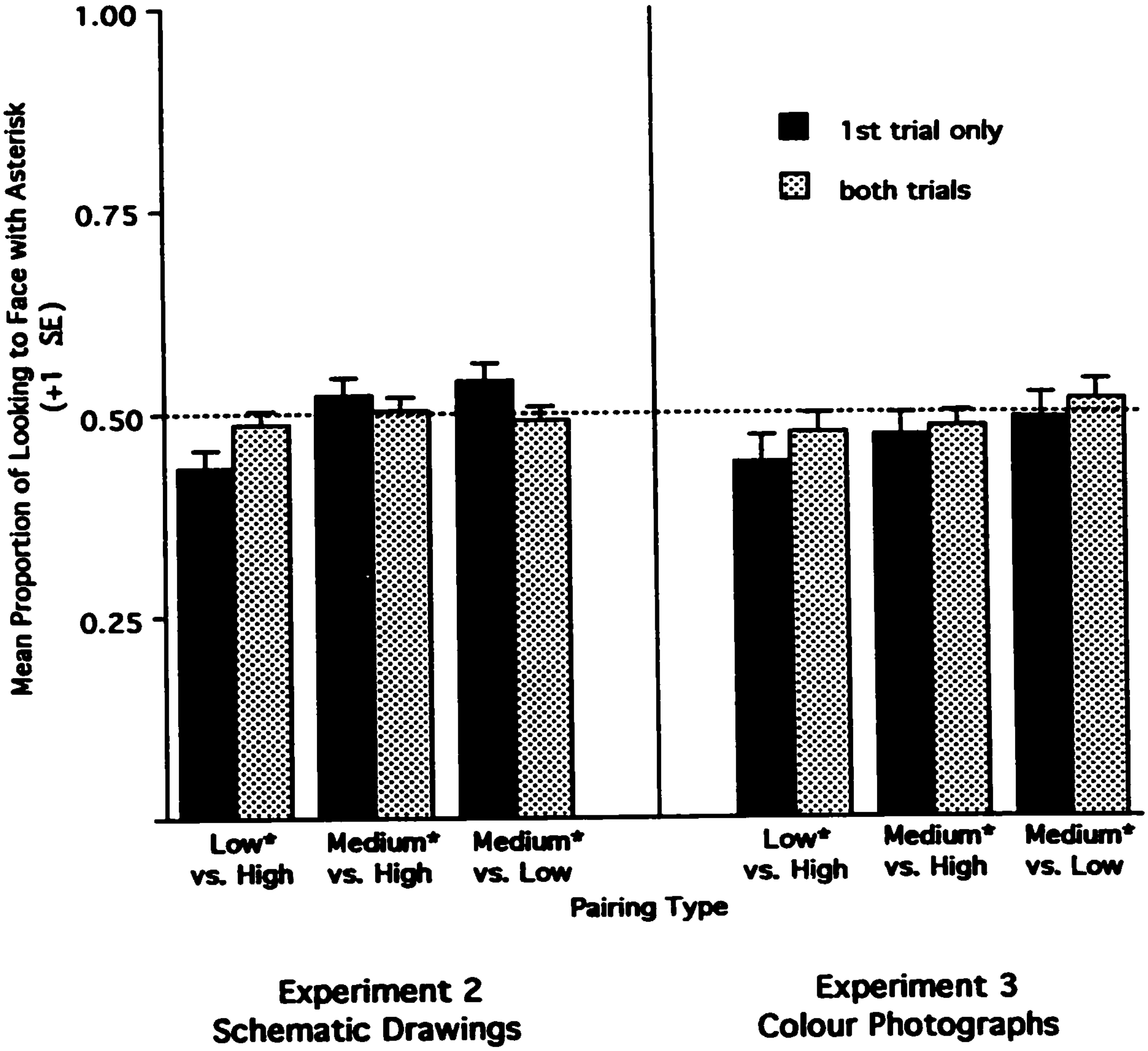

Mean Relative Attractiveness Ratings (+1 SE)
Version With Asterisk More Attractive
Equal
Version Without Asterisk More Attractive
2
1
0
-1
-2
Low* vs. High
Medium* vs. High
Medium* vs. Low
Low* vs. High
Medium* vs. High
Medium* vs. Low
Pairing Type
Experiment 2
Schematic Drawings
Experiment 3
Colour Photographs

Figure 7.

Five-month-olds' mean proportion of looking time (+1 SE) to each of the three types of pairing of schematic drawings of faces used in Experiment 2 (left side) and of coloured photographs of faces used in Experiment 3 (right side): versions of a face with features at the low and high heights (Low vs. High); at the medium and high heights (Medium vs. High); and at the medium and low heights (Medium vs. Low). The bars indicate the proportion of looking time for the member of each pair depicted by an asterisk. The proportion of looking time to the other member of the pair is equal to this value subtracted from 1.00. The patterned bars show results from both trials with each face pairing; the black bars, for the first trial with each pairing.


1.00
0.75
0.50
0.25
Mean Proportion of Looking to Face with Asterisk (+1 SE)
■ 1st trial only
▨ both trials
Low* vs. High
Medium* vs. High
Medium* vs. Low
Low* vs. High
Medium* vs. High
Medium* vs. Low
Pairing Type
Experiment 2 Schematic Drawings
Experiment 3 Colour Photographs

Discussion

The height of the faces' internal features had different effects on adults' ratings of attractiveness and 5-month-olds' looking times. Like the adults in the study by Henderson et al. (1994) who viewed these faces presented one at a time rather than in pairs, adults rated faces with their features at the medium or low heights as more attractive than faces with their features at the high height, and they rated faces with their features at the medium height as more attractive than faces with their features at the low height. The faces with features at the medium height contain features in approximately the same positions as the features in averaged composite faces, which adults rate as more attractive than the component faces making up the composite (e.g., Langlois & Roggman, 1990). It may be that adults' ratings of composite faces are influenced not only by their average-looking features but also by the location of those features in an average position.

Adults also rated faces with low features as more attractive than faces with high features. This finding is consistent with one previous study of Caucasian adults asked to rate drawings of female faces differing only in the features' height (McArthur & Apatow, 1983-1984) and with several reports that adults rate females with characteristics of babies' faces, including a larger forehead and smaller chin, as more attractive than females with less babyish features (e.g., Cunningham, 1986; McArthur & Apatow, 1983-1984; McArthur & Berry, 1987). However, adults also rated male schematic faces with features in the low position as more attractive than faces with high features, unlike one previous study in which adults rated male faces with their features placed either at the high height or at a "supra" high height (much higher than in this study), as *most* attractive (McArthur & Apatow, 1983-1984; McArthur & Berry, 1987). It is also unlike other studies showing that adults judge male faces as more attractive, the larger their chin area (Cunningham, Barbee, & Pike, 1990; Keating, 1985). I am unable to account for the discrepant findings. In any event, the results of Experiment 2 suggest that under some circumstances, the babyishness of two features, the forehead and the chin, makes both male and female faces more attractive.

While adults' aesthetic ratings were influenced by the height of the internal features, this variable did not influence 5-month-olds' reactions in the same way. Infants did not look longer at the faces with medium features that the adults rated as more attractive. However, there was weak evidence that babies were influenced by the features' height, but in a direction opposite to adults: during the first presentation, babies looked significantly longer at the faces with their features at the high height than at the faces with their features at the low height. This pattern is similar to that observed in the Henderson et al. (1994) study in which 5-month-olds showed greater positive facial expression to the same schematic faces with high features than to the faces with low features. Taken together, these findings suggest that young babies do respond to variations in the height of the internal features, but not in the same way as adults: they react most positively to the version that adults find least attractive.

Young infants' mild preference for faces with high features that adults find least attractive might arise from familiarity. Young babies typically view faces from below the chin, a perspective that causes foreshortening of the face so that the chin is prominent and the features at the top are compressed. Such a foreshortened face resembles the faces in Experiment 2 with their features at the high height. Those faces might also seem familiar to babies because of the expressions of interest and positive affect that adults typically adopt when face-to-face with a baby (Hains & Muir, 1996). Those expressions involve raising the eyelids and brows, and thereby shortening the forehead area. They also involve opening the mouth and dropping the jaw, which enlarges the chin region. Thus, infants may show the most visual and affective responses to faces with high features because they are most similar to those with which they are familiar. In Experiment 3, I examined whether infants' visual preferences are stronger when viewing more realistic, colour photographs of faces varying in the height of their internal features.

Experiment 3

The purpose of Experiment 3 was to measure 5-month-olds' looking times and adults' ratings of relative attractiveness to colour photographs of faces in which I paired two versions of a face with its features at different heights. The experimental design and procedure were the same as in Experiment 2 with drawings except that I used only female faces and babies did not receive a break during the test.

Method

Subjects

Adults. Seventy-two (36 male) undergraduate students (M age: 21 years; range: 17 to 49 years) participated for points in a psychology course. Forty-five adults were Caucasian, 22 were Asian, and five were Black. One additional adult was excluded because he gave more than one rating per face.

Infants. Infant subjects were 72 (36 male) full-term 20-to 22-week-olds (M age: 20.8 weeks). An additional 27 babies were excluded from analyses because of side bias (n = 11; looking at one side ≥ 80% of the time), low inter-observer reliability (n = 10), procedural error (n = 5), or fussiness (n = 1).

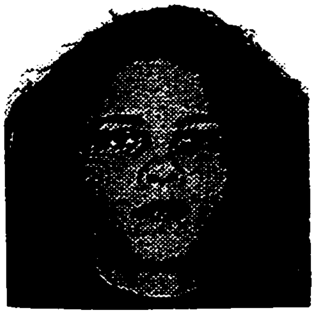
Stimuli

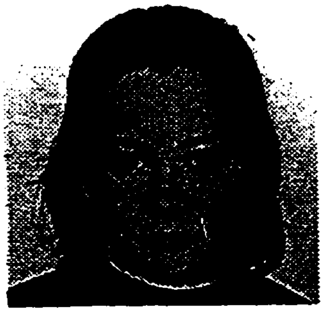
Selecting photographed faces. I selected 10 natural photographs of female faces from the set of 15 that were used in Experiment 1 for the manipulation of eye size. I chose to manipulate natural faces that had obtained a mean attractiveness rating close to average among pilot raters (see Appendix 2) rather than using faces that were either very attractive or unattractive so that there was room for adults' ratings to become either higher or lower after I altered the height of the features.

Manipulating faces and selecting final stimuli. I used Photoshop to create three versions of each of the 10 faces, i.e., faces with features at the low, medium and high heights. All measurements were the same as those used for the manipulation of the features' height in schematic faces and described in Experiment 2. The 30 images (i.e., 3 versions of each of 10 faces) were then made into slides and rated for attractiveness by 30 adult raters who did not participate in the final study. See Appendix 8 for details about these ratings. The 18 faces (i.e., 3 versions of each of 6 faces) selected as final stimuli were those in which changes in the features' height most strongly affected adults' ratings with minimal variability. They are illustrated in Figure 8.

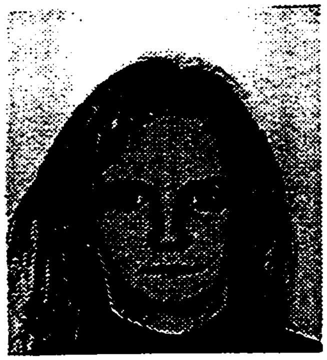
Figure 8.

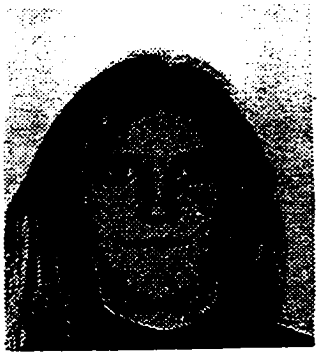
The three versions of faces varying in the height of their internal features in each of six photographs of female faces used in Experiments 3 to 5. In Experiments 3 and 5, faces were shown in pairings consisting of two versions of a face with its features at two different heights. In Experiment 4, faces were shown one at a time, in the center of the visual field. All faces were shown approximately lifesize and in colour.

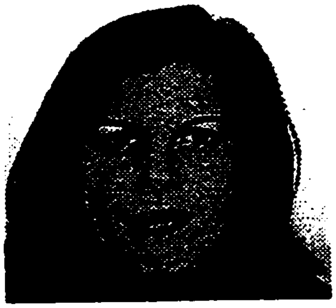
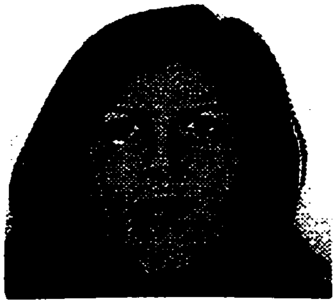










Design and Procedure

The design and procedures for adults and infants were the same as in Experiment 2 except as noted here. The six faces were divided into two sets of three, with half of the subjects starting with each set. Within that set, the subject saw each of the three types of pairing (e.g., high with low) illustrated with a different face followed by a left-to-right reversal. The face used to illustrate each type of pairing and their order were counterbalanced across subjects. Without a break, the subject then saw the three types of pairing with the other set of three faces. Each subject received 23 trials (i.e., 12 pairings separated by 11 non-facial patterns).

Data Analysis

Adults. The data for adults consisted of their ratings of relative attractiveness of six pairings of photographed faces, and their left-to-right reversals. As in Experiments 1 and 2, I included adults' ratings from only the first trial with each pairing. To see if the ratings could be collapsed across order and/or set of faces, I conducted an ANOVA on the six mean ratings of relative attractiveness, with one between-subjects factor (order) and two within-subjects factors (set of faces and type of pairing). The ANOVA showed a significant 3-way interaction between pairing type, set of faces and order, $\underline{p} < .01$, and further analyses indicated that pairing type interacted with order for one set of faces but not for the second set. Because of the interaction with order, and to reduce the probability of Type I error, I restricted the three one-sample t-tests (two-tailed) to the ratings for whichever set of faces adults had viewed first.

For Infants. The infants' data consisted of the proportion of time spent looking at each member of 12 pairings of photographed faces, as judged by each of the two observers. The Pearson correlation between the proportions measured by the two observers across the 12 trials ranged from 0.81 to 1.00 (mean $\underline{r} = 0.96$). I analysed these proportions only from the first presentation of each pairing in the first set of faces for three reasons: (1) infants in Experiment 2 had shown a visual preference during the first presentation of the pairing of high with low but not when data from the first presentation were averaged with data from the left-to-right reversal on the following trial; (2) an ANOVA showed a significant interaction between order and set of faces, $\underline{p} < .05$, the source of which was not revealed by analyses of simple effects; and (3) this made the analysis identical to those for adults. The three proportion scores representing infants' proportion of looking to low when paired with high, proportion to low when paired with medium, and proportion to medium when paired with high features were subjected to one-sample t-tests (two-tailed) to determine whether they differed significantly from a chance value of 0.50.

Results

Adults. Adults rated faces with their features at the low or medium height as more attractive than faces with their features at the high height (both $\underline{p}$s $< .0001$), but they rated faces with features at the medium and low heights as no different in attractiveness ($\underline{p} > .10$). Figure 6 (right side) shows adults' mean relative attractiveness ratings for the colour photographs of faces varying in the height of their internal features.

Infants. The infants' looking times did not differ from a chance distribution when viewing pairs of faces with features at the low and medium heights or the medium and high heights (both ps > .10). However, they tended to look longer at faces with high features than at faces with low features (p = .06). Figure 7 (right side) shows infants' mean proportion of looking to the photograped face depicted by the asterisk. The black bars represent infants' mean proportion of looking during only the first presentations of face pairs. For comparison, the patterned bars show the proportion scores averaged across both trials with the left-to-right reversals.

Discussion

The results for adults in Experiment 3 with female photographs are mostly similar to those found in Experiment 2 with male and female schematic faces: adults rated faces with their features at a high height, creating a smaller forehead and larger chin, as less attractive than faces with their features at a medium or low height. However, in Experiment 3 adults did not rate the photographs with medium features as more attractive than the faces with low features, as they did in Experiment 2 and in the earlier study (Henderson et al., 1994) that used schematic faces. The discrepancies across studies may be due, in part, to the particular faces used. It may also be true that adults perceive faces with features in low and medium positions as similarly attractive, and hence find it difficult to choose between them. That hypothesis is supported by the findings in both experiments that adults' ratings of the pairing of low and medium heights varied least from the midpoint of the scale, i.e., equal in attractiveness (see Figure 6).

Similarly, the results for 5-month-olds are consistent with those of Experiment 2: whether they saw pairs of schematic or photographed faces, infants did not show any significant visual preferences. However, babies in Experiment 3 did tend to look longer at the female photographs with high features than at the photographs with low features. Although this finding only approached statistical significance ($p = .06$), it is the same comparison that was significant in Experiment 2 with data from the first presentation of face pairs (Figure 7, black bars). It is the comparison that was also significant in the Henderson et al. (1994) study on babies' facial expression. In Experiment 4, I examined whether infants would also exhibit a mild looking preference for high features under conditions that more closely resemble those that occur in the real world—viewing colour photographs of faces shown one at a time in the center of the visual field. Because there was only one face present during a trial, I was also able to measure changes in infants' facial expressions as they viewed each of the faces.

Experiment 4

In Experiment 4, I measured adults' ratings of attractiveness and 5-month-olds' looking times during sequential presentations of the 18 colour photographs of female faces varying in the features' height. As in Henderson's (1993; Henderson et al., 1994) studies with schematic faces, I used an infant-controlled procedure (Horowitz et al., 1972) to time the duration of infants' first fixation on the photographed faces. In addition, to see if infants' reactions to the photographs were indexed similarly by their looking times and their facial expressions (e.g., smiles, grimaces) (Hains & Muir, 1996; Langlois et al., 1990; Muir & Hains, 1993), I videotaped the babies' faces so that I could later code their facial expressions.

Method

Subjects

Adults. Adult subjects were 36 (18 male) undergraduate students (M age: 19 years; range: 18 to 23 years) participating for points in a psychology course. Thirty-five adults were Caucasian and one was Asian.

Infants. Infant subjects were 36 (18 male) full-term 20- to 22-week-olds (M age: 21 weeks). An additional six babies were excluded from analyses because of fussiness (n = 1), low inter-observer reliability (n = 2), procedural error (n = 2), or equipment failure (n = 1). Another nine babies were replaced because their faces were too poorly focused on the videotape to allow scoring of their facial expressions.

Stimuli

The stimuli were the 18 colour photographs of female faces used in Experiment 3, presented individually in the center of the projection screen and nearly lifesize (12 cm wide x 16 cm high). Each face formed an image of 10° x 13° when viewed from 75 cm (for adults) and 17° x 21° when viewed from 45 cm (for infants). As before, the non-facial stimuli were shown at the start of the procedure and after every trial with faces, and in the same order for all subjects. Thus, each subject received 35 trials (i.e., 18 faces separated by 17 patterns). The order of the 18 faces was randomized. Two constraints on the orders were that two versions of the same face were never shown on consecutive trials, and that during the first three trials, each subject saw one example of a face with low features, one with medium features and one with high features. The order of the three versions within the first three trials was counterbalanced across subjects.

Apparatus

The apparatus was the same as in Experiments 2 and 3 except for a Sony Handycam VHS videocamera mounted above the projection screen and directed towards the infant's face and upper body. The consent form included permission to videotape the infant.

Procedure

The procedures for adults and infants were the same as in Experiments 2 and 3 except as noted below.

For Adults. Adults viewed the photographs sequentially and filled out a form on which they rated the attractiveness of each face using a 5-point Likert scale (1-very unattractive; 2-somewhat unattractive; 3-average; 4-somewhat attractive; 5-very attractive). Appendix 7 (c) contains one of the attractiveness rating sheets (taken from Henderson, 1993).

For Infants. Each baby saw a sequence of one face followed by a 5-second presentation of one pattern until he/she had seen all 18 faces. For trials with faces, I used an infant-controlled procedure (Horowitz et al., 1972) to measure the duration of the infant's first fixation on each face. Each face was presented until both observers had judged independently that the baby had fixated the face, then looked away from it. The observers were unaware of the face shown on each trial. A videocamera recorded the baby's face and upper body as he/she viewed each face.

Before the baby was tested, a parent viewed each of the slides and filled out a rating sheet on which he/she rated each face in response to the question "How likely is it that this face will look familiar to your baby?" using a 5-point scale (1-very unlikely; 2-unlikely; 3-possibly; 4-likely; 5-very likely).[1] See Appendix 7 (d) for the familiarity rating sheet. The parent used a remote control device to advance the projector after each rating. The parent viewed the faces in one of the orders that was used with babies, but in a different order from his/her own baby.

Data Analysis

For Adults. The data for adults consisted of their ratings of the attractiveness of 18 photographed faces. Because there was no correlation between trial number and adults' ratings, I averaged each adult's ratings across the six examples from the whole procedure for each feature height to yield three mean ratings: low, medium, and high height. These scores were subjected to an ANOVA on ratings of attractiveness, with one within-subjects factor (features' height), followed by Tukey post-hoc tests.

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[1] Parents' ratings were included in order to later examine each baby's looking times to the faces that the parent judged to be the most and least familiar to his/her baby. Although it is only an indirect measure of what is familiar from the infant's perspective, I thought it might reveal some interesting effects.

For Infants. The data for infants consisted of their looking time to the 18 photographed faces, as recorded by two observers. The Pearson correlation between the ratings of the two observers ranged from 0.84 to 1.0 (mean $\underline{r} = 0.97$). I averaged the looking times recorded by the two observers during each trial and then averaged babies' looking times across the six examples of each feature height to yield three mean scores: looking time to low, medium, and high height. These scores were subjected to an ANOVA with one within-subjects factor (features' height). Because babies' looking times decreased during the procedure ($\underline{r} = -.78$ between trial number and mean looking time), I also performed an ANOVA on looking times during the first three trials. Because the data for one of these scores (low height) were positively skewed, I used a logarithmic transformation (base 2) to normalize the distributions (Kirk, 1982).[2]

I also analysed the infant's looking time to the two faces judged by the parent as most and least familiar to his/her infant. If a parent gave one of these ratings for more than one face, I used the face that the baby had viewed earliest in the sequence. I used a paired t-test to compare the mean looking times to the "most familiar" and "least familiar" faces. Five parents gave the same rating for all 18 faces, and so the data from their infants were excluded.

To score facial reactions to each of the 18 faces, I used a 7-point scale adapted from Werker and McLeod (1989) (1-negative/distressed, agitated, actively avoiding; 4-neutral; 7-positive/happy, excited, seeking interaction). I was aware of which trials contained faces versus patterns, but was not aware

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[2] The results were the same when I analysed the raw looking times.

of which face was shown on each trial. I based my decision on any *change* in the baby's emotional expression from the period before the face was presented. Thus, a baby who smiled throughout the procedure received a rating of 4 (i.e., *neutral* or no change in affect). Appendix 7 (e) shows the affect scoring sheet.

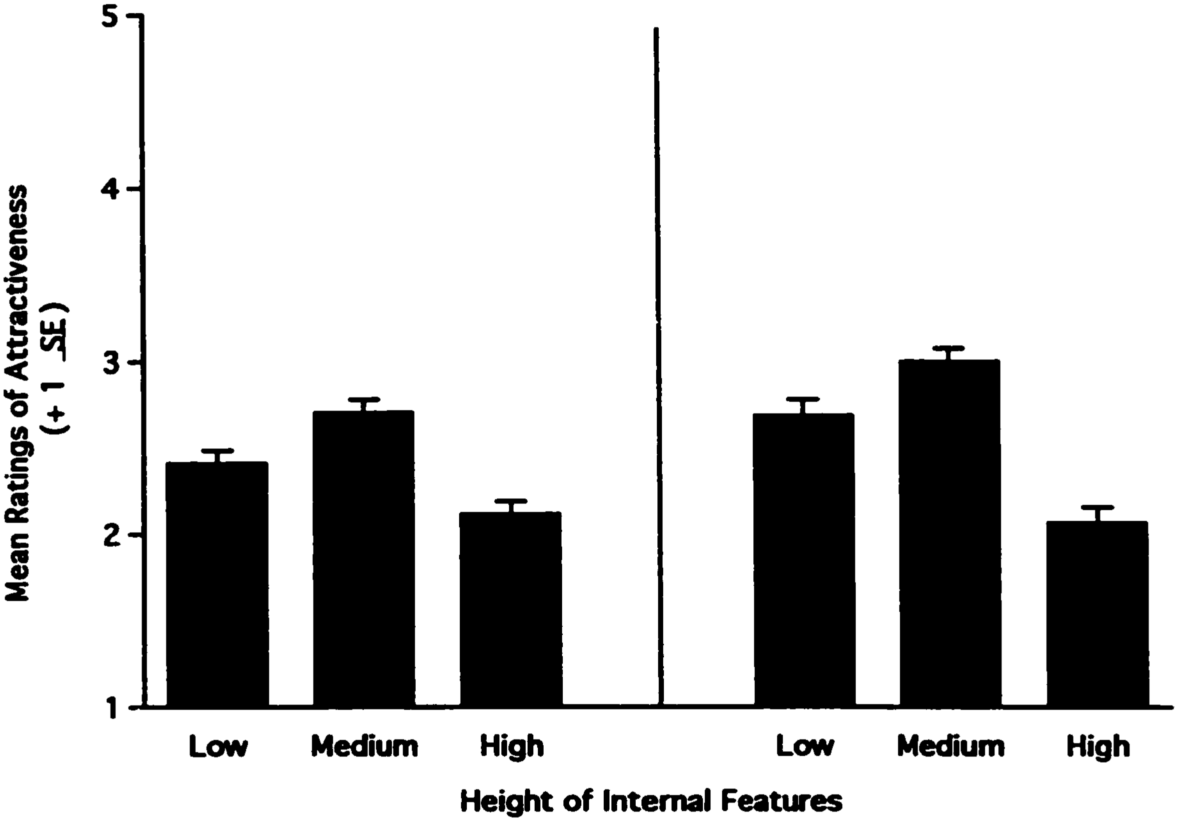
Babies' affect scores were averaged across the three examples of each height of internal features to create three scores: mean affect to faces with features at low, medium, and high height. I analysed these scores with an ANOVA with one within-subjects factor (features' height). I also conducted an ANOVA on affect scores during the first three trials.

Results

Adults. The ANOVA showed a significant effect of features' height on adults' ratings of attractiveness. $\underline{p} < .0001$. (A test of homogeneity of variance for the main effect of feature height was not significant, Mauchley's sphericity, $\underline{x}^2 (2) = 7.24$, $\underline{p} > .10$.) Adults rated the faces with their features at the low and medium heights as more attractive than the faces with their features at the high height, and they rated the faces with their features at the medium height as more attractive than the faces with features at the low height ($\underline{p}$s $< .01$). Figure 9 (right side) shows adults' mean ratings of attractiveness. For comparison, Figure 9 (left side) shows adults' mean attractiveness ratings from Henderson et al. (1994) that used sequential presentations of the black-and-white schematic faces.

Figure 9.

Adults' mean ratings of attractiveness (+1 SE) of the faces varying in the height of their internal features from Experiment 4 that tested adults with colour photographs (right side) and in the previous experiment by Henderson et al. (1994) that used black-and-white drawings (left side).



Schematic Drawings
(taken from Henderson et al., 1994)

Colour Photographs

Infants. Features' height did not affect babies' looking time during the first three trials or across the whole procedure (ps > .10), nor were babies' mean looking times correlated significantly with adults' mean aesthetic ratings for the 18 faces (Spearman rank correlation, p > .10). Figure 10 shows infants' mean *raw* looking times during the first three trials. Figure 11 compares infants' mean raw looking times averaged across the entire 18 trials for photographed faces in this experiment (right side) and for the black-and-white schematic faces used in the Henderson et al. (1994) study (left side).

Features' height did not affect babies' facial expressions during the first three trials or across the whole procedure (ps > .10). Figure 12 (right side) shows the observer's mean affect ratings for photographed faces with low, medium, and high heights during the first three trials. For comparison, Figure 12 (left side) also shows mean affect ratings to the black-and-white schematic faces from Henderson et al. (1994).

Babies' looking times were not related to the parents' judgments of familiarity: looking times to the faces rated as being most unfamiliar (9.3 seconds) and familiar (8.0 seconds) to their babies did not differ significantly, p > .10.

Figure 10.

Five-month-olds' mean *raw* looking times (+SE) to the female photographed faces with their features at the low, medium, and high heights in Experiment 4. The data are from the first three trials only.

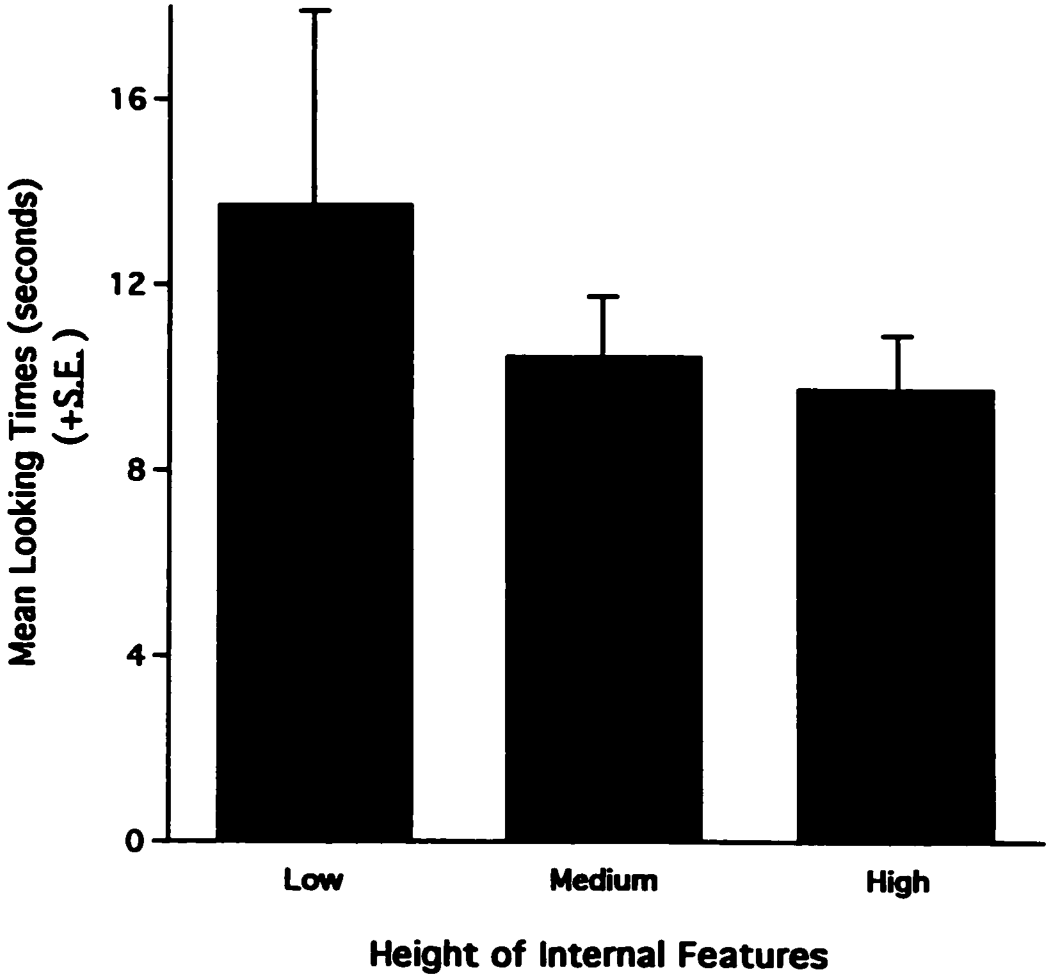
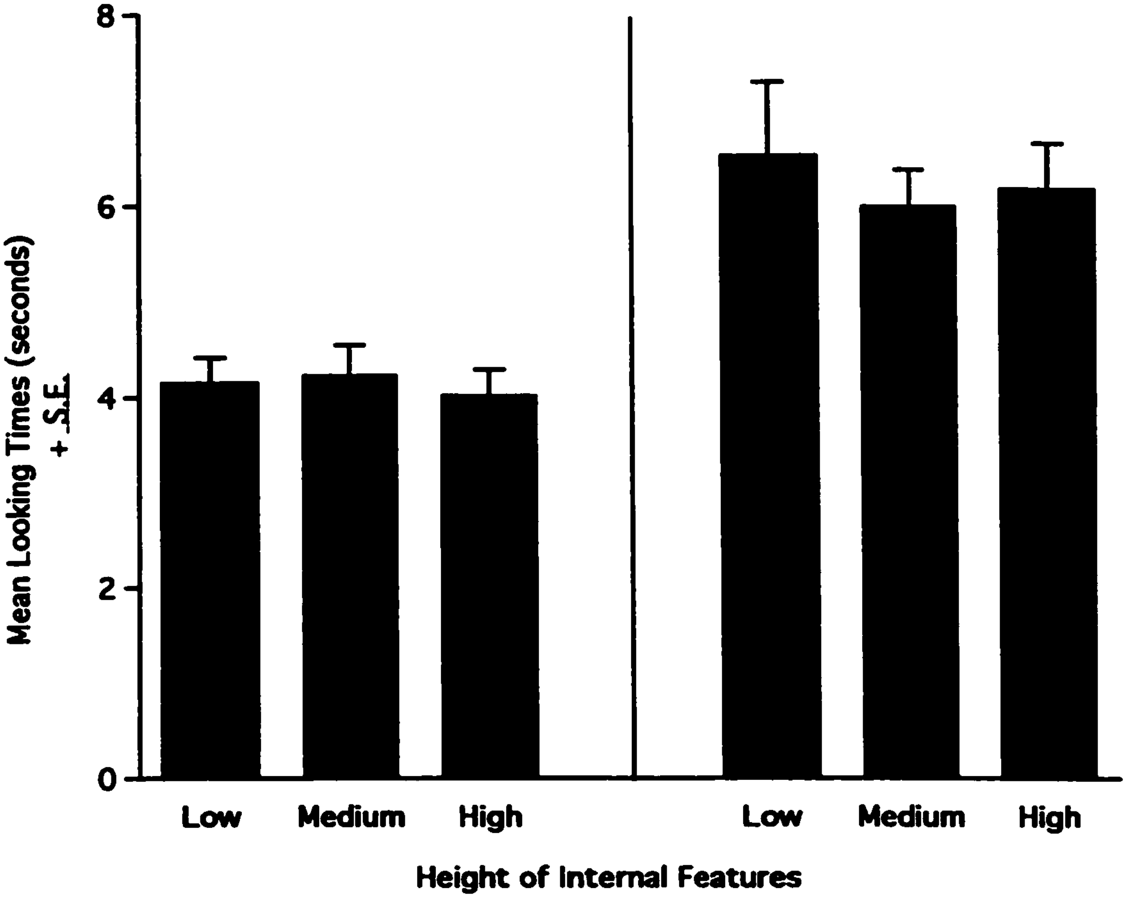

Mean Looking Times (seconds)
(+S.E.)
16
12
8
4
0
Low
Medium
High
Height of Internal Features

Figure 11.

Five-month-olds' mean *raw* looking times (+SE) to each of the three versions of faces with their features at the low, medium, and high heights of coloured photographs of faces used in Experiment 4 (right side) and of schematic drawings used in Henderson et al. (1994) (left side). The bars indicate the looking time averaged across the entire 18 trials of the procedure.

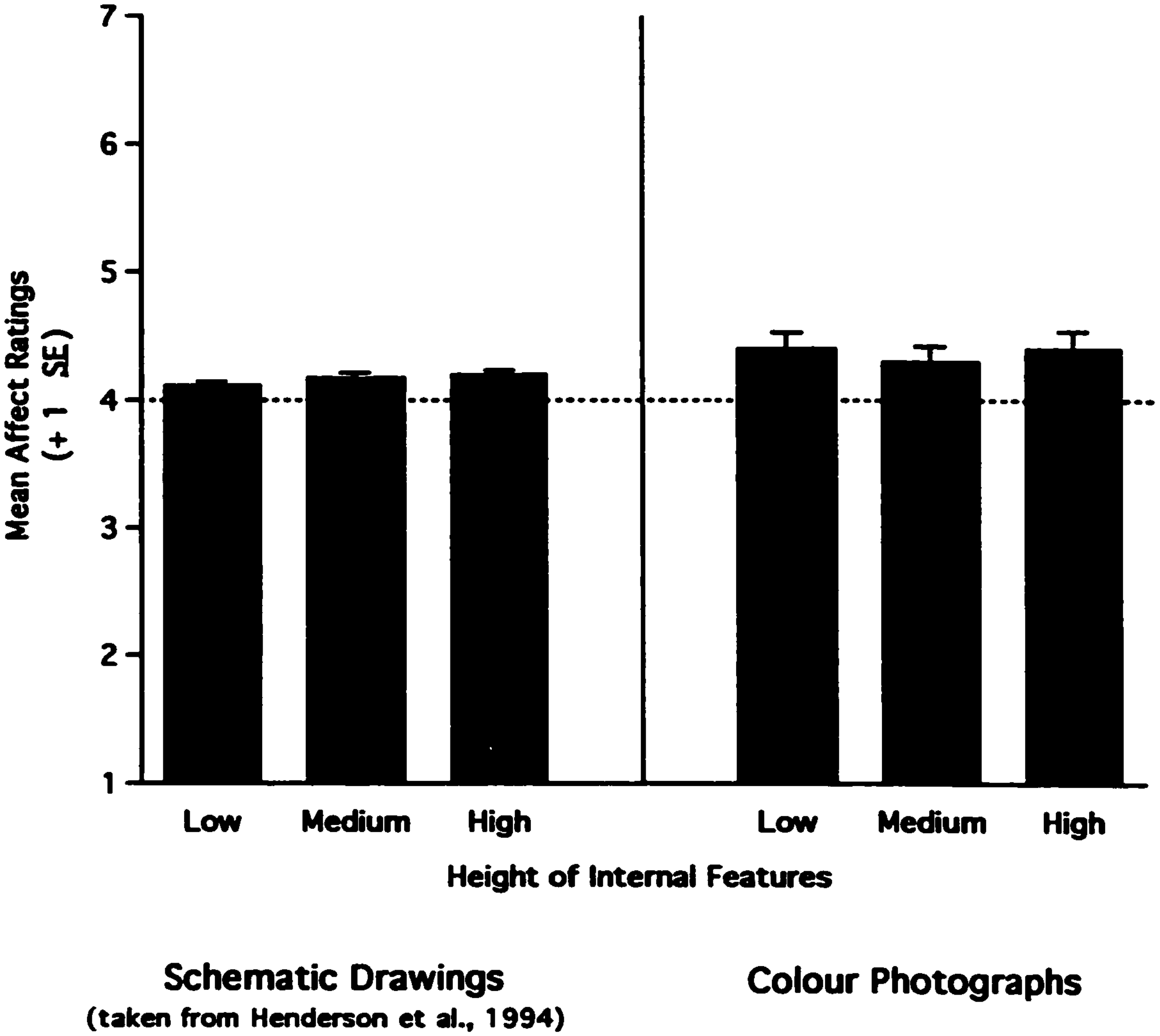


Schematic Drawings
(taken from Henderson et al., 1994)

Colour Photographs

Figure 12.

Mean ratings of 5-month-olds' affect (+1 SE) in response to the colour photographs of faces with their features at the low, medium, and high heights from Experiment 4 (right side) and to the schematic faces from Henderson et al. (1994) (left side). The bars in the left panel indicate babies' affect scores averaged across the first half of the procedure; in the right panel, babies' affect scores come from the first three trials.


Mean Affect Ratings
(+ 1 SE)
7
6
5
4
3
2
1
Low
Medium
High
Low
Medium
High
Height of Internal Features
Schematic Drawings
(taken from Henderson et al., 1994)
Colour Photographs

Discussion

In Experiment 4, adults rated the female photographs of faces with their features at the medium height as most attractive and the faces with their features at the high height as least attractive. These effects were also observed in Experiment 2 with male and female schematic faces, and with previous studies that tested both Caucasian and Korean adults' ratings of schematic faces (Henderson et al., 1994; McArthur & Berry, 1987). Adults respond favorably to faces with medium features—containing an averaged-sized forehead and chin—perhaps because faces with their features placed in average positions signal good gene quality or health (Grammer & Thornhill, 1994; Langlois & Roggman, 1990; Thornhill & Gangestad, 1993) and/or because of their resemblance to a "face" prototype (Langlois & Roggman, 1990; Langlois et al., 1994). Even without abstracting facial prototypes, adults may find average-looking faces to be attractive because they are most similar to the large number of examples that have been stored in memory (Brooks, 1987).

Adults in Experiment 4 also gave higher ratings of attractiveness for female faces with their features at a low height than for faces with their features at a high height, just as they had done in Experiments 2 and 3 with male and female faces. This result is consistent with previous findings from our laboratory (Henderson, 1993; Henderson et al., 1994) and with several published reports that adults rate female faces with more babyish features, including a larger forehead and a smaller chin, as attractive (Cunningham, 1986; Johnston & Franklin, 1993; McArthur & Apatow, 1983-1984). My findings for male faces agree with one study showing that adults rated male faces containing a group of babyish features as more attractive than male faces with less babyish features (Berry & McArthur, 1985), but they do contradict a different report that adults judge male faces with their features at a high height as most attractive (McArthur & Apatow, 1983-1984), and other reports that adults rate male faces containing a number of features labelled as "mature", including a larger chin, as well as prominent cheekbones, bushier eyebrows, and thinner lips, as more attractive than faces with less mature features (Cunningham et al., 1990; Keating, 1985). Keating (1985) proposed that dominant body features, such as larger physique, jawline, and teeth, may be reliable markers of reproductive success in adult males (i.e., success in competitions for access to mates and in protection of family against predation), and that being attracted to, and mating with, males with these features is an adaptation. My findings do not support this interpretation, but they do not rule it out either because I manipulated only two of the features that signal maturity, viz. possessing a large, prominent chin and a very small forehead, and there may be other facial features possessed by adult males that make them look more mature and more attractive. Also, contrary to the predictions of this particular evolutionary model, there may be an optimal size of chin and forehead that gives an impression of maturity and looks attractive. It is possible that none of the faces I used approximated that optimal size as well as the examples previously used (e.g., Cunningham et al., 1990; Keating, 1985; but see McArthur & Apatow, 1983-1984 for similar manipulations). In any event, the results of Experiments 2 to 4 suggest that the babyishness of these two features makes both male and female faces more attractive. Of course, it is not clear whether the greater appeal arises from the large forehead or the small chin, or from the combination of both.

In most cases, adults rated male and female faces with their features at the medium height as more attractive than faces with their features at the low height. This contrasts with a report that adults judge female faces with low features as most attractive (McArthur & Apatow, 1983-1984), but because those faces had small chins similar in size to those in my faces with medium features, the findings are not discrepant. In any case, adults may perceive both low and medium features, or by extension, neonatal and average-looking features, as attractive in female faces and have difficulty choosing between them (Cunningham, 1986; Johnston & Franklin, 1993; Langlois & Roggman, 1990). This interpretation is supported by the similarity of adults' ratings of low and medium features in all of my experiments (see Figures 6 and 9) and the absence of a significant effect in Experiment 3.

Adults' ratings of attractiveness might also reflect their sensitivity to the golden section, the proportion for splitting a figure that adults find most pleasing (Piehl, 1978; see also Green, 1995 for a review). It is interesting to note that in the faces with high features, the location of the eyes—a feature known to be important to adults (e.g., Cunningham, 1986; Experiment 1)—split the face into two segments that deviated most from the golden section. The golden section, or a ratio of approximately 40:60, is achieved when the ratio of the shorter segment to the longer segment is the same as the ratio of the longer segment to the whole. In the faces in Experiments 2 to 4, the ratios, with the shorter segment defined by the distance from the top of the forehead to the eyebrows, and the longer segment defined as the distance from the eyebrows to the chin, were 50:50, 40:60, and 30:70 for the low, medium, and high features, respectively. Thus, adults rated faces with proportions farthest from the golden section as less attractive than faces with proportions closer to it. It may be that the influence of the height of internal features on adults' judgments of faces' attractiveness reflects their sensitivity to basic proportions and not something that is special about faces.

The height of the features influences adults' aesthetic ratings, though it appears to exert only a subtle effect. Adults' higher aesthetic ratings for medium and low features over high features was significant but not strong: in Experiments 2 and 3, the mean rating of relative attractiveness was closer to the value on the Likert scale labelled "somewhat more attractive" (+1) than it was to the value labelled "much more attractive" (+2); in Experiment 4, it was close to the midpoint of the 5-point Likert scale, indicating that adults perceived them as "average" (3) rather than as "somewhat attractive" (4) or "very attractive" (5). The faces I created differed in only the height of the internal features, and it is known that adults' aesthetic judgments are influenced strongly by other characteristics (e.g., Cunningham, 1986; Langlois & Roggman, 1990). Adults' attractiveness ratings in this experiment are similar to those reported by Henderson et al. (1994) who manipulated only the features' height in drawings (refer to Figure 9) and in other studies that manipulated drawings of faces along one dimension (e.g., eye size, height of features) (e.g., Carney, 1995; McArthur & Apatow, 1983-1984). However, they are less extreme than those reported in experiments using drawings of faces in which many features were manipulated simultaneously (e.g., McArthur & Apatow, 1983-1984; McArthur & Berry, 1987) and in studies using nonadulterated colour photographs of faces that will have differed in many features (e.g., Cunningham et al., 1995; Langlois et al., 1987).

The results from 5-month-olds suggest that the height of the internal features begins to exert its influence in an adult way only after early infancy. In Experiment 4, like Experiments 2 and 3, the infants did not look longer at faces rated as attractive by adults. Just as there were no differential responses based on looking times, in Experiment 4 infants' facial expressions to the photographs varying in the features' height did not differ significantly. This finding is not consistent with the earlier finding by Henderson et al. (1994) that babies expressed more positive affect to the version of schematic faces with high features than to the version with low features. However, a look at Figure 12 reveals that whether they saw drawings in that study or photographs in Experiment 4, the infants' facial expressions were close to neutral (i.e., no change), a finding that suggests that feature height has a negligible effect, if any, on babies' facial expressions.

With the exception of Experiment 4, there were some signs that the 5-month-olds did respond to the features' height, but in a direction opposite to adults: infants in Experiment 2 looked significantly longer at schematic faces with high features than at schematic faces with low features, and in Experiment 3, they tended to do the same with photographs. Babies' preference for high features failed to reach significance with colour photographs in Experiment 4 perhaps because the photographs were more interesting to view than the drawings. In support of this hypothesis, infants' overall mean looking times to faces were longer when they viewed the colour photographs in Experiment 4 than when they viewed the schematic drawings used by Henderson et al. (1994) (see Figure 11 for a comparison of looking times for schematic faces vs. colour photographs).

The finding that in some cases, babies look longer at faces with their features at the high height than at faces with their features at the low height, and the previous finding that 5-month-olds have greater positive facial expressions when viewing schematic faces with high features (Henderson et al., 1994) collectively suggest that 5-month-olds have a mild preference for faces with high features. I have speculated that babies' preference arises from their familiarity with smaller foreheads and/or larger chins—as they typically view faces from below the chin. If this is true, then the preference might change when the child starts to have more frequent face-to-face interaction from an en face perspective. In the next section, I describe Experiment 5 that examined the influence of the height of the faces' internal features on young children's ratings of prettiness. The goal was to determine whether the adultlike influence emerges at around three years of age, an age at which many children have much more contact with the faces of peers, which have a larger forehead and a smaller chin than the faces of adults (Enlow, 1982).

2.4. THE EFFECTS OF THE HEIGHT OF FACES' INTERNAL FEATURES ON 3-YEAR-OLDS' RATINGS OF PRETTINESS

A. Background and Purpose

Experiments 2 to 4 suggest that young infants have a mild preference for faces with their features at a high height—which adults rate as least attractive—over faces with low features. In no condition did 5-month-olds differentiate between faces with features at a medium height—which adults rate most attractive—and those with low or high features. These findings complement earlier findings from our laboratory showing that 5-month-olds demonstrate more positive affect for faces with high features (Henderson et al., 1994). One possible explanation is that young babies' preferences may be based on their familiarity with faces as they appear when viewed from below the chin. Experiment 5 was aimed at determining when during development the adultlike influence of the features' height begins to emerge.

If the development of adultlike preferences for faces varying in the height of their features depends on significant experience with faces from an en face perspective, then those preferences might be expected to emerge only after the child begins to have more experience looking at faces en face and less exposure to faces from below the chin. This might happen after the first few years of life, in the presence of physical changes (e.g., sitting upright, standing, becoming taller) and increasing mobility (crawling, walking). Their emergence might also be related to significant experience viewing the faces of other children from eye level, which would be quite common in 3-year-old children, who converse and play with others in preschool and playgroups.

Even so, children's first face-to-face experiences from eye level may be with faces with their features at a low height because the features of children's faces are lower on the face than is true in adults (Enlow, 1982; see also Alley, 1981). They are also typically low on the faces of dolls and stuffed animals. Thus, I suspected that by three years of age, children may perceive faces with their features at a low height, yielding a larger forehead and a smaller chin, as attractive or "pretty"—just as adults find them more attractive than the faces with high features—because such faces resemble the children's mental prototype of the faces to which they have been exposed.

There are other reasons to suspect that the pattern of adult aesthetic preferences might be present by three years of age, if not earlier. Like adults, children as young as three years of age demonstrate aesthetic preferences verbally (Dion, 1973; Langlois & Stephen, 1977; Martin, Eisenbud, & Rose, 1995). Those perceptions also influence their behaviours. Just like adults, young children demonstrate the "beauty is good" stereotype by attributing positive qualities (e.g., friendliness, intelligence) to individuals they judge as more attractive or pretty and by attributing negative qualities to those they judge as less attractive (e.g., Dion, 1973; Dion, Berscheid, & Walster, 1972). More importantly, young children share similar opinions concerning which faces in a set are more attractive, and their aesthetic ratings are in the same direction as adults' aesthetic judgments: when asked to point to the face in a pair that they judge as more pretty, 3- to 6-year-olds point to the face previously judged by adults as more attractive (Dion, 1973).

In Experiment 5, I examined the influence of the height of the faces' internal features on 3-year-olds' ratings of prettiness. Using a method adapted from a study of preschoolers' ratings of the prettiness of adults' faces (Dion, 1973), the 3-year-olds viewed pairs of colour photographs of female faces with their features at two different heights, and for each pair, pointed to the face they perceived as more pretty. In addition, to see if aesthetic judgments were influenced by exposure to similar-aged peers, I asked parents the number and ages of siblings and the types and frequency of social activities in which their child was involved, and then split the children into groups with more or less exposure to peers.

To give the children practice with the task and to assess whether they understood the instructions, all children were given a preliminary screening task that assessed their aesthetic preferences when viewing pairs of non-face objects (e.g., dolls' dresses, balls). These objects differed in colouring, style, and in prettiness as judged by 3-year-olds and adults in pilot testing.

B. Experiment 5

Method

Subjects

The subjects were 24 (12 male) 3-year-olds (M age: 36 months; age range: 34 to 38 months). The children were recruited from responses to announcements in the department and from names on file of mothers who had volunteered their babies at birth for later study. Three additional children were tested but excluded from analyses because they failed the screening pretest (see Procedure). All subjects were Caucasian.

Stimuli

The face stimuli were the 18 colour slides of female faces (i.e., 6 faces x 3 versions) varying in the height of their internal features that had been used in Experiments 3 and 4 with 5-month-olds and adults. The faces were presented in pairs as in Experiment 3. The six female faces were divided into two sets of three, with half of the subjects viewing one set and the other half viewing the second set. The children viewed only one set of three faces to reduce the length of the procedure because pilot testing showed that 3- and 4-year-olds had difficulty maintaining their attention on the task after only three or four trials.

Within each set of three faces, the child saw each of the three types of pairing (i.e., low with high, low with medium, and medium with high height) illustrated with a different face. The face used to illustrate each type of pairing and their order were counterbalanced across subjects. A non-facial stimulus followed each pairing of faces. To shorten the procedure for 3-year-olds, and because I planned to analyse the ratings based on children's first impressions of faces, there was no left-to-right reversal of each pairing as there had been for subjects in Experiments 2 and 3. Thus, the test consisted of only five trials (i.e., 3 pairings of faces separated by 2 non-face patterns).

There were four pairs of non-face objects used in a screening pretest designed to give children practice with the task. The objects within each pair were of the same class: (1) a bouncing blue-coloured ball; a bouncing red ball with coloured, plastic gems decorated in a pattern of vertical stripes; (2) a doll's dress made from green cotton fabric and containing a simple design; a doll's ballgown made of light blue satin, white lace, and sequeins; (3) a black haircomb; a shiny-gold haircomb with a handle patterned with coloured jewels; and, (4) an old, chewed yellow pencil; a new, gold-trimmed blue pen. These pairs of objects were chosen based on the assumption that one member would be perceived as more pretty, an assumption which was later confirmed in pilot testing with 3-year-olds and adults. The order of presentation of the four pairs of non-face objects, and which item appeared on the left side, was randomized across subjects.

Apparatus

Each child sat in a child's chair in front of a child's table containing a small wooden frame that held the projection screen (64 cm wide x 28 cm high). The carousel projector from which the faces were rear-projected was placed on a platform behind the screen. A remote control device was used by the tester to advance the slide projector.

For the pretest with non-face objects, the child's chair was turned so that he/she faced the tester rather than the screen. The four pairs of objects were held in a bag and then brought out in front of the child one pair at a time. The tester held both objects by the tips of her fingers so that they were about 40 cm apart and 50 cm from the child's eyes.

Procedure

The procedure began with the practice task in which the child viewed four pairs of non-face objects, and for each pair, was asked to point to the object perceived as more pretty. To be included in the analyses a subject was required to choose, for at least three of the four pairings, the member of each pairing that had been preferred by most adults and children in pilot tests.

For testing with face pairs, the child sat in a chair with his/her eyes 75 cm from the projection screen. The tester faced the child rather than the screen so that she was unaware of the faces shown on each trial. When the child appeared ready, the tester advanced the slide projector to the first pair of faces, and said "These are the faces of two women. Show me the face you think is more pretty by pointing to her." Following the child's pointing response, the tester coded it on the scoring sheet, advanced the projector to present a non-facial pattern, and said "This is not a face, is it? Let's go on and look at more faces." She then presented the next pair of faces. This procedure continued until the child provided ratings for all three types of pairings of faces. No child took more than five minutes to complete the ratings.

After the child was tested, the tester asked the parent questions about his/her child's social contacts and recorded the responses on the scoring sheet. The parent was asked to indicate the number and ages of the child's siblings, and the frequency (e.g., hours, days per week) with which the child participated in social activities outside of the home, including school (e.g., bible school, nursery school, daycare), group lessons (e.g., swimming, dance), and playgroups. The parent was also asked to list the approximate age(s) and numbers of children who participated in each activity. See Appendix 7 (f) for a copy of the scoring sheet. The parent was told about the purpose of the questions and the experimental hypothesis after completing the questionnaire.

I rank-ordered the children on the basis of the quantity of their interaction with other children and then split the sample at the median and classified the groups as either "more exposed" or "less exposed" to peers. A second observer, who independently rank-ordered the subjects, agreed with my classification for 21 of the 24 subjects. Our rank orderings were significantly correlated (Spearman correlation, $p < .05$). We then reviewed the ranks together and came to an agreement about the discrepancies.

Results

As shown in Table 2, the 3-year-olds' ratings of prettiness were distributed randomly between the two versions of each face, regardless of whether they saw pairs of faces with low and high features, low and medium features, or with medium and high features (two-tailed binomial tests, $ps > .10$).

Table 2.

For each of the three types of pairings consisting of two versions of colour photographs of faces with their features at two different heights, the number of 3-year-olds who rated each version as *more pretty*.

Low vs. High	Medium vs. High	Medium vs. Low
15 vs. 9	13 vs. 11	10 vs. 14

N = 24

all ps > .10 (2-tailed binomial test)

Table 3 shows the number of 3-year-olds in each of the two groups who rated one version as more pretty for each of the three face pairings. A 2 x 2 Chi Square test on independent samples was significant for the pair of faces with low and high features, $\underline{x}^2$ (1) = 5.55, $\underline{p} < .05$, but was not significant for the pair of faces with low and medium features, nor with medium and high features ($\underline{x}^2$ [1] = 0 and 0.17, respectively, $\underline{p}$s > .10) . In the group of children with less exposure to peers, the height of the internal features had no effect on their ratings of prettiness. The results were similar for the group having more exposure to peers, with one exception: these children rated the faces with their features at the low height as more pretty than the faces with their features at the high height.

Table 3.

For each of the three types of pairings consisting of two versions of colour photographs of faces with their features at two different heights, the number of 3-year-olds in each group classified as having "less exposure to peers" and "more exposure to peers" who rated each version as *more pretty*.

Group†	Low vs. High	Medium vs. High	Medium vs. Low
Less Exposure	5 vs. 7	6 vs. 6	5 vs. 7
More Exposure	10 vs. 2*	7 vs. 5	5 vs. 7

†n = 12 per group

*$p < .05$ (Chi Square test)

Discussion

In general, the height of the internal features did not influence 3-year-olds' ratings of faces' prettiness. These results are different from those for adults in Experiment 3 who rated these same photographs of faces with their features at the low and medium heights as more attractive than the version of the face with its features at the high height.

It is unlikely that the results are an artifact of the task being too difficult for the 3-year-olds. They merely had to point to the face of a pair that they perceived as more pretty, and all of those included in the final study had performed well during the practice trials with non-face objects. Moreover, using the same method, Dion (1973) found that 3-year-olds' aesthetic ratings of photographs of adults' faces matched adults' ratings. It is possible that the children in Experiment 5 did not look at the facial stimuli as carefully as the non-face objects in the practice trials and/or had trouble making decisions about two similar-looking faces differing only in the features' height. Either could have led to random responses. However, it is unlikely that task difficulty caused the overall pattern of results because the subgroup of 3-year-olds with more exposure to peers exhibited one significant preference: they rated faces with their features at the low height as prettier than faces with their features at the high height. This finding shows that 3-year-olds are capable of making aesthetic judgments based on changes in feature height, and that their judgments are like those observed in adults (Experiments 2 to 4).

The pattern of results from the two groups of children in Experiment 5 supports the hypothesis that amount of exposure to peers' faces plays a role in the development of aesthetic preferences for faces with their features at a particular height. There was no influence of feature height in children who had infrequent contact with other children, unlike the group with more social contact. Frequent exposure to the young-looking faces of other children (Enlow, 1982) may cause 3-year-olds to perceive young-looking features, including a larger forehead and a smaller chin, as familiar and appealing. This preference for low features is likely to be present in most children by age five or six, when formal schooling enables them to have a wealth of en face interactions with same-aged children. As shown in Experiments 2 to 4 with adults, the aesthetic preference persists into adulthood. Such preferences were not observed in 5-month-old infants' looking times or facial expressions in Experiments 2 to 4, presumably because babies' interactions with people are mostly from below the chin rather than from eye level.

In any event, additional experience with faces after three years of age may be necessary for the development of other adultlike aesthetic preferences. As children grow taller, they have more opportunity to view the mature faces of their parents, teachers, and older friends from an en face perspective. With more frequent en face interactions with adults, children may begin to perceive the typical proportions of adults' faces, i.e., faces with a medium sized-forehead and chin, as more familiar, and hence, as more attractive. Such preferences may emerge during mid- to late childhood because they depend on gaining experience less biased towards the young-looking faces of play dolls and young peers, and a change from a mental prototype of a face based on babyish features to one based on average-looking features (see Langlois & Roggman, 1990).

Although I have shown that children's aesthetic judgments of faces varying in the features' height correlated with their frequency of exposure to children's faces, and hence, may be based on that exposure, there might have been other influences on their perceptions. The 3-year-olds with more involvement in outside social activities (e.g., daycare, preschool) might have had more exposure to societal norms because of more exposure to adults and greater access to fairytale books and juvenile television programs. They might have learned that young-looking faces appear in heros/heroines (e.g., Cinderella, Snow White) whereas more dominant faces are associated with villains (e.g., Cinderella's stepmother, wicked witch). However, this explanation seems unlikely because all young children are exposed to adults' faces and have access to television and dolls. Children with less involvement in social activities, if anything, are more likely to have more exposure to television.

In conclusion, the results indicate that the influence of the height of the internal features on perceptions of attractiveness is not adultlike by three years of age. Although the preschoolers in this study differ from infants in that some of them showed the adultlike preference for faces with low features over high features, other aspects of adult aesthetic preferences—higher aesthetic ratings for faces with medium features than for faces with low or high features—do not emerge until sometime after early childhood, perhaps because they depend on additional experience with faces and/or social learning.

2.5. GENERAL DISCUSSION

The findings reported in Experiments 1 to 5 support the hypothesis that there is an influence of experience on the development of the perception of faces' attractiveness. The results of Experiment 1 suggest a role for experience with faces during infancy in the development of a preference for faces with larger eyes. The findings from Experiments 2 to 5 suggest that many years of experience may be necessary for the development of adult aesthetic preferences for features in low and medium positions on the face.

In my study on the influence of eye size, adults rated colour photographs of female faces with larger eyes as more attractive than faces with smaller eyes and 5-month-olds looked longer at the faces with larger eyes. The 5-month-olds responded to variations in eye size when viewing realistic, colour photographs but not when viewing black-and-white drawings of faces in a previous study (Carney, 1995), and the differences between the faces with larger and smaller eyes in size and amount of contour were *smaller* in the photographs. This pattern shows that the infants' preference is not based solely on patterns' physical size or contour but rather on what they have learned by viewing real faces. I have speculated that the adultlike aesthetic preference develops sometime during infancy, namely after infants at two months begin to scan the internal facial features, especially the eyes (e.g., Maurer & Salapatek, 1976), after they become able at three or four months to recognize faces based on the internal features, including the size of the eyes (e.g., Deruelle & de Schonen, 1998; de Schonen & Mathivet, 1990), and when they have had significant exposure to larger eyes during interaction with adults showing wide-eyed expressions of interest and positive affect. It may be that as a result of often seeing expressive faces with larger eyes, young infants come to see them as familiar and as appealing. An effect of familiarity has also been proposed for the influence of facial averageness on both 6-month-olds' visual preferences and adults' aesthetic preferences: experiences viewing many examples of faces and then being able to extract a "face" prototype may cause both adults and infants to respond to average-looking faces that resemble the prototype as familiar and appealing (e.g., de Haan et al., submitted; Rubenstein et al., 1999).

Even if early visual experience with faces is important for the development of aesthetic preferences, those preferences might have been built from more general preferences present at birth. Newborns' preferences for visual patterns with elements of larger physical size and/or more energy at low spatial frequencies (e.g., Banks & Salapatek, 1981; Fantz et al., 1975) may contribute to the later-appearing preferences by biasing the young infant to look at features that are large in size, such as the eyes. Those natural preferences may even mediate the visual preferences for "attractive" faces observed in newborn infants (Slater et al., 1998), though the basis for the preference likely changes postnatally with developing cortical mechanisms. Support for the hypothesized change comes from studies showing that the period between two to four months of age is a time during which there are dramatic changes in the cortex (see Johnson, 1990, for a review) and during which new face processing capabilities emerge, such as face recognition based on the internal features alone (e.g., de Schonen & Mathivet, 1990), recognition of a face posing with different head orientations (e.g., Pascalis et al., 1994), discrimination of various facial signals (emotional expression, gaze direction) (e.g., Barrera & Maurer, 1981; Vecera & Johnson, 1995), and the formation of a mental prototype of faces (e.g., de Haan et al., submitted). Our findings suggest that by five months of age, babies' reactions to larger eyes are controlled by cortical mechanisms influenced by experience that they could generalize to the coloured photographs used in Experiment 1.

Additional research is needed to learn more about the mechanisms that underlie behavioural preferences for faces with larger eyes. One could test whether there is a mechanism present at birth that contributes to the older infants' preference. Newborns may exhibit longer looking to faces with larger eyes regardless of whether they are viewing photographs or drawings of faces, and the effects may be stronger the larger the size of the eyes, a pattern unlike that observed for 5-month-olds' looking times or adults' aesthetic ratings.

One could also explore whether the cortical mechanisms that we presume govern the older infant's response to faces with larger eyes is especially influenced by exposure to expressive faces. Experience with highly expressive faces is probably similar for infants across cultures (e.g., Kisilevsky et al., 1998), but a different pattern might hold for infants whose parents convey their emotions in a subtle manner. For example, less experience with faces showing positive affect and interest due to parental neglect and depression may make some babies less sensitive to larger eyes, and hence, may lead to perturbations in the typical aesthetic preferences later in life. Similarly, some infants exposed mainly to smaller-eyed faces (e.g., Oriental faces) may exhibit a preference for faces with *smaller* eyes rather than for faces with larger eyes. Studies of individual differences would help to delineate the role of the physical size of the eyes in relation to head frame and the faces' expressiveness on the development of the perception of beauty.

In any event, additional experience after infancy and/or childhood that comes from learning about particular facial characteristics, learning about society's norms, or both, also may be important for the development of adult aesthetic preferences. My studies show that the height of the faces' internal features does not exert its adultlike influence on reactions to faces from early infancy. Adults rated faces with their features at a medium or low height as more attractive than faces with their features at a high height, and in most cases, they rated faces with their features at the medium height as most attractive. In no condition did 5-month-olds look longer at the faces with low or medium features that adults rated as more attractive. Nor did infants show more positive affect to those faces.

Interestingly, the 5-month-olds had a mild tendency to look longer at the faces with their features at the high height that adults found least attractive, just as they expressed more positive affect for drawings of faces with high features in an earlier study (Henderson et al., 1994). One possible explanation for the differences is that adults' aesthetic judgments are influenced by the position of the features in a prototypical face (Langlois & Roggman, 1990), but that infants are not influenced in the same way because they typically inspect faces from below the chin—with a shrunken forehead and a prominent chin. If this interpretation is correct, it provides additional evidence that aesthetic preferences are influenced by familiarity, beginning in infancy. In this case, however, adults' preferences appear not to be founded on the early learning. It would be interesting to see whether the effects in infants are the same when tested with faces photographed from the viewing perspective of the infant. Those faces may more closely resemble the baby's prototype of a face than do my faces with high features, and consequently, may lead to stronger behavioural preferences for high features than were observed in Experiments 2 to 4.

Experiment 5 provides independent evidence that experience viewing faces from an en face perspective contributes to the development of adult aesthetic preferences. The findings from 3-year-olds suggest that a change from a preference for faces with high features to a preference for faces with low features is related to the amount of en face exposure to faces. Although 3-year-olds as a group did not exhibit differential ratings, a subgroup with more exposure to peers rated faces with their features at the low height as more pretty than faces with their features at the high height, just as adults rated those faces as more attractive. The children's preference may be based on a mental prototype that resembles a face with low features like those of their peers. Even without a face prototype, young children might find faces with their features at a low height to be pretty because they resemble the many examples stored in memory (Brooks, 1987).

One aspect of adult aesthetic preferences—preferences for faces with medium features over high features—appears to emerge late in development. It may be only after physical growth and more exposure to adults' faces from an en face perspective that individuals begin to perceive the typical proportions of adults' faces (i.e., faces with a medium-sized forehead and chin) as most attractive. The development may also depend on social learning, possibly by learning to value individuals whose features resemble the norm rather than individuals who deviate from average. One could test these hypotheses by examining the effect of training with numerous examples of adults' faces from an en face perspective on 3-year-olds' aesthetic ratings. Additional research on the aesthetic preferences in adults with experience viewing faces from a perspective different from eye level—caused by being taller or shorter than average adult height—may also provide more insight about the effects of perceptual learning.

In conclusion, the results reported in Chapter 2 suggest an influence of visual experience with faces on the development of the perception of faces' attractiveness. These findings add to our understanding of the development of face perception, and lead to additional questions. More specifically, are there influences on perceptions of beauty in addition to eye size (Experiment 1) that are rooted in a visual preference during infancy, before extensive cultural conditioning? Does visual experience with faces during infancy shape other adult aesthetic preferences, as seems to be the case for eye size and facial averageness (Rubenstein et al., 1999)? Additional studies could explore other characteristics of faces that adults find attractive (e.g., higher set/arched eyebrows, smaller nose, larger lips, wider smile) (e.g., Cunningham, 1986; Cunningham et al., 1990; Johnston & Franklin, 1993) to see whether they influence young infants in the same way.

Questions also remain about the mechanisms involved in aesthetic preferences that emerge after infancy and/or childhood. Just as I found for the height of the faces' internal features (Experiments 2 to 4), the bilateral symmetry of the facial features influences adults' ratings of attractiveness (e.g., Grammer & Thornhill, 1994), but not the looking times of 4- to 9-month-old infants (Samuels et al., 1994). Thus, each of these characteristics only begins to influence people's reactions to faces in an adult way sometime after early infancy. Future research in this area should be aimed at tracing the age at which bilateral symmetry begins to exert its adultlike influence. This type of research will help to elucidate the role of visual experience during childhood and/or adulthood and the contribution of cultural/social learning.

CHAPTER 3

EXPERIENTIAL INFLUENCES ON THE DEVELOPMENT OF FACE PROCESSING

In Chapter 3, I explore whether adult face processing skills depend on early visual input by comparing subjects with a normal visual history to those who missed visual input because they were born with bilateral congenital cataracts. Patients were treated sometime during infancy by having the cataractous lenses removed and their eyes fitted with contact lenses that allowed nearly normal visual input. The patients participated in the study sometime after the age of 10, when they were old enough to complete tasks designed to measure different face processing skills, and hence, after having had many years of delayed experience with faces. The battery of tasks included: recognizing faces' identity, recognizing facial expression, lip reading, and decoding direction of gaze (Experiment 6); recognizing faces' identity on the basis of individual facial features and on the basis of the spatial relationships among the features (i.e., local and configural processing); and, for comparison, recognizing geometric figures based on the individual elements and the spacing between the elements (Experiment 7). Similarities between patients and normals would indicate that visual experience during early infancy is not necessary for the development of face processing. Any differences would imply that early visual experience may play a role. The chapter begins with a review of recent theories that visual experience with faces during the first weeks of life is critical for the development of face processing and a review of the literature on face processing in normal adults and children. It concludes with an interpretation of the findings, including alternative interpretations of any differences between patients and normal participants.

3.1. BACKGROUND LITERATURE

A. The Development of Face Processing and the Role of Early Visual Experience

Recent theories put forward by Johnson and Morton (1991; Morton & Johnson, 1991) and de Schonen and her colleagues (de Schonen, Deruelle, Mancini, & Pascalis, 1993; de Schonen & Mathivet, 1989) suggest that experience with faces during the first weeks of life is critical because it causes the cortex to form the cortical circuits that will become specialized for face processing over the subsequent months and years. Such cortical circuits are thought to begin exerting a strong influence on infants' behaviour sometime after two months of age when the cortex begins to dominate subcortically-mediated responses.

Johnson and Morton (1991) propose that newborns begin life with a subcortical mechanism, which they term Conspec, that biases them to look at stimuli with high-contrast elements in the configuration of facial features. Such natural preferences for face-like stimuli in human infants may be analogous to the filial preferences in the chick for the mother hen, and for an intact stuffed hen containing the correct arrangement of the features of the head and neck regions over a "jumbled" version of the hen with its features and pelt in scrambled positions (e.g., Johnson & Horn, 1988; also see Morton & Johnson, 1991). According to Johnson and Morton (1991), Conspec gives young infants a wealth of exposure to the faces of their conspecifics, which then enables a later-appearing cortical mechanism, called Conlern, to learn about faces' features and the arrangement of those features. Conlern mediates the face processing capabilities that emerge after the first few months of age, such as recognizing individual faces, recognizing facial expressions and decoding direction of gaze (e.g., Barrera & Maurer, 1981; de Schonen, Gil de Diaz, & Mathivet, 1986; Vecera & Johnson, 1995). After Conlern emerges, the Conspec mechanism is thought to lose its function.

As would be expected if Conspec is present at birth, newborn infants have been shown to move their eyes, and sometimes their heads, further to follow a moving paddle containing facial features placed in the correct spatial locations of the eyes and mouth than to follow a paddle containing features placed in some non-correct locations (e.g., scrambled faces) (Goren, Sarty, & Wu, 1975; Johnson, Dziurawiec, Ellis, & Morton, 1991; Maurer & Young, 1983). Newborns also preferentially orient toward a face-like pattern (i.e., 3 blobs placed on a head shape in the correct locations for eyes and mouth) when it is paired with the same pattern inverted within the head shape, and this is true when the stimuli are placed 30° to 50° from the center of the visual field (Mondloch et al., 1999; Valenza et al., 1996). Johnson (Johnson & Morton (1991; Johnson & de Haan, submitted) has noted that newborns demonstrate visual preferences for faces when the stimuli are moving, as in a tracking procedure, or when they are presented in the far periphery, and he suggests that these methods increase the probability of stimulating a subcortical neural pathway rather than a cortical pathway. The subcortical structures likely to be involved are the superior colliculus and/or the pulvinar, which contain neurons that are more sensitive to moving than to static stimuli and that fire before eye movements toward peripheral stimuli (see Johnson, 1995, for a review).

However, not all studies have found a preference for faces at birth (Easterbrook, Kisilevsky, Hains, & Muir, 1999; Hershenson, Kessen, & Munsinger, 1967; Kleiner, 1987; Johnson et al., 1991; Maurer & Young, 1983). The discrepancy across studies may be due, at least in part, to procedural differences that favour subcortical or cortical pathways. It is also likely due to differences among the stimuli used, which have ranged from being very simple (e.g., Johnson et al., 1991; Mondloch et al., 1999) to very complex (e.g., Dannemiller & Stephens, 1988; Kleiner, 1987; Maurer & Barrera, 1981). It may also be explained by the strong influence on young infants' visual preferences of the energy at the spatial frequencies that can be resolved easily by their immature visual system (Kleiner, 1987). A review of the findings across studies suggests that facedness has an influence on newborns' looking only when face-like and non-face stimuli are equated in visibility (e.g., Mondloch et al., 1999; Morton, Johnson, & Maurer, 1990; but see Easterbrook et al., 1999).[3]

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[3] Valenza et al. (1996) reported that newborns looked longer at a face when the non-facial stimulus, but not the face, had the optimal spatial frequency for the newborn visual system. However, the two stimuli likely did not differ in visibility because newborns are equally sensitive to the spatial frequencies in the two stimuli used (c.f. Atkinson, Braddick, & French, 1979; Atkinson, Braddick, & Moar, 1977).

The postnatal development of a Conlern learning mechanism is supported by the finding that young infants' preferences for moving or peripheral crude face-like stimuli disappear at about six weeks of age (Johnson et al., 1991; Mondloch et al., 1999), and that after two months of age, a face preference is elicited easily when the stimuli are shown singly in the central visual field (Johnson et al., 1991; Maurer & Barrera, 1981). Presumably the subcortical mechanism loses its function after two months of age because it is replaced by a functioning, cortical mechanism.

The existence of Conlern is also supported by changes in the ability to recognize faces during the first months of life. Newborns only four days old look longer at their mother than at a female stranger, even if they have not seen the mother during the preceding two minutes (e.g., Bushnell et al., 1989; Pascalis et al., 1995). However, newborns probably remember only the mother's external facial features (e.g., hair colour or shape) because they do not distinguish between the mother and the stranger if their hair is covered by identical scarves (Pascalis et al., 1995). As early as two months of age, babies recognize faces based on the internal features alone: By two months, infants look longer at their mothers than at a female stranger, even when the women are wearing identical scarves that mask the hair (Morton, 1993). By four months, they show the same ability with photographs (de Schonen, Gil de Diaz, & Mathivet, 1986). By three months of age, after becoming familiarized with an individual face wearing a scarf and posing with various head orientations (e.g., en face, 30° to the left), infants can recognize that face when it is presented in a new orientation (e.g., 30° to the right), even 24 hours later

(Pascalis, Matheny, de Schonen, & Nelson, 1994). Because the cues used for face recognition are different for newborns than they are for older infants, Johnson and de Haan (submitted) argue that a subcortical mechanism, perhaps in the hippocampus, allows the young infant with an underdeveloped cortex to encode isolated "snapshots" of images, such as faces' head shape, hair style or colour, and to have some memory for them. They further suggest that an important role of the Conlern mechanism available to the older infant is to encode faces based on how they differ from a mental prototype of a face, as is true in adults (see Rhodes et al., 1998 for a review of adults' recognition of faces using prototypes). In support of that hypothesis, 3- and 6-month-olds, but not 1-month-olds, provided evidence of forming a mental prototype of faces from a set of individual faces to which they were exposed, and they treated the face prototype as more familiar than the individual faces, as do adults (de Haan et al., submitted; Rubenstein et al., 1999).

The older infants' ability to recognize faces also may depend on the development of a specialized mechanism in the right hemisphere of the cortex: In one study, 4- and 5-month-olds learned to distinguish between two faces more quickly when the faces were presented in the infants' left visual field (i.e., right hemisphere) than when they were presented in the right visual field (i.e., left hemisphere) (de Schonen & Mathivet, 1990). Similarly, 4- to 9-month-olds learned to distinguish between two faces that varied in the spatial relationships among the faces' internal features more quickly when those stimuli were presented in the infants' left visual field (right hemisphere) than when they were presented in the right visual field. In contrast, the infants distinguished between two faces that varied in a single facial feature more quickly when they were shown to the right visual field (Deruelle & de Schonen, 1998). Taken together, the findings suggest that a cortical mechanism located in the right hemisphere may play a role in the ability to encode and differentiate between individual faces based on how they differ in the spatial relationships among the internal features. According to de Schonen and her colleagues (e.g., Deruelle & de Schonen, 1998; de Schonen & Mathivet, 1989), the emergence of that mechanism at around three to four months of age accounts for why the infant begins to recognize individual faces on the basis of the internal features alone and can recognize a particular face despite changes in point of view.

The development of a cortical mechanism used for face processing is supported by many other changes in infants' responses to faces that occur between two to four months of age. Beginning at two months of age, infants switch from scanning primarily the external regions of faces to scanning mainly the internal facial features (Haith et al., 1977; Maurer & Salapatek, 1976). At four months of age, but not at two months, infants demonstrate discrimination of the direction in which a face is looking (e.g., gaze en face vs. 45° to the left) (Hains & Muir, 1996; Hood et al., 1998; Vecera & Johnson, 1995). At three months, infants demonstrate discrimination between some facial expressions, including discrimination of happy (smiling) from sad (frowning) expressions (Barrera & Maurer, 1981) and discrimination of happy from surprise expressions (Young-Browne, Rosenfeld, & Horowitz, 1977). By the second half of the first year, infants are sensitive to a greater variety of facial expressions, including fearful, angry, and neutral expressions (see de Haan & Nelson, 1998, for a review).

Like Johnson and Morton (1991), de Schonen and Mathivet (1989) argue that early visual experience influences the way in which the cortical mechanism used in face processing develops. They argue further that the nature of the early visual input influences the development of hemispheric specialization for face processing. From birth to two months of age, infants' bias to scan the external contours of faces (e.g., Maurer & Salapatek, 1976) causes them to encode features located mainly in the external regions and to be less influenced by any of the features located inside the face.

de Schonen and Mathivet (1989) also argue that young infants' poor visual acuity and contrast sensitivity make them insensitive to the detailed characteristics of faces and other patterns. The finest black-and-white stripes a newborn can resolve are 30 times wider than those an adult can resolve (reviewed in Maurer & Lewis, in press). Although visual acuity improves rapidly during the first months of life, it is still not near adult levels at the end of the first year (e.g., Mayer et al., 1995). Even with wide stripes, young infants need much more contrast than do adults (Atkinson, Braddick, & Moar, 1977; Banks & Salapatek, 1978). By three months of age, infants respond to somewhat higher spatial frequencies, but they still require much greater contrast than adults. For example, 3-month-olds can detect stripes of two cycles per degree with contrast as low as 30 percent, but that contrast threshold is 20 to 30 times higher than in adults. It is not until seven years of age that contrast thresholds become adultlike (Ellemberg, Lewis, Liu, & Maurer, 1999).

Thus, during the first few months of life, infants' poor visual acuity and contrast sensitivity limit encoding of faces and other objects to information carried by the lower spatial frequencies. Because of this, de Schonen and Mathivet (1989) suggest that young babies should be sensitive to the shape of larger facial features and the spatial relationships among those features but relatively insensitive to the fine details in faces. Based on this input, the cortex begins to form stable networks that will eventually become specialized for configural processing of those patterns. These networks are thought to develop in the right hemisphere rather than in the left hemisphere because the right hemisphere matures at a faster rate during the first year of life (e.g., Rosen, Galaburda, & Sherman, 1987) and because there is no apparent transfer of information between the hemispheres during this period (e.g., Liegeois & de Schonen, 1997). Different cortical circuits in the left hemisphere that will become specialized for a different encoding strategy—one that involves parsing and analysing the individual features independently from each other—are presumed to be formed sometime later when the infant gains experience encoding patterns on the basis of small, local features. The formation of such cortical circuits necessary for local processing are thought to emerge sometime after the first few months of life, when improvements in visual acuity and contrast sensitivity allow the infant to encode the details inside the face.

Based on theories about the influence of early visual experience on the development of face processing (de Schonen & Mathivet, 1989; Johnson & Morton, 1991), my research explored whether face processing depends on visual experience during the first weeks of life or can instead develop normally with delayed visual input. To do so, I compared face processing in individuals with a history of normal visual experience to that in patients with a history of bilateral congenital cataracts that deprived them of patterned visual input during early infancy. The patients were born with a dense and central opacity in the lens of both eyes that prevented patterned stimulation from reaching the retina. They were treated by surgical removal of the natural lens and fitting of the eye with an optical correction that gave them nearly normal visual input. The cohort I studied had visual deprivation in both eyes from birth until anywhere from eight weeks to two years of age. They were studied after age 10, and consequently, following many years of experience viewing and processing faces. Hence, the patients provided an opportunity to examine how various face processing capabilities had developed when visual input began only after the first few months of life. If patients performed similarly to normal control subjects of the same age, the findings would suggest that early visual experience is not necessary for the development of such capabilities. If patients did not show the same capabilities as normals, the findings would suggest that the development of those capabilities depends on early visual input. (Alternative interpretations of any differences between patients and normal individuals will be discussed later in the chapter.)

Previous studies from our laboratory indicate that patients with a history of bilateral congenital cataracts have deficits in several visual abilities that normally take several months or years to develop, including sensitivity to contrast, peripheral vision and visual acuity (e.g., Maurer et al., 1989). In contrast, abilities that are relatively mature at birth, such as the discrimination of large forms and colour perception, are essentially unaffected by early visual deprivation (reviewed in Maurer et al., 1989). The findings with human subjects are supported by studies of cats and monkeys showing that visual deprivation from birth produced by eyelid suture causes a dramatic impairment in acuity, contrast sensitivity and peripheral vision (e.g., Mitchell & Murphy, 1984; Sherman, 1973), whereas it causes little impairment in the ability to discriminate between large forms (e.g., Van Hof-van Duin, 1976). On the basis of these findings, Maurer and her colleagues (e.g., Maurer et al., 1989; Lewis & Maurer, 1993) have suggested that the visual functions that are relatively mature at birth are unaffected by early visual deprivation, whereas the functions that are affected most severely by deprivation are immature at birth and are slow to develop. My research explored whether higher-level capabilities in face perception that are immature at birth and that develop postnatally are similarly adversely affected by early visual deprivation.

In the next section, I review the literature on adults' face processing to delineate the nature of their proficiency. I then review the literature on face processing during childhood to determine when during development those skills become adultlike. This review allowed me to gain insight about what types of tasks would be suitable for measuring skills in face processing in the patients, all of whom were at least 10 years old at the time of the test.

B. Adult "Expertise" in Face Processing

Adults are "experts" in face processing: they can identify large numbers of individual faces rapidly and accurately (e.g., Bahrick et al., 1975), and they can easily recognize specific aspects of a single face, including emotional expression, head orientation, and direction of gaze. They can also recognize what a person is saying just by reading his/her lips (reviewed in Bruce & Young, 1986).

One way that adults easily recognize faces and their signals is by using a strategy of local processing that involves parsing and analysing individual facial features. Local processing involves encoding small features, usually inside the face (e.g., shape of eyes or mouth), and the features located on the faces' external contour (e.g., the shape of the ear, the global shape of the chin, hairstyle). Another way that adults recognize faces is by using configural processing, which involves analysing the relationships among the individual facial features. Configural processing, otherwise known as relational or "second-order" processing, encompasses more than one type of relational information in faces, though they have not always been distinguished in the literature. The most common usage refers to processing the spatial relationships among the features inside the face, such as the distance between the two eyes or between the nose and the mouth.[4] It can also involve processing the spatial relationships between the internal features and the features located on the face's external contour (e.g., distance between the eyebrow and bangs) or the relationship between two internal features (e.g.,

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[4] Unless noted otherwise, I will use the term configural processing in this first sense.

pupil and sclera—for detection of gaze direction). These types are contrasted with "first-order" or "holistic" processing, which involves the perception of a facial Gestalt that cannot be easily decomposed into individual features (see Searcy & Bartlett, 1996, for a review of terminology). Whereas the first types of configural processing are useful in distinguishing among individual faces, holistic processing is useful in distinguishing faces from non-face objects.

Despite the fact that human faces are relatively homogeneous in the spatial relationships among the facial features, adults are sensitive to small differences in relational information. Adults can detect very slight changes in spacing among the eyes, nose and mouth (e.g., Bruce, Doyle, Dench, & Burton, 1991; Tanaka & Sengco, 1997), and they easily and quickly recognize faces presented for such short durations that there is insufficient time to parse and analyse each feature separately (e.g., Hole, 1994; Sergent, 1984). Even under normal viewing of faces, adults seem to rely on configural processing more than local processing to differentiate between faces. Researchers have distinguished local and configural processing by manipulating faces so as to favour one form of processing over the over. For example, adults are faster and are more accurate in identifying faces when faces are presented in their normal, upright orientation than when the faces are inverted (e.g., Diamond & Carey, 1986; see Valentine, 1988 for a review). The deleterious effect of inversion is much smaller when adults are asked to recognize other objects, including houses, airplanes, and stick figures (Yin, 1969), and when they are asked to recognize the individual features of objects (e.g., windows of a house, eyes removed from the context of a face) (e.g., Tanaka & Farah, 1993). The inversion effect for faces is thought to occur because adults use their expertise in configural processing to recognize upright faces, but they are unable to perceive the configuration of the features in inverted faces, and so they treat them as non-face objects and adopt a less efficient strategy of local processing that they typically use for differentiating other classes of visual stimuli (e.g., Diamond & Carey, 1986; Yin, 1969). The notion that adults' reliance on configural processing is based on many years of viewing and differentiating among human faces comes from the finding that the deleterious effect of inversion is stronger for homogeneous classes of objects for which subjects have expertise, e.g. dogs of the same breed viewed by dog judges, than it is for stimuli to which adults have had less exposure (Diamond & Carey, 1986; Gauthier & Tarr, 1997). According to both Rhodes (e.g., Rhodes & Tremewan, 1996) and Carey (1992; 1996), adults with a wealth of experience differentiating among homogeneous stimuli (e.g., human faces, dogs of the same breed) are proficient at encoding the spatial relationships among the features, forming a highly-specified mental prototype of the average spatial relationships among the features, and then recognizing any individual exemplar based on how it differs from the prototype.

Adults are also sensitive to the "first-order configuration" of the features (i.e., eyes positioned above nose, and nose positioned above mouth), even under conditions that demand local processing. Young, Hellawell, and Hay (1987) presented the top halves of the photographs of famous people's faces (e.g., Mick Jagger, John F. Kennedy) and trained adults to associate the appropriate name to each half-face. Each top half was then combined with the bottom half of a different person's face to create a "fused" composite, and adults were again asked to name the person in the top half while ignoring the bottom half. Adults were slow to do so, presumably because it was difficult for them to perceptually isolate the halves of the facial gestalt. However, adults' naming improved when the fused faces were inverted or when the two halves of the faces were misaligned horizontally. With inverted and misaligned faces, the facial gestalt was eliminated, so that it was easier for adults to switch from a strategy of holistic processing to a strategy of local processing that was more appropriate for the task.

Even when simply matching unfamiliar faces, adults' reliance on holistic processing can interfere with local processing. Hole (1994) had adults report whether the top halves of pairs of unfamiliar composite faces were the same or different. Adults' decisions were slower when the faces were shown upright than when they were shown inverted. However, this effect was observed when adults saw the faces for 80 milliseconds and not when they had one second to view the faces. At the longer duration, subjects were just as fast and accurate in their judgments whether the faces were upright or inverted. Thus, when the task calls for local processing, and when given enough time to parse and analyse the parts, adults can switch from holistic processing to effective local processing.

Adults' expertise in identifying people's faces, identifying other facial signals, and in using strategies necessary to efficiently recognize faces, appear to be based on specialized neural mechanisms in the temporal cortex, particularly in the right hemisphere. Moreover, different aspects of face processing may be controlled by unique cortical systems (Bruce & Young, 1986). Evidence comes from electrophysiological studies in animals and neuroimaging studies of human adults. Single-cell recordings in the macaque monkey reveal groups of "face" cells within the infero-temporal area and the superior temporal sulcus (similar to the human temporal cortex) that fire most strongly when the monkey is viewing familiar monkey or human faces (Baylis, Rolls, & Leonard, 1985; Rolls, 1984). In addition, some cells are selective for particular head orientations (i.e., en face, profile, head up, head down), a particular direction of gaze, or specific combinations of head and gaze direction (Perrett, Rolls, & Cann, 1982; Perrett et al., 1992). In humans, positron-emission tomography (PET) reveals that metabolic activity is high in the right hemisphere of the temporal cortex when adults match faces based on their sex, and that there is additional activity in the posterior (occipito-) temporal cortex of the right hemisphere, the anterior temporal cortex of both hemispheres, and the right parahippocampal gyrus, when they match faces' identity (Sergent et al., 1992). Other studies that have compared adults' processing of faces and non-face objects further suggest a specialized role of the temporal cortex in the right hemisphere for face processing. For example, functional magnetic resonance imaging (fMRI) and event-related potential (ERP) measures of brain activity reveal that regions on the right side of the temporal cortex are activated more strongly in the presence of upright faces than inverted or scrambled faces or non-face objects (e.g., Allison et al., 1994; Kanwisher, McDermott, & Chun, 1997; Puce, Allison, Gore, & McCarthy, 1995). In contrast, regions of the temporal cortex in the left hemisphere are activated more strongly when adults view non-face objects, such as words or houses (e.g., Puce et al., 1996).

Lateralized tachistoscopic studies in adults suggest a specialized role of the right hemisphere for processing faces based on configural cues. In tachistoscopic studies, a visual stimulus, such as a photograph or drawing of a face, is presented in one visual field at a time. When the visual stimulus is presented to the left visual field, the optic nerves project the stimulus first to the visual cortex of the right hemisphere, and when it is presented to the right visual field, the optic nerves project it first to the cortex of the left hemisphere. The information can subsequently pass to the other hemisphere via the corpus callosum, but faster recognition in one visual field suggests that the hemisphere to which that field projects first is more efficient in that type of visual processing. Using this method, many studies have demonstrated an effect of face inversion: When adults recognize faces presented upright, they respond faster when the faces are presented to the left visual field (i.e., right hemisphere) than when the faces are presented to the right visual field (i.e., left hemisphere) (e.g., Hillger & Koenig, 1991; Leehey, Carey, Diamond, & Cahn, 1978). In contrast, recognition of inverted faces is slower when they are shown to the left visual field (i.e., right hemisphere) than when they are shown to the right visual field. These findings imply that cortical systems in the right hemisphere are more adept at configural processing of faces than are cortical systems in the left hemisphere.

Neuropsychological studies also suggest an important role of the temporal cortex, particularly in the right hemisphere, for processing specific aspects of faces, such as their identity and emotional expression. Adult patients who suffer damage to the occipito-temporal cortex show a loss in the ability to recognize faces (e.g., Bruyer et al., 1983; de Renzi, 1986; see de Renzi et al., 1994 for a review). Some adult patients with lesions confined to the right or left side of the temporal cortex show a dissociation in face processing that is related to the hemisphere of the damage: patients with damage primarily in the right hemisphere have difficulty classifying facial expressions and recognizing faces but preserved ability to lip read, whereas patients with damage in the left hemisphere can recognize facial identity but are impaired in lip reading (Campbell, Landis, & Regard, 1986; de Renzi et al., 1994; Mandel, Tandon, & Asthana, 1991). Patients with damage to the right hemisphere also appear to have difficulty in recognizing faces' identity based on configural cues. In one study, when faces or houses were presented upright, patients with right-sided damage performed no differently than patients with left-sided damage or normal adults in their recognition of houses, but they did perform more poorly in the recognition of faces (Yin, 1970). When the faces and houses were inverted—which presumably disrupts the ability to process faces configurally and facilitates the use of local processing—the patients with right-sided damage performed just as well as normals, and they performed more accurately than patients with left-sided damage. Thus, patients with damage to the right hemisphere exhibited a deficit in recognizing upright faces that appears to stem from a deficit in configural processing.

In summary, adults have "expertise" in many aspects of face processing—recognizing faces, recognizing facial signals (e.g., emotions, gaze directions) and recognizing faces on the basis of both local and configural cues, even when the faces they are comparing are highly similar in the individual features and the spacing of those features. Adults' skills in several aspects of face processing—particularly those that require configural processing—appear to depend on a specialized mechanism located in the right hemisphere. This right-sided mechanism may also be important for adults' expertise in identifying faces from non-face stimuli, i.e., holistic processing.

C. The Development of Face Processing during Childhood

In some ways face processing is adultlike in early childhood. Children as young as six years of age rely on holistic processing in the same way as adults, at least when viewing and differentiating familiar faces: 6- and 10-year-olds name fused composites of two faces much more slowly, and with more errors, when presented upright and intact than when they are presented inverted or with their halves misaligned (Carey & Diamond, 1994). Thus, like adults (Hole, 1994; Young et al., 1987), the children had difficulty naming the upright faces, presumably because they relied on holistic processing and that strategy interfered with their ability to process the upper halves of faces independently from the bottom halves.

Also like adults, young children use specialized neural mechanisms for processing faces. In lateralization studies, both adults and 6-year-olds recognize faces more quickly when the faces are presented in the left visual field (i.e., right hemisphere) than when they are presented in the right visual field (Young & Bion, 1980; Young & Ellis, 1976). For both ages, recognition of inverted faces—which presumably requires/facilitates local processing, is faster when the faces are presented in the right visual field rather than the left visual field. Thus, during childhood, as during infancy (de Schonen & Mathivet, 1990), cortical mechanisms in the right hemisphere play a prominent role in the recognition of individual faces. Those mechanisms are also important for the ability to process emotional expression: matching of facial expressions is faster in adults and more accurate in 6-year-olds when the faces are shown in the left visual field compared when they are shown in the right visual field (e.g., Saxby & Bryden, 1985).

Despite the early development of cortical mechanisms used for face processing, some face processing skills are still not adultlike in early childhood. Children around six years of age are less skilled than adults in recognizing individual faces, and in some comparisons, perform as poorly as adult patients with right hemisphere damage (Carey & Diamond, 1980; Carey, Diamond, & Woods, 1980; Flin, 1980; Goldstein & Chance, 1964). For example, in a memory task in which subjects are shown photographs of faces for five seconds each, and then are asked to choose those faces from a larger set, 6-year-olds perform at chance whereas adults perform at ceiling levels (Carey et al., 1980). Even when memory demands are minimized by reducing the size of the stimulus set or by testing children with matching tasks, children do not perform in the adult range until about 10 years of age (Carey & Diamond, 1994; Diamond & Carey, 1977). Some studies have shown that face recognition improves steadily from ages 6 to 10 or 12, but then declines temporarily at ages 12 to 14 before reaching adult levels (Carey, 1981; Flin, 1980). The dip in performance around adolescence may be caused by hormonal changes associated with the onset of puberty, which may interfere with the efficiency of the cortical mechanisms involved in face recognition (Carey, 1981).

Although they are capable of using specialized strategies for face processing, at least under some conditions in the laboratory, young children do not appear to rely on the same strategies as older individuals. Children under the age of 10 make more errors in recognizing a photograph of a classmate that reveals only the internal features (i.e., eyes, nose, mouth) than in recognizing a photograph that contains only the hairline and outer facial contour, a pattern in the opposite direction from 10-year-olds and adults (Campbell, Walker, & Baron-Cohen, 1995). Similarly, children under 10 years of age are "fooled" by paraphernalia into stating incorrectly that two faces with common external characteristics (e.g., the same glasses, hat, or scarf) are the same person (e.g., Baenninger, 1994; Diamond & Carey, 1977). A study of 6-year-olds indicated that they are fooled by misleading, external cues when recognizing unfamiliar faces, but not when recognizing familiar faces (Diamond & Carey, 1977). Thus, under many conditions young children have a bias to use external cues to distinguish among faces.

There is independent evidence that young children do not rely on configural processing to the same extent as adults. In one study (Freire, 1997), 4- to 7-year-old children and adults were trained to discriminate among faces that differed very slightly in the spacing between the eyes or between the eyes and the mouth. Only one-third of the children achieved accuracy above chance, and then not near adult levels, even after 24 training trials with feedback. When the stimuli were modified so that they varied more widely in the spacing between the internal features, the children's accuracy was above chance and they required less training, though again their accuracy was not adultlike. Additional evidence comes from studies showing that face inversion, which presumably disrupts configural processing (e.g., Yin, 1969), impairs the recognition of faces to a lesser extent in children under the age of 10 than it does in adults (Carey, 1981, Carey & Diamond, 1994). According to Carey (1992), the increase in the inversion effect from 6 to 10 years of age may reflect additional experience encoding the spatial relationships among the features in faces and forming a highly-specific prototype of the average spatial relationships among the features, and then recognizing faces based on how they differ from the prototype.

Much less is known about children's skills in other aspects of face processing. The available evidence suggests that children as young as five years of age are proficient in identifying faces' sex and emotional expression, at least when viewing familiar faces (Ellis, Ellis, & Hosie, 1993). It is not known whether they are as proficient as adults in identifying emotional expression in unfamiliar faces, in lip reading and decoding direction of gaze. One goal of my research was to test children's ability to process unfamiliar faces in ways in which adults are known to be proficient, specifically lip reading and processing faces' identity, facial expression, and direction of gaze. Another goal was to examine whether children rely on configural and holistic processing to recognize unfamiliar faces, as is true in adults (e.g., Hole, 1994; Sergent, 1984), by manipulating faces in ways that favour one type of processing over another.

D. Current Study: Face Processing in Normal Individuals and Patients with a History of Early Visual Deprivation

The main purpose of the current study was to examine whether face processing skills for which normal adults and children are known to be proficient are exhibited in the same way in patients with a history of early visual deprivation caused by bilateral congenital cataracts. This is the first study to examine the effects of early visual deprivation on the development of face processing. Because I did not know whether the patients would have only subtle deficits in a few face processing skills, large deficits in most skills, or no deficits at all, I constructed a battery of tasks to probe a large number of skills. As a result, each task was designed to be short and easy to complete. I first compared the data from normal groups of 6-year-olds, 10-year-olds and adults to examine normal development and to determine the appropriate comparison group for patients, all of whom were 10 years of age or older at the time of the test. If normal 10-year-olds and adults performed similarly on the tasks, as expected from the literature (see Carey, 1992 for a review), then I planned to compare their combined data to those from patients.

The participants completed all of the tasks during one testing session. However, for ease of description, I have divided the presentation of the tasks into two experiments. In Experiment 6, I describe the tasks that tested participants' abilities to match faces in: (1) identity despite changes in facial expression; (2) identity despite changes in head orientation; (3) facial expression despite changes in identity; (4) vowel sound expression (lip reading) despite changes in identity; and, (5) direction of gaze despite changes in head orientation and identity. A similar battery has been used to demonstrate deficits in face processing related to the hemisphere of congenital brain damage (Mancini et al., 1994). One goal of Experiment 6 was to examine the normal development of these skills. Another goal was to examine whether distinct aspects of face processing are differentially affected by early visual deprivation, just as they are differentially affected by early brain damage.

In Experiment 7, I describe the tasks designed to distinguish local from configural and holistic processing. In one task, I examined the ability to match faces' identity when faces varied only in an individual feature (local processing) or on the basis of the spatial relationships among the internal features (configural processing). In a second task, I examined the ability to match identity when fused facial composites—having the same top halves and different bottom halves—were shown intact, as in a normal-looking face (holistic processing), or with their halves misaligned horizontally (to facilitate local processing). To gain insight about whether the specialized strategies underlying face processing are similar to those underlying shape (non-face) processing, I included analogous tasks with geometric figures.

In both experiments, I used computerized matching tasks. In Experiment 6, the subject saw a single, target face for two seconds, immediately followed by a set of three faces. The subject was asked to move a joystick toward the face that he/she judged to match the original. To make it difficult to solve the tasks on the basis of colouring or global shape, I used black-and-white photographs of faces wearing identical scarves that covered the hair and ears, I removed natural facial markings (e.g., moles, freckles), and I matched the faces to-be-compared on the basis of chin shape and shading of complexion, eyes and eyebrows. In Experiment 7, a single stimulus was shown for very short duration (i.e., 180 ms or 360 ms), immediately followed by a second stimulus, and participants moved the joystick to indicate whether the stimuli were the same or different. I used short exposures to give subjects little time to parse and analyse each feature, and I asked that they match quickly. By making it difficult to solve the tasks on the basis of local and/or external cues, I was able to evaluate whether differences between children and adults might be related to age-related changes in configural processing (see Carey, 1992). I was also able to see whether differences between normals and patients could be attributed to differences in configural processing, as predicted by the theory of de Schonen and Mathivet (1989).

In Section 3.2, I first describe the characteristics of the participants and the general apparatus used for testing. I then present the tasks, procedure and the results from Experiment 6, followed by a similar description for Experiment 7. I describe the tasks in the order in which they were presented, which was the same for all subjects. There were too few patients to counterbalance the order of presentation of the tasks. Instead, I assumed that any effect of order—caused by practice and/or fatigue—was comparable across subjects, regardless of their age or group. Tasks of shape processing were presented last because they required attending to small, individual elements and to the global shape and I did not want to influence subjects to respond to the facial stimuli based on strategies they had just been biased to use for shapes.

3.2. THE EFFECT OF EARLY VISUAL DEPRIVATION ON THE DEVELOPMENT OF FACE PROCESSING

A. Participants

All participants were Caucasian and all of the stimulus faces were Caucasian so that the results would not be influenced by variability in their familiarity with faces' race (e.g., see O'Toole, Peterson, & Deffenbacher, 1996 for the "other race" effect). Because brain laterality effects are stronger in right-handed individuals than in left-handed individuals (e.g., Levy, 1980), and because I used tasks that are affected by lateralization (e.g., Deruelle & de Schonen, 1998), I included only subjects who reported being right-handed.

Patients with a History of Early Visual Deprivation. The final sample consisted of 17 patients treated for bilateral congenital cataracts. The patients were at least 10 years of age at the time of testing (M age: 16 years; Age range: 10 years, 9 months to 38 years, 5 months). An additional patient was tested but not included in the final sample because she is Oriental. Most patients were tested at their homes (n = 14), and a few were tested at The Hospital for Sick Children in Toronto (n = 2) or in the Vision Laboratory at McMaster University (n = 1).

Table 4 provides clinical information about the patients included in the sample. The patients' medical histories were taken from hospital charts and files from the Vision Laboratory, except for D.D., for whom only the patient's own report was available.

Table 4.

Clinical details of the 17 patients treated for bilateral congenital cataracts. Cases are in order of increasing deprivation.

Patient (Age-Yrs) (Sex)	Refraction* (diopters)	Days of Deprivation	Snellen Acuity*	Additional Details
J.J. (14.5) (M)	OD +18.25 OS +15.75	53 53	20/60 20/30	Latent nystagmus OU
A.H. (10.7) (F)	OD +16.25 OS +15.75	64 64	20/200 20/50	Microcornea OD; Manifest nystagmus OU; Strabismus surgery OD, age 1 year
K.M. (13.5) (F)	OD +12.50 OS +13.50	71 71	20/25 20/25	Glaucoma OU diagnosed age 13; Latent nystagmus OS
J.G. (12.0) (F)	OD +20.50 OS +23.75	83 83	20/60 20/60	Microcornea OU; Latent nystagmus OU
C.B. (13.7) (F)	OD +17.75 OS +17.50	91 91	20/30 20/200	Latent nystagmus OS; Strabismus surgery for esotropia OS, age 2
T.S. (12.0) (M)	OD +12.50 OS +12.50	94 94	20/40 20/70	Glaucoma OU diagnosed age 9; Microcornea OU; Latent nystagmus OU
A.D. (13.1) (M)	OD +17.50 OS +15.50	97 97	20/80 20/100	Latent nystagmus OU
A.R. (16.8) (F)	OD +17.00 OS +12.50	103 103	20/100 20/100	Microcornea OU; Manifest nystagmus OD; Latent nystagmus OS; Strabismus surgery for esotropia OD, ages 1, 5 and 7
M.D. (17.3) (F)	OD +9.75 OS +9.00	129 129	20/30 20/60	Latent nystagmus OS

continued

Table 4 continued.

Patient (Age-Yrs) (Sex)	Refraction* (diopters)	Days of Deprivation	Snellen Acuity*	Additional Details
Z.C. (11.4) (M)	OD +14.50 OS +15.25	142 142	20/300 20/400	Glaucoma OS diagnosed age 4; Latent nystagmus OU
A.C. (17.9) (M)	OD +11.25 OS +12.25	196 161	20/40 20/50	Manifest nystagmus OU
B.B. (11.1) (F)	OD +13.00 OS +14.50	165 165	20/70 20/70	No complications
C.P. (16.0) (M)	OD +10.25 OS +11.75	187 187	20/25 20/50	Latent nystagmus OU; strabismus surgery for esotropia OS, age 2
T.C. (17.8) (F)	OD +18.50 OS +19.00	209 209	20/70 20/200	Glaucoma OS diagnosed age 4; Latent/manifest nystagmus OU
S.S. (13.1) (M)	OD +12.75 OS +12.00	228 228	20/60 20/200	Latent nystagmus OU
D.D. (38.4) (F)	- -	330 330	- -	Glaucoma OU; No medical records available
S.G. (22.0) (M)	OD +8.50 OS +9.75	586 586	20/100 20/100	Glaucoma OU diagnosed age 22; Manifest nystagmus OU

OD = right eye; OS = left eye; OU = both eyes.

*Values based on the measurement closest to the testing date.

Patients were included in the sample only if they had dense and central cataracts in both eyes diagnosed on their first eye examination and prior to six months of age. We assume that an infant diagnosed with cataracts before six months was deprived from birth because it would be unusual for a dense and central cataract to develop rapidly during the first half-year of life. In the patients selected for study, an ophthalmologist had determined that the cataract interfered seriously with vision because: (i) the infant did not fixate objects or follow moving stimuli, (ii) the opacity completely blocked the view of the fundus through an undilated pupil, (iii) no red light reflex was visible through an undilated pupil, and/or (iv) the opacity looked dense and central. Patients were excluded if the cataract was not dense (i.e., dull red reflex reflected through an undilated pupil), located only in the periphery of the lens, or smaller than 5 mm.

The patients were treated by surgical removal of the natural lenses, which left the eyes with no means to focus images. About one to two weeks following surgery, the eyes were fitted with contact lenses so that, for the first time, visual input was focused on the retina. Input from this point was only nearly normal because the contact lenses focused input perfectly for only one distance and the eyes could not accommodate for other distances. (The implications of this continuing mild deprivation will be considered in the discussion.) By school age, most patients began to wear bifocal glasses so that their eyes could accommodate to both a near and a far distance. When necessary for the testing, each patient wore an additional optical correction so that the eyes were focused at the testing distance of 100 cm. Refractive error at the time of testing is shown in Table 4.

The duration of visual deprivation for each eye was defined as the period from birth until the fitting of the contact lenses following surgery. Table 4 shows that the eyes in this study were deprived for as long as 20 months and as little as 8 weeks (mean duration of deprivation = 5.5 months).[5] Patients who had trouble with contact lenses switched to glasses. Patients were excluded from the sample if they had continuing severe visual deprivation at some later time because they failed to wear their contact lenses or glasses regularly (i.e., wearing an optical correction < 75% of the waking time).

Most of the patients have one or more visual problems that commonly occur with a cataract, including microcornea (small cornea), strabismus (misalignment of the eyes), and/or nystagmus (repetitive, jerky movements of the eye, usually in the horizontal direction) (see Table 4). Some patients also have glaucoma, caused by raised intraocular pressure that can damage the retina, but they were included only if the glaucoma had been treated successfully by medication to lower the pressure. Patients were excluded from the sample if they had glaucoma that had not been treated successfully and/or any other eye condition (i.e., detached retina, retinal damage, optic nerve atrophy) that could seriously interfere with their vision and/or their visual development.

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[5] The patient (S.G.) with the longest deprivation had cataract surgery and received contact lenses a few weeks after birth, but continued to be visually deprived for many months because his parents did not use the contact lenses. It was only at 20 months that his deprivation ended because he began to wear glasses.

Because performance on my tasks could be affected by cognitive level, patients were excluded if there was evidence of significant developmental delay. Developmental delay was evaluated by checking score(s) on previously-administered standardized cognitive tests, namely the Bayley Scale of Infant Development (at age 2) and the McCarthy Scale of Children's Abilities (at age 5). Patients whose scores on those tests were more than two standard deviations below the normal mean were excluded from the sample.

Normal Children and Adults with a History of Normal Visual Experience. All normal participants did not need glasses or contact lenses and passed a screening examination for normal vision (see below). The final sample consisted of 24 subjects in each of three age groups: 6-year-olds (M age: 6 years, 11 days; range: 5 years, 9.5 months to 6 years, 2.5 months), 10-year-olds (M age: 10 years, 1 month; range: 9 years, 10 months to 10 years, 3 months), and adults (M age: 19 years, 10 months; range: 17 years, 8 months to 32 years, 2 months). Children were recruited from names on file of mothers who had volunteered them at birth for later study. Adults were undergraduate students participating for five dollar payment or for points in a psychology course at McMaster University.

Each normal participant was screened on tests designed to detect any signs of previous abnormal visual experience. The measures included in the screening battery are ones most likely to have been affected by a period of abnormal input during early development, namely, visual acuity and binocular vision. To detect amblyopia and myopia (nearsightedness), subjects read letters from a distance of 6 meters, one eye at a time. Adults and 10-year-olds were tested with a chart containing letters arranged in rows (i.e., Snellen or Bailey-Lovie), and to pass, they were required to read the 20/20 line or better. The 6-year-olds were tested with the Goodlight Crowding test, which are cards containing single letters surrounded by crowding bars. Because visual acuity may not be adultlike until sometime after age 5 or 6 (e.g., Ellemberg et al., 1999), the 6-year-olds were required to read the 20/25 line or better. To detect a hyperopia (far-sightedness) greater than 3 diopters, subjects were required to read the letter chart monocularly through a +3 diopter lens. The effect of the +3 lens on a normal eye is to cause light to be focused in front of the retina, and therefore to cause acuity to be worse with the lens than without it. If there is a hyperopia of +3 or more, then light will be focused closer to the retina with the lens than without it, and acuity of the eye will be at least as good with the lens as without it. To pass, subjects of all ages had to have poorer acuity with the +3 diopter lens than without it.

To detect problems in binocular vision, participants were given the Worth Four Dot test of binocular fusion at near and the Titmus Fly test of stereoacuity. The Worth Four Dot test assesses whether there is fusion of information from the two eyes, whether there is suppression of vision in one eye under binocular viewing conditions, or whether there is double vision. Subjects of all ages were required to show fusion to be included in the normal sample. On the Titmus Fly test, subjects of all ages were required to show stereopsis for the smallest disparity tested, which corresponds to a stereoacuity of 40 seconds.

An additional 19 normal subjects were excluded because they failed the visual screening test (3 6-year-olds, 4 10-year-olds, 5 adults) or a face screening task designed to give them practice with the computerized procedure (3 6-year-olds) (see section on tasks, Experiment 6), because they were not Caucasian (3 adults), or because of equipment failure (1 6-year-old).

B. Testing Sites & Apparatus

McMaster University. The equipment was assembled in a dark testing room in the Vision Laboratory at McMaster University. The subject sat in a chair in front of a table that held a 21" black-and-white Radius 21-GS monitor and a Macintosh LC 475 computer, so that his/her eyes were 100 cm from the computer screen. A joystick, held by the subject to make responses, was connected to the computer via a keyboard. The keyboard was placed in front of the tester, who used it to initiate each trial. Cedrus Superlab software was used to initiate the trials following each press of the spacebar and to record the accuracy and latency of the subject's responses. All responses were stored in an Excel data spreadsheet.

To compare lighting conditions at the McMaster testing site to those in other testing sites, I took measurements of the luminance of the stimuli on the computer screen using a Tetronix photometer (Model J16). For five faces used in Experiments 6 and 7, I measured the contrast between light and dark regions (e.g., pupil and sclera) at the testing distance. The contrast levels of these faces were the standard against which I compared measurements obtained at patients' homes and The Hospital for Sick Children.

Testing at Patients' Homes. The computer equipment was re-assembled in a living room or kitchen at the patient's home. So that they could view the images from eye level, some patients sat on chairs (sometimes propped with books or cushions) and others sat on the floor. To minimize distraction, I covered patterned furniture with black cloths, I asked parents to turn down background noise from television and radio, and I asked family members to leave the room during testing.

I conducted luminance measurements using the same procedures as at McMaster University with a hand-held Minolta Spotmeter (Model F). When necessary to increase the contrast levels of the facial stimuli, I darkened the room by switching off lamps and ceiling lights and by covering windows with black cloths. These procedures were effective in making the luminance levels on the screen comparable between homes and the testing room at McMaster University.

The Hospital for Sick Children. A few patients were tested at the hospital. The equipment was set up in the same way as at McMaster University, in a small, windowless room. Using the spotmeter, I found the contrast levels of the stimuli to be the same as those at the university.

C. Experiments

Experiment 6

Participants were administered five computerized tasks of face matching that required matching faces in identity despite changes in facial expression, identity despite changes in head orientation, facial expression despite changes in identity, expression of a vowel despite changes in identity, and gaze direction despite changes in identity and head orientation.

Method

Stimuli

Photographing faces. A Chinon ES-3000 electronic still camera was used to create digitized images (640 x 480 pixels) of faces. I took photographic images of several hundred adult Caucasian male and female faces, all under 28 years of age. Models wore a cape to cover clothing, wore a cap over the hair and ears to mask hair colour and hair/ear shape, and removed paraphernalia from the head region (e.g., glasses, earrings). One flash unit was positioned behind the camera and faced a wall to diffuse the light and minimize shadows on the face. See Appendix 9 for details of the method of photographing faces.

To create a large set of neutral faces, all models were asked to pose by directing their eyes and head toward the camera (en face) without emotional expression. In addition, each model posed in one or more of the following poses. For the tasks involving facial expression, the model directed his/her head and eyes toward the camera and was asked to express happiness, surprise, or disgust. For the task involving lip reading, the model posed with the head and eyes en face and pronounced the long vowel a, e, or u. The photographer modelled the facial expressions and vowel sounds immediately before taking each picture. For the task involving changes in head orientation, the model posed with a neutral expression and directed both the head and eyes 45° to the right of the camera, 45° to the left of the camera, or 45° upwards or downwards. Four markers were placed 45° from the camera (i.e., to the left, right, up, down) to guide the model's head orientations. For the task combining changes in gaze and head orientation, the model posed with a neutral expression and directed the eyes and head 30° to the left of the camera, the eyes and head 30° to the right of the camera, the eyes en face and the head 30° to the left, the eyes 30° to the right and the head en face, or the eyes 30° to the left and the head en face. To assist models, two markers were placed 30° to the left and right of the camera.

Manipulating Faces. All digitized images were downloaded onto a Macintosh LC 475 and viewed on a 21" black-and-white Radius 21-GS monitor using Photoshop software. Photoshop was also used to transform the images from colour to grey scale (256 x 256 pixels), to remove natural markings (i.e., freckles, moles), and to crop the facial images so that each image measured 10 cm wide and 15 cm high. All faces had the same height from the top of the forehead to the bottom of the chin.

The faces were made large enough to be visible to patients who have reduced visual acuity and contrast sensitivity. I based the size of the iris on previous measurements of grating acuity in a similar cohort of patients (Maurer & Lewis, 1993). Grating acuity measures the smallest size of stripe that can be resolved at high contrast, and hence, is a fair estimate of patients' ability to discriminate between the regions of light-coloured sclera and dark-coloured pupil/iris. For 95% of the cohort, grating acuity is 10 minutes of arc or better in at least one eye. Therefore, I made the faces large enough that the widths of the sclera and iris were about 20 minutes of arc, i.e., well above patients' threshold.

Because direction of gaze might be difficult to discern in faces with low contrast between the eye's white-coloured sclera and light-coloured iris (e.g., blue, green), I determined the minimum necessary contrast based on previous measurements of contrast thresholds in a similar cohort (Tytla, Maurer, Lewis, & Brent, 1988). Ninety-five percent of the cohort can detect stripes comparable to the widths of the iris and sclera of the faces in my study with contrast of 10 percent or less. After using Photoshop to increase the contrast of the facial images by 10 percent, the contrast between the iris and sclera of the eyes in the lightest-coloured faces in my study was at least 22 percent (average = 27%), or double the patients' threshold. (Darker faces, which were more typical of the set, had a mean contrast of 50%.) The contrast between other light/dark regions of the face, including between the lips and the chin and between the nose and the cheek, was also above patients' threshold (i.e., mean: 28%; range: 11 to 38%).

Tasks

General Design. There were six test trials for each of five tasks and a practice task. Each trial contained four faces of the same sex. With the exception of the practice task, those four faces were matched as closely as possible on external contour and shading of complexion, eyes and eyebrows. On each trial, one of the four faces, called the target face, was shown at the top of the computer screen for two seconds. Following an inter-stimulus interval of 200 ms, three test faces were presented side-by-side at the bottom of the screen. On each trial, the subject chose the face that matched the target face by moving a joystick to the left, middle, or right. The test faces disappeared from the screen once a response was made.

All tasks, including the practice task, began with three practice trials. During the first practice trial, the target face was shown until the tester pressed the spacebar, and then called for the test stimuli by a second press of the spacebar. During the second and all subsequent trials, the tester pressed the spacebar only once to call for the target face for two seconds, after which the test stimuli appeared. The second practice trial was repeated for subjects who had trouble.

Decisions concerning the inclusion of practice trials, and the number of practice trials, were based on pilot testing with normal 6-year-olds and adults ($\underline{n}$= 10 per group). All pilot subjects were eager to have practice before each task. Practice was particularly helpful for tasks that came later, presumably because it avoided confusion about the instructions for matching. In both age groups, only a few practice trials were needed for subjects to feel comfortable with the task.

The choice of exposure duration of the target face was also based on pilot work. The goal was to make the exposure duration of the first face short enough to give subjects little time to parse and analyse each of the features separately, but not too short that it would interfere with encoding. Pilot testing suggested that a one-second exposure was not sufficiently long for 6-

year-olds because they had many errors in matching, regardless of task (unlike adults who were above chance in every case). I chose the two-second exposure because it resulted in better than chance performance across tasks in 6-year-olds, as in adults, and because it did not cause subjects to be at ceiling levels for every task.

Half of the trials for each task used male faces and half, female faces. The location of the matching face was counterbalanced across all 36 test trials that made up the six tasks (practice + 5 tasks). Each task also had at least one trial in which the correct matching face was positioned on the left, middle and right of the computer screen. I did not counterbalance the location of the matching face within each task because there were only six test trials per task and I did not want subjects to be able to guess the correct location for the last one or two trials. In addition, I created a second version of each task that differed in the number of correct responses in the left, middle, and the right, but otherwise followed the same constraints, and then randomly assigned subjects to one of the two versions of each task.

Description of the tasks. The tasks are described in the same order in which they were presented. There were six trials for each task. Each task was preceded by three practice trials.

Practice Task: Matching faces in identity (with no transformation). The practice task used faces posing with their head and eyes toward the camera and with a neutral facial expression. Each trial contained three models' faces: one target face, followed by three test faces consisting of the target face and two novel faces. The subject was asked to find the same person that he/she saw before. Unlike the experimental tasks, some of the faces in the practice task had unique markings (e.g., moles, freckles) or chin contours, and the faces were not matched on shading of complexion, eyes and eyebrows. Because these faces could be differentiated on the basis of configural cues and/or local cues, it was possible to assess whether subjects understood and could perform the task, regardless of what strategies they used. Figure 13 (a) illustrates four faces used on a typical practice trial.

The subject was given the instructions for matching immediately before the first trial. The tester pointed to the top of the computer screen and said "You will see a person's face here for a very short time and then that face will disappear." The tester then pointed to the bottom of the screen and said "You will then see three faces shown in a row. Your job is to find the person that you saw before."

Task 1: Matching facial identity despite changes in facial expression. Task 1 used faces posing with their head and eyes toward the camera and with one of four emotional expressions: neutral, surprise, happy, or disgust. Each trial contained all four facial expressions: the target face had one facial expression (e.g., happy) and was followed by the same person's face but with a different facial expression (e.g., neutral) and two novel faces, with the two remaining facial expressions (i.e., surprise, disgust). Figure 13 (b) illustrates the faces used on a typical trial.

The subject was asked to find the same person that he/she saw before, but with a different facial expression. The tester explained "As before, you will see a person's face at the top of the computer screen for a short time. This time the person might show a particular feeling or emotion, such as being happy, disgusted or surprised. Or the person might show no emotion (illustrated by the tester modelling a neutral expression). When that face disappears there will be three faces on the bottom row. Your job is to find the person that you saw before even though he/she has changed his/her facial expression. For example, he might look happy at first, and then the next time you see him he will look surprised."

Task 2: Matching facial identity despite changes in head orientation.

Task 2 used faces that had a neutral facial expression and their head (including the eyes) directed en face, 45° to the right of the camera, 45° to the left of the camera, up or down. Each trial had four of the five possible head orientations: the target face posed with one head orientation (e.g., right), and was followed by the same face but with a different head orientation (e.g., left) and two novel faces, posing with two different head orientations (e.g., down, up). The subject was asked to find the same person that he/she saw before, with changed head orientation. Specifically, the tester said "The person you will see at the top of the screen will be posing with his/her head directed in a particular way. The head might be directed toward you. Or it might be facing up, down, to the left or to the right. When the three faces appear at the bottom, your job is to find the person that you saw before even though the person won't be looking at the same place as before. For example, she first might be looking at the left, and then when you see her again she will be looking at you (illustrated by the tester turning her head first to the left and then en face)." Figure 13 (c) shows the faces from a typical trial.

Each of the non en face poses (up, down, left, right) appeared equally often as the target face and as one of the test faces. The en face pose appeared only as the target face and never as a test face because I suspected that it might be difficult to identify a test face posing en face when it had been encoded as it posed looking away from the camera with some of the features masked.

Task 3: Matching facial expression despite changes in identity. As in task 1, the faces in task 2 posed with their eyes and head en face and with one type of facial expression. Each trial had three possible facial expressions: the target face with one expression (e.g., surprise) was followed by one novel face posing with the same expression (i.e., surprise) and two novel faces, each with different expressions (i.e., happy, disgust). The subject was asked to find the same facial expression that he/she saw before, but in a different person's face. The tester explained the task by saying "The person at the top of the screen will be posing with a particular emotion or with no emotion. When the three faces appear at the bottom, your job is to find the same expression that you saw before but in a different person's face. For example, if you saw someone looking happy, then your job will be to find happy in a new person's face. If you saw no expression, then your job is to find no expression in a new face."

Each of the four facial expressions (surprise, happy, disgust, and neutral) appeared equally often as the target face and as one of the test faces. The facial expressions appearing in the target face were the same as in task 1. Figure 13 (d) illustrates the four faces used on a typical trial.

Task 4: Matching lip reading despite changes in identity. Task 4 used faces posing with their head and eyes en face and pronouncing one of three long vowels: a, e, or u. Each trial contained all three vowel sounds: the target face had been photographed sounding one vowel (e.g., u), and was followed by one novel face sounding the same vowel, and two novel faces sounding two different vowels (i.e., a, e). The subject was instructed to find the face making the same vowel sound that he/she saw before, but now in a different person's face. Specifically, the tester said "The person at the top of the screen will be saying a vowel, either a, e, or u. Your job is to find someone else at the bottom of the screen who is saying the same vowel. For example, if the first person says "a", then you must find another person who is also saying "a"." Figure 13 (e) illustrates the faces used on a typical trial.

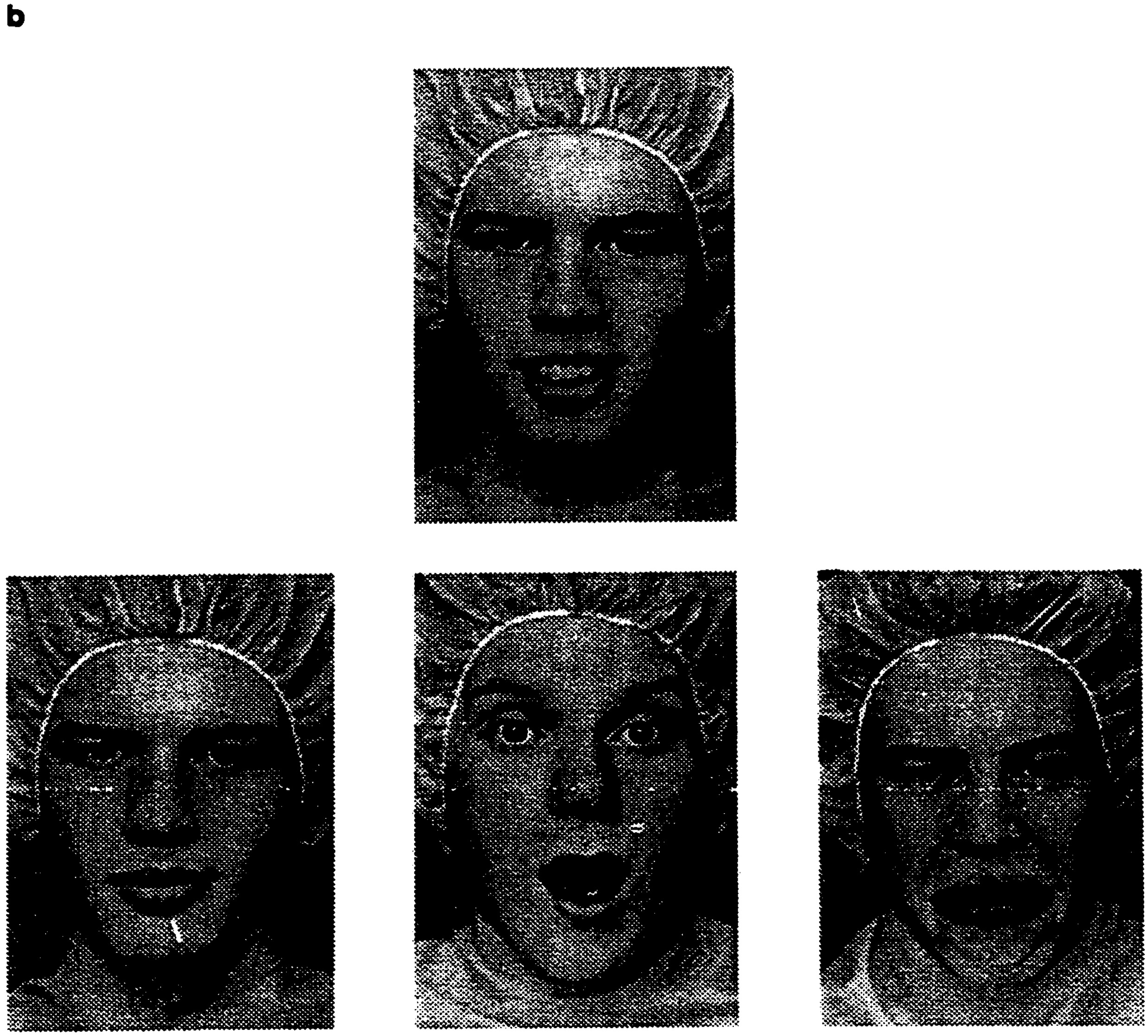
Task 5: Matching direction of gaze despite changes in identity and head orientation. Task 5 used faces posing with a neutral expression and in one of six possible combinations of gaze and head orientations: eyes and head en face; eyes and head 30° to the left of the camera, eyes and head 30° to the right; eyes en face and head 30° to the left; eyes 30° to the right and head en face; eyes 30° to the left and head en face. Each trial contained four types of gaze/head directions: the target face posed with one gaze direction and head orientation (e.g., eyes 30° left; head en face), and was followed by one novel face with the same gaze direction as the target (i.e., 30° left) but a different head orientation from that of the target (e.g., 30° left), and two novel faces with a different gaze direction from the target and the same or different head orientation as the target (e.g., en face, 30° right). The subject was asked to find the same gaze direction that he/she saw before in a different person's face, and to ignore any changes in the direction of the head. Figure 13 (f) shows the four faces used on a typical trial.

The tester modelled some of the poses of gaze/head orientations for the subject when giving the instructions for the task. The tester said "The person at the top of the screen will be directing his/her eyes either at you, to the left, or to the right. From the three faces that you see at the bottom, you must find the same direction of eyes in a new person. For example, if the eyes of the person you see first are looking to the left, your job is to find another person with the eyes looking to the left. It is important to pay attention to the eyes and to ignore where the head is turned. The head may be in the same direction as the eyes or in a different direction. Let's say the eyes of the first person are looking to the right and his head is facing straight ahead (illustrated by the tester positioning her head en face and the eyes to the right). In this case, your job is to find another person with the eyes turned to the right even if his head is turned another way (illustrated by positioning her head and eyes to the right)."

Figure 13.

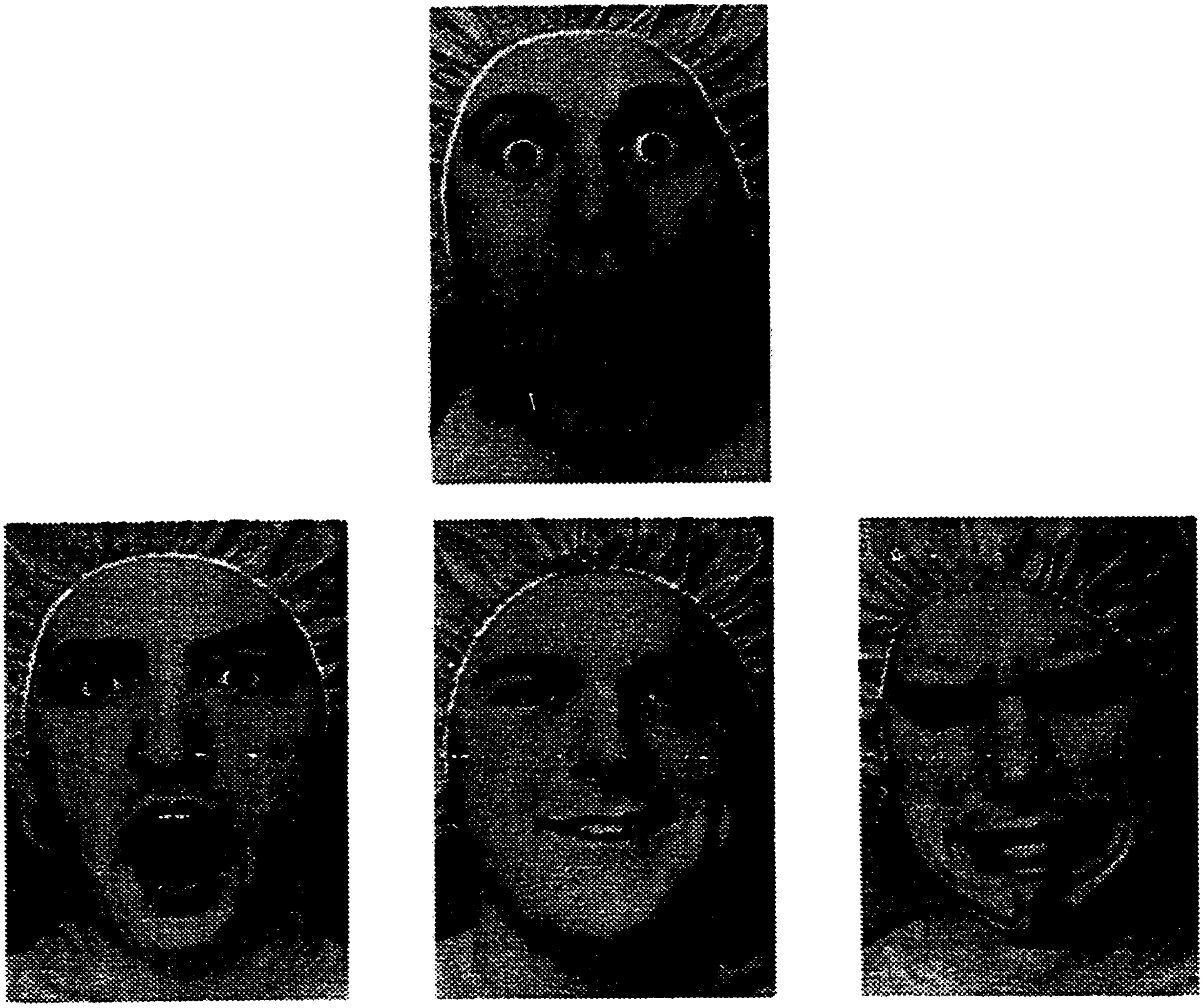
Illustrations of the four black-and-white photographs of faces used on a typical trial from the practice task and the five tasks of face matching in Experiment 6. The illustrations are presented in the following order. Matching faces in: identity (with no transformation) (a); identity despite changes in facial expression (b); identity despite changes in head orientation (c); facial expression despite changes in identity (d); vowel sound (lip reading) despite changes in identity (e); and, direction of gaze despite changes in identity and head orientation (f). For each example shown, the target face (which appeared immediately before the three test faces) is depicted above the three test faces.

a


b


c

d



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Procedure

The participants were tested individually. I began by explaining the procedure and obtaining informed consent from participants over 15 years of age or the parent of younger children. I also obtained informed assent from children who were between 7 and 15 years of age.

For Normal Participants. Normal participants were tested in the Vision Laboratory at McMaster University. Each participant completed the visual screening test (see Participants) and then the computerized tasks.

For computerized testing, the subject sat in the chair with his/her eyes 100 cm from the screen. The tester introduced the tasks or "games" (for children) with a description of the procedure. The tester explained that one face would appear for a short time and then would be followed by three faces (illustrated by pointing to the top and bottom of the screen, respectively). The task was to find the matching face, and to do so by moving the joystick to the left when the subject judged that the matching face was located on the left, to the right when he/she judged that it was located on the right, and to move it forward toward the center of the screen when he/she judged the matching face to be in the middle. The tester emphasized accuracy but asked that the subject try to respond as quickly as possible.

The tester explained on what basis to find the matching face (e.g., facial expression, lip reading) immediately before each task. When the subject appeared ready, the tester pressed a key on the keyboard to initiate the first trial of the practice task. Following the subject's response, the tester provided feedback about accuracy. Before presenting the next trial, the subject was told that the target face would be shown only for two seconds. For all remaining trials, the subject was not informed about his/her correctness. The tester initiated each trial only when she judged that the subject was looking at the top center of the screen.

Any subject who failed the criterion of at least 5/6 correct on the practice task was allowed to repeat it up to three times, in each case with a different version that re-positioned the correct matching face (e.g., left side on practice test 1; right side on test 2; middle on test 3) so that subjects could not find it simply by guessing. Most subjects reached the criterion in the first or second attempt. The three 6-year-olds who failed the practice task on the third attempt were excluded from further testing.[6]

Participants were then tested with the five tasks of face processing, presented in the same order as described earlier (see Tasks). Pilot testing with normal 6-year-olds and adults (n = 10 per group) showed no difference in accuracy on the five tasks whether they received task 1 first or last in the series. However, some pilot adult subjects reported that it was easier to follow the instructions for the two tasks of matching faces' identity (tasks 1 and 2) when they were presented immediately after the practice task than when they were presented last. Therefore, I used only that easier order for all subjects.

For two of the tasks—task 2 that required matching faces' identity despite changes in head orientation, and task 5 that required matching faces' gaze direction despite changes in head orientation and identity—the subject made a response verbally or by pointing to the left, middle, or right side of the

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[6] During pilot work, few 6-year-olds, but most 5-year-olds, failed the criterion even with repeated testing and extensive feedback. Based on these results, I administered the computerized tasks only to participants who were six years of age and older.

screen rather than by moving the joystick. During pilot testing, adults made many errors in moving the joystick that were systematically related to the direction of the models' head or eyes. For example, if the correct matching face had the head turned to the left and was positioned on the right side of the screen, many adults incorrectly moved the joystick to the left side. To prevent these errors, the tester moved the joystick for the subject following the subject's verbal or pointing responses. With this alteration, subjects appeared not to have difficulty signalling their intended response correctly on tasks 2 and 5.

Subjects who did not pass the practice task or showed poor matching across all five tasks of face processing were given a computerized shoe task designed to assess their ability to match shoes and to determine whether any difficulties with faces were extended to non-face objects. Because all subjects who completed the shoe task performed perfectly, and because it was not used to distinguish between patients and normal controls, I do not discuss it further in the text. Refer to Appendix 10 for details of the shoe task.

For Patients. Like normals, patients were tested binocularly. The procedure for patients was the same as for normal participants except as noted here. Patients were not given the visual screening test designed to exclude normal participants with a history of abnormal visual input. Also, patients were optically corrected for the testing distance. Most patients wore contact lenses that focused their eyes at infinity, and the additional optic power necessary for them to focus at my testing distance of one meter is +1.00 diopters (D) (a value equal to the inverse of the distance in meters). That added lens was placed in a trial frame worn over the contact lenses.[7] Patients with glasses removed them and wore a trial frame containing lenses with the power in their glasses plus the +1.0 D add. Additional or less power, as necessary, was given if the patient's current correction did not focus the eyes at infinity. For example, if the eyes needed +1.5 D over the contact lens to focus at infinity, then I added +2.5 D to the existing power of their lenses (+1.5 D + 1.0 D). If the eyes needed -1.0 D over the contact lens to focus at infinity, then I did not add any power.

Data Analyses

Accuracy

The data for each subject consisted of his/her accuracy on each of six test trials for each of the five tasks. For each subject, I calculated the proportion of responses that were correct for each of the five tasks. To examine normal development, and to determine the appropriate normal comparison group for patients, the mean proportion scores from normal participants were subjected to an ANOVA, with one within-subjects factor (5 tasks) and one between-subjects factor (3 ages). A significant interaction was followed by analyses of simple effects, and significant main effects were analysed with Dunnett t-tests that compared the mean scores from the 6-year-olds and 10-year-olds to those from the adult group (controls).

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[7] The +1.0 D lens provides little added strength to the existing power of the lens, and consequently, many patients reported that they could see the stimuli just as well with the add as without it. Patients who did not benefit from the add and preferred not to wear it were tested with their current correction only.

Because the data from 10-year-olds and adults did not differ significantly (see Results), I used their combined scores as the normative group for patients, all of whom were over 10 years of age (with a mean age of 16 years). To examine the effect of early visual deprivation, I conducted a second ANOVA, with one within-subjects factor (5 tasks) and one between-subjects factor (2 groups), that examined the mean proportion of correct responses in patients and normal controls. In addition, to determine whether patients' accuracy scores could be predicted by the length of their visual deprivation (i.e., the time from birth to when they were fitted with contact lenses following surgery) and/or by their visual acuity, I conducted simple regression analyses that examined the relationship between patients' mean proportion of correct responses on a given task and (a) the duration of their visual deprivation ($\underline{n} = 17$), or (b) the Snellen acuity of the better eye at the time nearest to testing ($\underline{n} = 16$).[8]

Reaction Times

For three of the tasks (1, 3, and 4), each subject had a reaction time on each trial defined as the period from when the test stimuli appeared on the screen to when he/she responded with the joystick. (Reaction times were not collected for tasks 2 and 5 because the tester moved the joystick following the subjects' verbal/pointing responses.) For each subject, I calculated a median reaction time for the test trials with correct responses that made up each of the three tasks: identity despite changes in facial expression, facial expression

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[8] One patient for whom data on Snellen acuity were not available is not included in the regression analysis involving acuity.

despite changes in identity, and lip reading despite changes in identity. I used the median reaction time because it is less affected than the mean by occasional extremely long reaction times.

The mean (of the median) reaction time scores from normal subjects were subjected to an ANOVA, with one within-subjects factor (3 tasks) and one between-subjects factor (3 ages). The ANOVA showed that 10-year-olds were slower than adults, but that their patterns of reaction times across the three tasks were the same. Because patients ranged in age from 10 to 38 years, in a second ANOVA I compared their reaction times to those from the combined data of normal adults and 10-year-olds. The second ANOVA was used to examine only interactions between task and subject group (patients, normals) because any main effect of age was contaminated by the change in reaction time with age. Regression analyses were conducted to determine whether patients' reaction times could be predicted by the duration of their visual deprivation and/or by their visual acuity.

Results

For Normal Participants. The normals' mean proportion of correct responses for the five tasks are shown in Figure 14. The ANOVA on the mean proportion scores showed significant main effects of age and task, and a significant interaction between age and task. See Table 5 for $\underline{F}$ and $\underline{p}$ values of the ANOVA and the analyses of simple effects for the significant interaction. The analyses of simple effects revealed a significant effect of age for each of the five tasks. On every task, 10-year-olds were as accurate as adults (Dunnett t-test, $\underline{p}$s > .05) and 6-year-olds made significantly more errors than adults (all $ps < .05$). The analyses of simple effects also revealed a significant effect of task type at each age. In both 6- and 10-year-olds, errors on the two tasks of identity (with changed facial expression or head orientation) were no different from each other (Tukey post-test, $ps > .05$), and both were significantly greater than errors on every other task ($ps <.05$). The same was true in adults except that errors on the task of matching identity with changed head orientation were no different from their errors on the task of matching direction of gaze ($p > .05$). In both 10-year-olds and adults, errors on the three non-identity tasks were all low and no different from each other ($ps > .05$). Six-year-olds' errors in matching facial expressions and vowel sounds were also low and similar to each other ($p > .05$), and both were significantly lower than their errors for matching gaze direction (both $ps < .01$). Thus, when compared to adults, 6-year-olds were most mature on the tasks requiring lip reading and matching facial expressions, were least mature on the two identity tasks, and were intermediate on the task requiring decoding direction of gaze.

The mean (of the median) reaction times for the three tasks are shown in Figure 15. The ANOVA on normal participants' median reaction times showed significant main effects of age and task (both $ps < .0001$), but no significant interaction between age and task ($p > .10$). Across tasks, both 6- and 10-year-olds' reaction times were significantly longer than those in adults (Dunnett $ps < .0001$ and .05, respectively). For subjects at every age, reaction times in matching facial expressions and vowel sounds were not significantly different from each other (Tukey $p > .05$), and both were significantly shorter compared to the task that required matching faces' identity despite changes in facial expression ($ps < .01$).

Figure 14.

Normal participants' mean proportion of correct responses (+1 SE) on the five tasks of face matching in Experiment 6: matching faces in—identity despite changes in facial expression, identity despite changes in head orientation, facial expression despite changes in identity, vowel sound despite changes in identity, and gaze direction despite changes in identity and head orientation. Examples of a typical trial for each task are shown in Figure 13 (b-f).

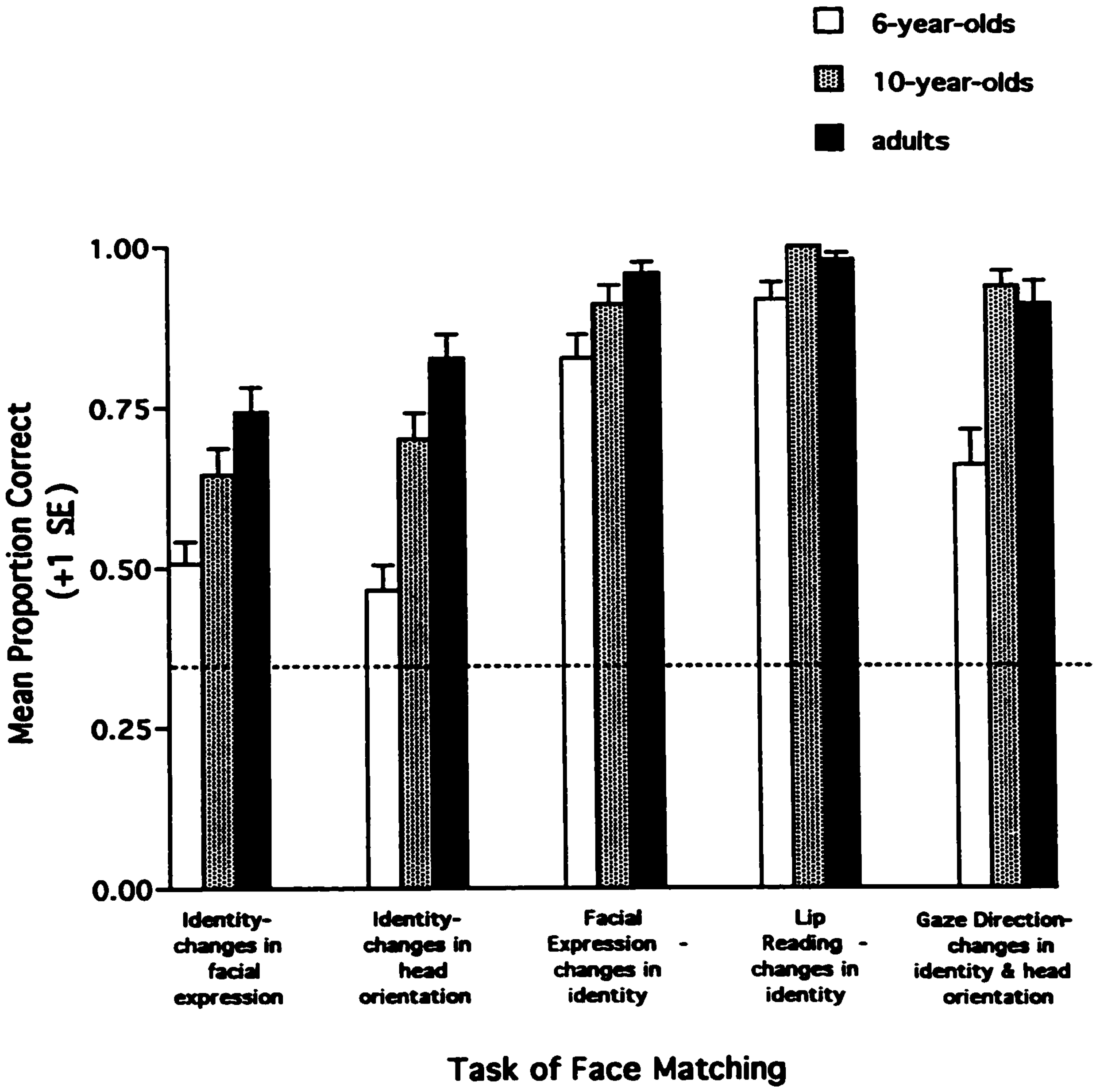

6-year-olds
10-year-olds
adults
Mean Proportion Correct (+1 SE)
1.00
0.75
0.50
0.25
0.00
Identity-changes in facial expression
Identity-changes in head orientation
Facial Expression - changes in identity
Lip Reading - changes in identity
Gaze Direction-changes in identity & head orientation
Task of Face Matching

Table 5.

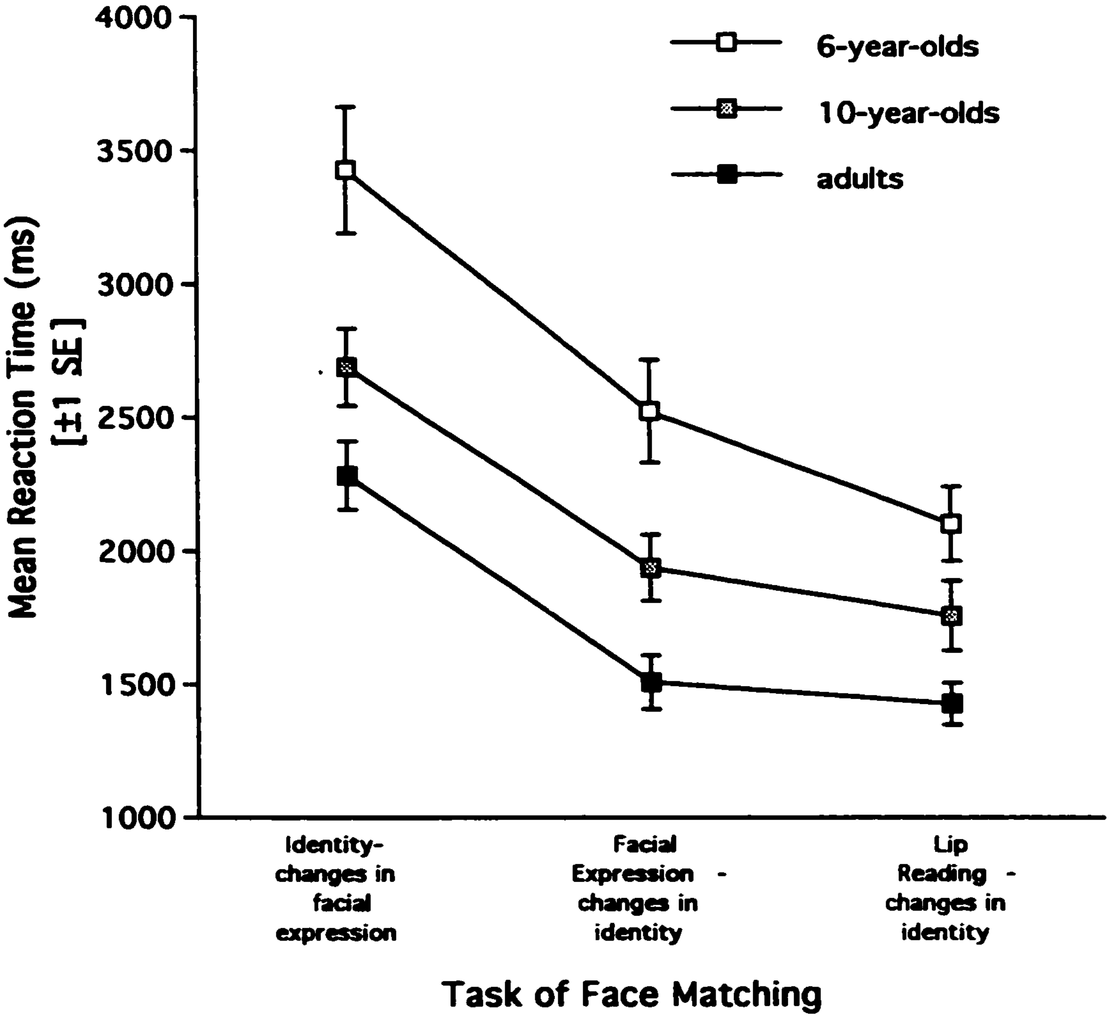
Results of the 2-way ANOVA on normal participants' mean proportion of correct responses on five tasks of face matching—with age group (6, 10, adults) and task type*, and the analyses of simple effects (indent).

Effect	F	df	p
Age group	**37.87**	**2, 69**	**< .0001**
Type of matching task	**61.64**	**4, 276**	**< .0001**
Age group x type of matching task	**4.18**	**8, 276**	**< .0001**
Age group at task 1	**10.05**	**2, 69**	**.000**
Age group at task 2	**21.58**	**2, 69**	**.000**
Age group at task 3	**5.16**	**2, 69**	**.008**
Age group at task 4	**6.74**	**2, 69**	**.002**
Age group at task 5	**14.46**	**2, 69**	**.000**
Task type at age 6	**37.26**	**4, 276**	**.000**
Task type at age 10	**23.47**	**4, 276**	**.000**
Task type at age adult	**9.31**	**4, 276**	**.000**

*tasks 1-5 = matching faces in: identity despite changes in facial expression (1), identity despite changes in head orientation (2), facial expression despite changes in identity (3), vowel sound despite changes in identity (4), and gaze direction despite changes in identity and head orientation (5).

Figure 15.

Normal participants' mean reaction times (±1 SE) on the three tasks of face matching in Experiment 6: matching faces in—identity despite changes in facial expression, facial expression despite changes in identity, and vowel sound despite changes in identity. Reaction times for each task were based on the median reaction time for test trials with correct responses. To facilitate comparisons across tasks, the points on the graph representing the reaction times for each group (normal 6-year-olds, 10-year-olds, and adults) are connected by a line.


4000
3500
3000
2500
2000
1500
1000
Mean Reaction Time (ms) [±1 SE]
6-year-olds
10-year-olds
adults
Identity-changes in facial expression
Facial Expression - changes in identity
Lip Reading - changes in identity
Task of Face Matching

For Patients vs. Normal Controls. The mean proportion of correct responses in patients and normal controls (10-year-olds and adults) for the five tasks are shown in **Figure 16**. The ANOVA showed significant main effects of group and task, and a significant interaction between group and task. Analyses of simple effects indicated a significant effect of task in each group, and a significant effect of group for only one task. See Table 6 for $\underline{F}$ and $\underline{p}$ values of the ANOVA and analyses of simple effects. The patients made significantly more errors than normal controls when they matched faces in identity despite changes in head orientation, but were not significantly different from normals on the other four tasks. There was a tendency for the patients to make more errors than normals on task 1 that required matching identity despite changed facial expression ($\underline{p} = .07$). There was also a tendency for patients to make more errors on task 4 that involved lip reading ($\underline{p} = .09$), though the means for both groups are so similar that any possible deficit on this task is negligible at best. The main effect of task reflected the fact that both patients and normal controls made more errors when they matched faces in identity (despite changes in facial expression or head orientation) than when they matched faces in facial expression, vowel sound or gaze direction (all $\underline{p}$s $< .01$).

Figure 16.

The mean proportion of correct responses (+1 SE) in patients with a history of early visual deprivation and in the normal group (10-year-olds and adults) on the five tasks of face matching in Experiment 6: identity despite changes in facial expression, identity despite changes in head orientation, facial expression despite changes in identity, vowel sound despite changes in identity, and gaze direction despite changes in identity and head orientation.

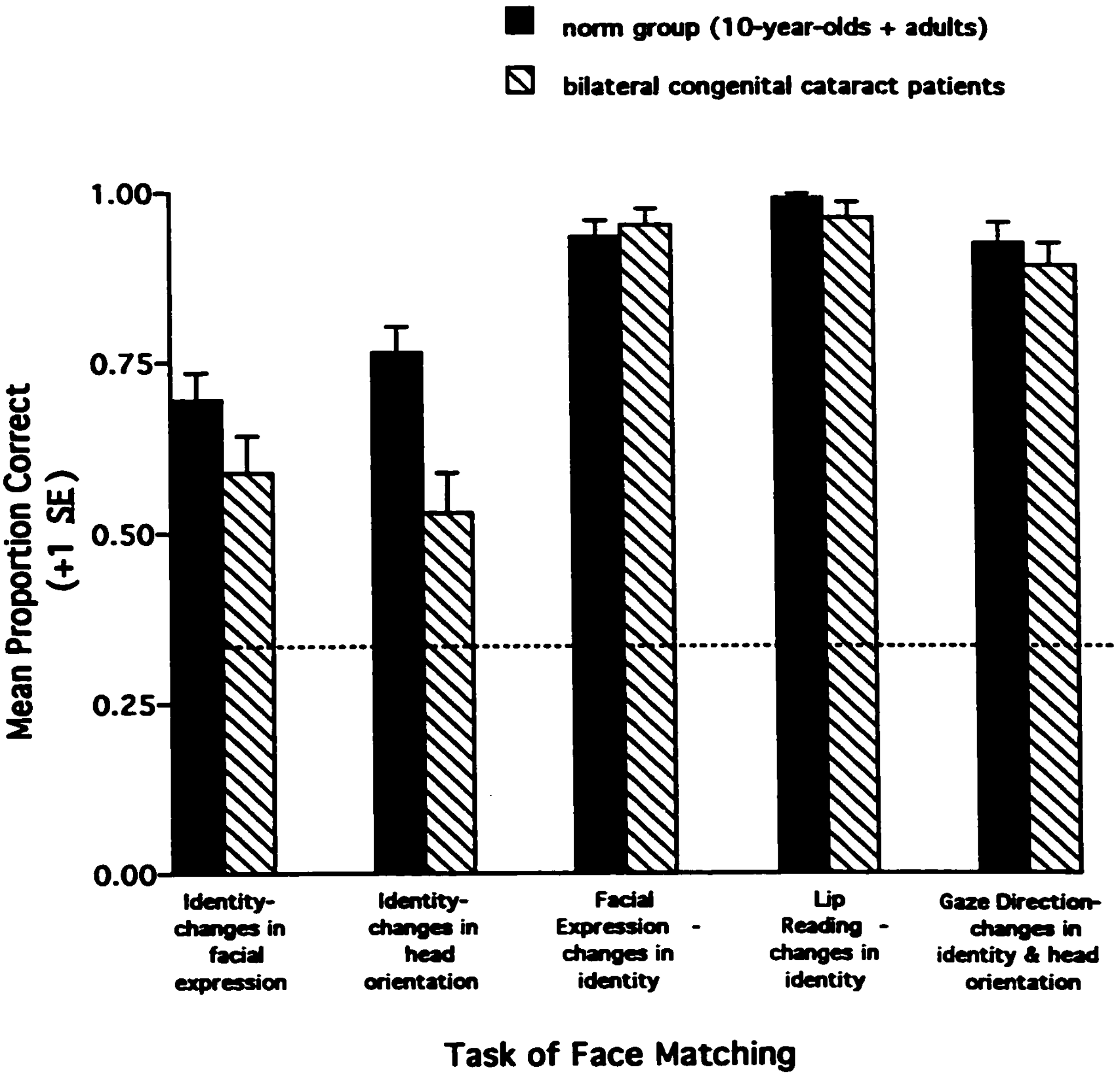

■ norm group (10-year-olds + adults)
▨ bilateral congenital cataract patients
Mean Proportion Correct (+1 SE)
1.00
0.75
0.50
0.25
0.00
Identity-changes in facial expression
Identity-changes in head orientation
Facial Expression - changes in identity
Lip Reading - changes in identity
Gaze Direction-changes in identity & head orientation
Task of Face Matching

Table 6.

Differences between patients with a history of early visual deprivation and the normal comparison group of adults and 10-year-olds on the five tasks of face matching. Results of the 2-way ANOVA on mean proportion of correct responses with subject group and task type*, and the analyses of simple effects (indent).

Effect	F	df	p
Subject group	12.76	1, 63	< .001
Type of matching task	57.35	4, 252	< .0001
Subject group x type of matching task	5.13	4, 252	< .001
Subject group at task 1	3.46	1, 63	.068
Subject group at task 2	15.33	1, 63	.000
Subject group at task 3	0.26	1, 63	.609
Subject group at task 4	3.00	1, 63	.088
Subject group at task 5	0.59	1, 63	.446
Task type at normal group	31.74	4, 252	.000
Task type at patient group	31.06	4, 252	.000

*tasks 1-5 = matching faces in: identity despite changes in facial expression (1), identity despite changes in head orientation (2), facial expression despite changes in identity (3), vowel sound despite changes in identity (4), and gaze direction despite changes in identity and head orientation (5).

There was no significant relationship between patients' mean proportion of correct responses on any task and the duration of their visual deprivation (range of rs = .10 to .35, all ps > .10). Similarly, there was no significant relationship between patients' Snellen acuity in their better eye and their mean proportion of correct responses on any task (range of rs = .09 to .48, all ps > .05). Refer to Appendix 11 for the scatterplots of individual proportion scores for each of the five tasks as a function of (a) the patients' duration of visual deprivation and (b) their visual acuity.

Figure 17 portrays patients' and normals' mean reaction times on the three tasks. The ANOVA on patients' and normal controls' median reaction times showed a significant main effect of task and a significant interaction between group and task, but no main effect of group. Analyses of simple effects indicated a significant effect of task in each group, but no significant effects of group for the three tasks. See Table 7 for F and p values of the ANOVA and analyses of simple effects. In both patients and normal subjects, reaction times for matching facial expressions and vowel sounds were not significantly different from each other (Tukey ps > .05), and both were significantly shorter than those for matching faces' identity despite changes in facial expression (ps < .01). Inspection of the figure suggests that the interaction arose because patients differed from normals more on the task of matching faces' identity than on the other two tasks.

Figure 17.

The mean reaction times (±1 SE) in patients with a history of early visual deprivation and in the normal group (10-year-olds and adults) on the three tasks of face matching in Experiment 6: identity despite changes in facial expression, facial expression despite changes in identity, and lip reading despite changes in identity. Reaction times for each task were based on the median reaction time for test trials with correct responses. The points representing the reaction times for each group are connected by a line in order to facilitate comparisons across tasks.

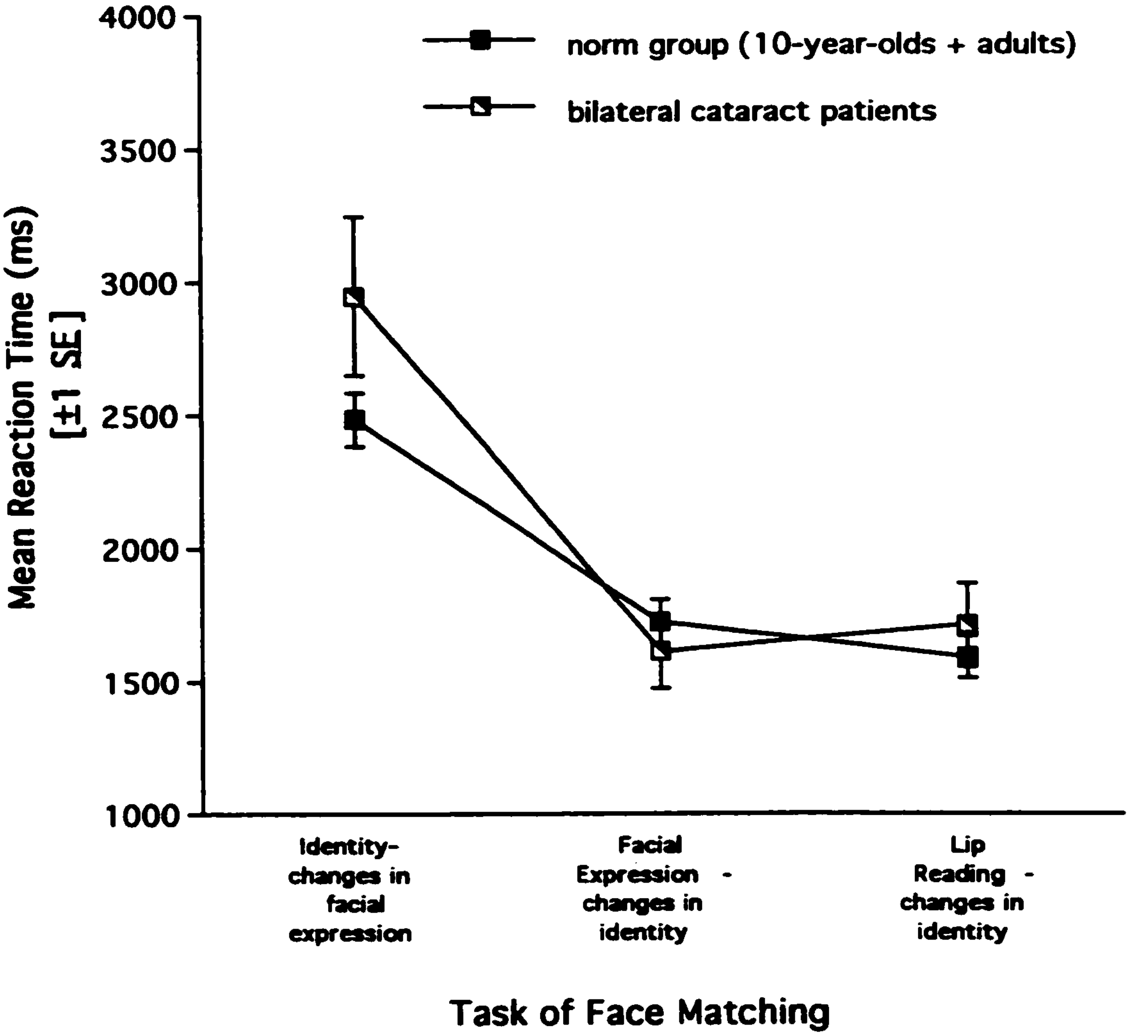

4000
3500
3000
2500
2000
1500
1000
Mean Reaction Time (ms)
[±1 SE]
norm group (10-year-olds + adults)
bilateral cataract patients
Identity-changes in facial expression
Facial Expression - changes in identity
Lip Reading - changes in identity
Task of Face Matching

Table 7.

Results of the 2-way ANOVA on patients' and normals' (10-year-olds and adults) mean reaction times on the three tasks of face matching—with subject group and task type*, and the analyses of simple effects (indent).

Effect	F	df	p
Subject group	1.03	1, 63	.313
Type of matching task	73.22	2, 126	< .0001
Subject group x type of matching task	4.09	2, 126	.019
Subject group at task 1	3.62	1, 63	.062
Subject group at task 3	0.44	1, 63	.508
Subject group at task 4	0.54	1, 63	.464
Task type at normal group	43.75	2, 126	.000
Task type at patient group	36.84	2, 126	.000

*tasks 1, 3, 4 = matching faces in: identity despite changes in facial expression (1), facial expression despite changes in identity (3), and vowel sound despite changes in identity (4).

The relationship between patients' median reaction times and the duration of their visual deprivation was significant for the tasks of matching facial expressions and vowel sounds (lip reading) (rs = .65 and .57, respectively, ps < .05), but not for the task of matching faces' identity despite changes in facial expression (r = .43, p > .05). As shown in Appendix 11 (c), the relationship between reaction time on each task and duration of deprivation was produced by one patient (S.G.) with the longest deprivation in the sample (i.e., 586 days). Those correlations were no longer significant after removing this patient's score from the analyses (rs = .13 and .22, respectively, ps > .10).

There was no significant relationship between patients' Snellen acuity in their better eye and their reaction times on the two tasks that required matching facial expression and vowel sound (rs = .29 and .42, respectively, ps > .10). However, patients with worse visual acuity had longer reaction times on the task involving matching identity despite changes in facial expression, r = .62, p < .05. A look at Appendix 11 (d) reveals that the relationship between acuity and reaction time on that task was produced by the patient (Z.C.) with the poorest vision. That relationship no longer reached statistical significance when his score was removed, r = .46, p > .05.

To determine whether the results from patients and normal controls were maintained after controlling for the possible effects of poor visual acuity on patients' reaction times, I re-analysed the data on reaction time after excluding the data from the patient (Z.C.) with the poorest vision and from the patient (D.D.) for whom there was no information available on visual acuity. The re-analyses showed a main effect of task, but no effect of group and no significant interaction between task and group, ps > .05. Both patients and normals were just as fast on the task of matching facial expressions as on the task of matching vowel sounds (Tukey $p > .05$), and were significantly faster on both of those tasks than on the task of matching faces' identity despite changes in facial expression (both $ps < .01$).

Discussion

In Experiment 6, normal 10-year-olds' accuracy was adultlike on all tasks of face matching. Normal 6-year-olds made more errors on all tasks, and they differed from adults most on the tasks that required matching facial identity and least on those that required lip reading and matching facial expressions. The results from normal participants suggest that many aspects of face processing do not become adultlike until after six years of age. They also suggest that some aspects of face processing—particularly those that involve processing facial identity—may take longer to develop than others. Patients with a history of early visual deprivation caused by bilateral congenital cataracts performed as accurately as normal control subjects in matching facial expression, direction of gaze, and lip reading despite changes in faces' identity. However, the patients were significantly less accurate in matching faces in identity despite changes in head orientation, and they tended to be less accurate in matching faces' identity despite changes in facial expression. The results suggest that early visual experience influences the development of at least one aspect of face processing.

Normal Development

Normal adults made few errors on any of the five tasks of face processing, and this finding is consistent with a large literature showing that adults are "experts" in face processing (reviewed in Bruce & Young, 1986). The finding that 10-year-olds performed as accurately as adults on all five tasks while 6-year-olds did not suggests that the adult expertise in face processing emerges after six years of age. Six-year-olds' relatively poor performance on the two identity tasks is consistent with previous studies showing that children under the age of 10 are less skilled than adults in recognizing faces (e.g., Carey, Diamond, & Woods, 1980; Flin, 1980; Goldstein & Chance, 1964). Taken together, the findings suggest that the ability to process facial identity takes more than six years to develop.

This is the first study to show that 6-year-olds also perform more poorly than adults in tasks requiring reading lips, detecting emotional expression, and decoding direction of gaze despite changes in identity. Such relatively poor performance might have been due to young children's bias to encode faces on the basis of cues irrelevant to the tasks. Previous studies have shown that 6-year-olds, unlike 10-year-olds and adults, differentiate between adults' faces on the basis of misleading external cues (e.g., presence/absence of hats or glasses) (Baenninger, 1994; Diamond & Carey, 1977), and that they recognize the faces of their peers on the basis of external features rather than internal features (e.g., hairline vs. eyes, nose, mouth) (Campbell et al., 1995). In Experiment 6, I attempted to minimize the influence of external cues by presenting faces without paraphernalia or hair (by covering them with scarves). The cues available were configural cues (both spacing among the internal features and spacing between the internal features and the external contour), local cues inside the face (e.g., shape of the eyes or mouth) and some aspects of global shape (e.g., shape of the chin). Perhaps the 6-year-olds made more errors than adults on all tasks because they normally rely on external cues such hair colour/shape and presence/absence of glasses that were unavailable for solving the tasks. Of course, differences in performance might also have been due to the demands of the tasks on children's memory and/or attention, but these alternatives will be discussed later in the chapter.

An interesting pattern of findings is that the 6-year-olds differed from older subjects least on the tasks that could be solved using strategies based on local features. Six-year-olds were nearly adultlike on tasks involving matching facial expression or lip reading, and both could be solved on the basis of the shape of the eyes, mouth, or chin. The large variations in speech (e.g., "u" vs. "a") and emotion (e.g., surprise vs. disgust) expressed by the models might have made it easy to rely on such large, local features, just as one might do so in real interactions with people who express distinct emotions, slow discourse, and full pronunciations. Interestingly, even young babies are known to discriminate between faces based on a single feature: newborns can recognize their mother from a stranger based on hairstyle (e.g., Bushnell et al., 1989; Pascalis et al., 1995), and by four months, they can differentiate between two faces on the basis of eye shape alone (Deruelle & de Schonen, 1998). Perhaps the ability to recognize facial expression and speech, at least as measured by my tasks, develop early because they can be based on a well-developed strategy of local processing.

Six-year-olds' accuracy on both identity tasks fell far below those of adults, perhaps because those tasks required configural processing and, unlike the other tasks, could not be solved easily by alternative methods. The 6-year-olds might have tried to solve them by attending primarily to the small, local features (e.g., shape of eyes, eyebrows, nose) that changed or disappeared following the change in facial expression or head orientation. Poor performance might have also been caused by attending only to the shape of the mouth that altered with facial expression (e.g., from happy to surprise) and/or by attending to the chin that changed shape with changes in head orientation (e.g., from en face to left position). Success on the identity tasks likely required attending to the spatial relationships among the internal features that varied less across transformations than did the local features, and 6-year-olds may simply be less skilled than older subjects in configural processing. Success may also depend on calculating what the new spatial relationships among features would be following a change in head orientation or emotional expression, and 6-year-olds may have more trouble than older subjects with these mental transformations of spatial relationships. Previous studies have shown that while children under the age of 10 can discriminate between faces from either individual features inside the face or the spatial relationships among those features, they are less sensitive to configural changes (e.g., distance between two eyes) than adults, even after extensive training (Baenninger, 1994; Carey & Diamond, 1994; Freire, 1997). Moreover, while adults are much more proficient at recognizing upright faces than inverted faces (e.g., Diamond & Carey, 1986; Yin, 1969), children under the age of 10 are less affected by face inversion (e.g., Carey, 1981; Carey &

Diamond, 1994). The inversion effect is thought to occur because adults rely on configural processing to recognize normally-viewed, upright faces, and must switch to a less efficient strategy of local processing with inverted faces because the configuration of the features is more difficult to perceive in unfamiliar orientations. According to Carey and her colleagues (e.g., Carey, 1981; Diamond & Carey, 1986), adultlike expertise in recognizing faces' identity and sensitivity to face inversion develop slowly during childhood because it depends on many years of experience using configural cues to encode and differentiate between people's faces.

One task was of intermediate difficulty for the 6-year-olds, namely, matching direction of gaze despite changes in faces' identity and head orientation. Errors on this task would be expected if the 6-year-olds had trouble encoding the relationship between the iris/pupil and the sclera (or outer region) of the eye. While even young infants are able to respond to large differences in gaze direction (e.g., Hood et al., 1998; Vecera & Johnson, 1995), adultlike expertise may be slow to develop because it depends on the protracted development of expertise in configural processing.

The interpretation of 6-year-olds' pattern of errors in terms of their dependence on local processing must be made with caution because adults showed a similar pattern of errors, despite better performance overall. Subjects at all ages were fast and accurate in tasks requiring matching facial expressions and lip reading, and as I have suggested earlier, that may be because I chose manipulations of expressions and speech that were particularly easy to differentiate. Conversely, the tasks involving matching faces' identity were difficult at all ages. Perhaps the facial examples selected for the identity tasks were very similar to one another, and hence, difficult to differentiate. The same pattern of difficulty is evident in the reaction times. Despite overall longer reaction times in both 6-year-olds and 10-year-olds than in adults, subjects at every age took longer to respond when matching faces' identity despite changes in facial expression than when matching facial expressions or lip reading. (Comparisons with the other tasks were not possible because reaction times were not collected.) The longer reaction times on the task for which subjects made more errors is evidence that they did not simply sacrifice accuracy for efficiency in response. Instead, participants' poorer accuracy combined with their longer reaction times on tasks involving facial identity indicate that these tasks were more difficult to solve, at least in the versions I used.

However, it is unlikely that task difficulty (by adult standards) determined the pattern of developmental results because there was at least one task—matching direction of gaze—in which the 6-year-olds made an intermediate number of errors and the older subjects made virtually no errors. On that task, the tester specifically asked the subject to match faces in terms of their gaze direction (e.g., eyes looking left or en face) while at the same time ignoring changes in the faces' identity and orientation of head. As I have suggested, the 6-year-olds' relatively poor performance may be related to their difficulty encoding the relationships between the eye features. That task also required not paying attention to the direction of the model's head, and it may be that the 6-year-olds, unlike the older subjects, were unable to ignore the irrelevant information from the external contour (see Diamond & Carey, 1977). Although this may have made the task difficult for 6-year-olds, it is likely to reflect the way in which faces are often processed in the real world. The fact that 10-year-olds did show adult competence suggests that decoding direction of gaze is an important component of everyday face perception that is learned by middle childhood.

In general, the results from normal participants suggest that face processing continues to develop during childhood and does not become adultlike until sometime after six years of age. I have speculated that the development may be related to the slow development of the skill at encoding facial features using a strategy of configural processing. In Experiment 7, I explored that hypothesis directly with tasks designed to measure children's ability to identify faces based either on small, local cues or configural cues.

Effects of Early Visual Deprivation

Patients with a history of early visual deprivation caused by bilateral congenital cataracts performed normally on four of the five tasks, but they did show a deficit in the task that required matching faces' identity despite changes in head orientation. On that task, patients' mean accuracy was lower than that of normal controls by about 20 percent (see Figure 16). This was the task that I argued earlier in the discussion required encoding faces on the basis of the spatial relationships among the internal features because that spacing varied less with changed head orientation than did the local features (e.g., nose, eyes, shape of chin). Like 6-year-olds, the patients may be less skilled than normal in configural processing, and consequently, attempted to solve the task using a less effective strategy of local processing. It may also be true that, like 6-year-olds, patients have difficulty computing how the spacing between features would change following head rotation. Of course, deficits might have been due to factors other than early visual deprivation, and these alternatives will be discussed later in the chapter.

Although not significantly different from normal, the patients also tended to be less accurate in matching faces' identity despite changes in facial expression ($\underline{p} = .07$). The usual strategy for solving this task is probably based on configural cues, but success could also have been achieved by attending to the faces' outer contour, at least on some trials. For example, patients might have been able to easily find the correct person's face that had changed from a neutral to a happy expression because the frame of the face looks essentially the same for both expressions. However, patients would have had more trouble when alterations in the faces' emotion produced a radical change in the shape of the outer contour, e.g. when it changed from disgust to surprise.

Nevertheless, the finding that patients performed normally on at least some tasks of face processing suggests that the development of some adultlike skills does not depend on visual input during early infancy and/or can be learned from delayed experience. The patients in my study had a period of visual deprivation from cataracts lasting at least two months, but following treatment, they had many years of observing and processing faces. Prolonged visual input that began after early infancy may have been sufficient to develop proficiency in the strategies normal individuals use for these aspects of face processing or to develop different strategies. In Experiment 6, patients' errors did not differ from normal when asked to match faces' emotional expression or speech across novel faces, and both of those tasks could have been solved by simply attending to a large feature—shape of mouth or outer contour. In addition, patients were accurate in matching faces' direction of gaze despite changes in identity and head orientation, and hence, appeared to have no trouble encoding the relationship between the iris/pupil area and the sclera. Matching direction of gaze was less challenging for the patients than the two identity tasks—which also seemed to require configural processing—perhaps because it required noting the relationship between only two of the features located on a small part of the face and/or because the tester specifically asked that they ignore conflicting information from the external contour. In any case, these findings suggest that at least under some circumstances, patients are as proficient as normal individuals in processing the small, individual features and how they are positioned relative to each other on the face.

The finding that patients performed abnormally on at least one task of face processing provides support to the theory of Johnson and Morton (1991) arguing for an important role of visual experience with faces during early infancy for the development of face processing. All of the patients had been deprived of visual input for at least the first seven weeks of life, and during that period, they did not have the opportunity to look at stimuli with elements in the configuration of facial features. By the time patients' visual deprivation ended, the subcortical Conspec mechanism that normally biases newborns' attention to faces is no longer functioning, at least in normally-seeing babies. At that point, the Conlern mechanism that developed in the absence of biased input with faces might not have been able to learn about faces' identity in a normal way.

The results also support de Schonen and Mathivet's (1989) theory that the specialization of the right hemisphere for configural processing is set up by experience during the first weeks of life viewing and processing faces when visual acuity and contrast sensitivity are poor. Because the patients did not have experience processing faces and other objects during the first weeks of life, that specialization will not have commenced prior to treatment. Immediately after their visual deprivation ended, patients' visual acuity is similar to that of newborns (Maurer, Lewis, Brent, & Levin, 1999; Tytla et al., 1988), which restricts their processing of objects to the lower spatial frequencies, and hence, might be expected to allow them to begin to encode faces on the basis of the spatial relationships among large features. By that time, however, the cortex in the right hemisphere had been developing on the basis of non-visual input, and hence, may no longer have been available to become specialized for configural processing. If this were true, it would explain why patients showed a deficit in a component of face processing that appears to depend on configural processing, i.e., processing facial identity.

To gain more insight into the strategies underlying face processing in patients with a history of visual deprivation, in Experiment 7 I administered a task that examined capabilities to match faces' identity based on either individual features or the spatial relationships among the internal features. The task allowed me to evaluate whether patients' difficulty in one aspect of face processing—matching faces' identity despite changes in head orientation—might be related to a deficit in configural processing. Patients' difficulty also may be due to an abnormal reliance on local processing, and so I included a second task with "fused" facial composites of the type that have demonstrated adults' reliance on holistic processing to the detriment of local processing (Hole, 1994; Young et al., 1987). For comparison, I included tasks that examined the ability to match geometric figures on the basis of the elements or the spatial relationships among the elements. These tasks allowed me to indirectly test the theory put forward by de Schonen and Mathivet (1989) that early visual experience is necessary to form networks in the right hemisphere that can become specialized for configural processing of faces and other visual patterns.

Experiment 7

In Experiment 7, I administered four computerized tasks designed to measure the ability to match faces or geometric figures on the basis of holistic cues, configural cues, and small, local cues. One task used "fused" facial composites—made from combining the top and bottom segments of different faces—to examine subjects' reliance on holistic processing of faces (Carey & Diamond, 1994; Hole, 1994; Young et al., 1987). Previously, adults and children have been trained to name celebrities' faces from their top halves alone, and then later asked to recognize them in the top half when combined with a bottom half from a different person (Carey & Diamond, 1994; Young et al., 1987). Subjects are slower and make more errors when the two halves are fused together to make a real, upright face compared to when the two halves are inverted or grossly misaligned. Such difficulties disappear with misalignment presumably because subjects can switch from the holistic processing that is inevitable for a normal face to a more appropriate strategy of local processing. Inverting the face also appears to disrupt holistic processing, just as it disrupts configural processing, presumably because it makes the individual features more salient. Children as young as six years of age exhibit effects similar to those shown by adults (Carey & Diamond, 1994), and these findings suggest that by six years of age, children process familiar faces holistically.

One goal of my study was to examine whether children also process unfamiliar faces holistically. Another goal was to test the holistic processing of patients with a history of early visual deprivation. The procedure, adapted from Hole (1994), had subjects view pairs of unfamiliar fused faces presented intact or misaligned, and in each case, decide whether the eyes of the fused faces were the same or different (when the bottom halves were always different).

In a second task, I examined the ability to decide whether two faces were the same or different when they varied in eye shape (a local cue) or eye size (a configural cue). This task was modelled on one used to assess infants' hemispheric specialization for local and configural processing (Deruelle & de Schonen, 1998). As in Experiment 7, faces differing in eye shape were made by replacing the eyes in an original face with those of another person. The original and altered faces differed from each other primarily on the basis of an isolated local feature because the shape of the eyes was changed to a greater extent than were the spatial relationships among the features. Faces differing in eye size were created by reducing the size of the eyes in an original face, a manipulation which made the two versions different primarily in the spatial relations among the internal features. Deruelle and de Schonen (1998) found that when the 4- to 9-month-old infants saw pairs of faces that differed in eye shape, they learned to associate each member of the pair with a particular place of reward faster when the faces were in the right visual field (i.e., left hemisphere) than when they were in the left visual field. When they saw pairs of faces that differed in eye size, they learned faster in the left visual field (i.e., right hemisphere).

I tested subjects' ability to differentiate these stimuli in the central visual field. Based on the literature and my interpretation of the findings from Experiment 6, I predicted that normal subjects at every age would demonstrate sensitivity to differences in faces' eye size and eye shape, and that 6-year-olds would be less sensitive than adults, especially for changes involving eye size. Based on the finding that patients with a history of early visual deprivation showed a deficit in one aspect of face processing that appears to depend on configural processing, I predicted that the patients would be less sensitive to changes in faces' eye size than normal subjects of the same age. That prediction is also based on de Schonen and Mathivet's (1989) theory that the specialization of the right hemisphere for configural processing develops as a consequence of visual experience during the first weeks of life.

Two additional tasks were included to explore strategies used for the processing of shapes. In one task, I measured the ability to make same/different judgments about geometric figures that varied in the shape of the individual elements (local cue) or in the positioning of one of the internal elements (configural cue). Figures consisted of a cross constructed from small black circles or diamonds with an internal element that could appear in one of two positions—in the center to create a "good cross" form, and displaced from the center to create a "bad cross" form. Using these stimuli, Deruelle and de Schonen (1995) found that 4- to 9-month-olds learned to distinguish the individual elements faster in the right visual field (i.e., left hemisphere) and learned to distinguish the internal positions faster in the left visual field (i.e., right hemisphere). I used the same stimuli to examine whether children's errors in face matching in Experiment 6 reflect difficulties in configural processing of visual patterns in general. Another purpose was to see whether patients with a history of early visual deprivation exhibit deficits in configural processing of shapes, as would be predicted by de Schonen and Mathivet (1989) and my interpretation of their errors with faces in Experiment 6.

The second shape task assessed whether participants are adept at processing patterns on the basis of their global shape. To do so, I created hierarchical figures consisting of larger squares or circles made by the arrangement of smaller circles or squares, and I measured subjects' ability to decide that two figures were the same or different on the basis of either the smaller, individual elements or the global shape. Using hierarchical alphabetical letters, previous studies have shown that adults rely on global shape: adults are slower to name the smaller letters that make up a larger letter (e.g., a large H) when those letters are different from the larger letter compared to when they are the same (i.e., small As vs. small Hs) (e.g., Blanca et al., 1994; Martin, 1979; Navon, 1977). In contrast, when asked to name the larger letter, and to ignore the smaller letters, under most conditions adults are just as fast whether the elements are the same or different from the global form. Adults' difficulty in identifying the small letters, known as the "global superiority effect", occurs presumably because adults have a bias to process the patterns on the basis of their overall shape (or the shape of a large region on the external contour) and that strategy interferes with their ability to parse and analyse the smaller components (Navon, 1977). Because global superiority involves the arrangement of a pattern's elements in a whole or "Gestalt" that cannot be easily decomposed into individual elements, it may reflect "first-order" or holistic processing of the type described for face processing. This interpretation is supported by the finding that there are lateralization effects for processing global shape that parallel those for processing faces on the basis of holistic cues (i.e., differentiating faces from non-face objects) (e.g., Allison et al., 1994; Kanwisher et al., 1997). First, normal adults are faster to name the smaller letters when the hierarchical letter is presented to the right visual field (i.e., left hemisphere) than when it is presented to the left visual field, and they are faster to name the global form when it is presented to the left visual field (i.e., right hemisphere) (e.g., Blanca et al., 1994; Martin, 1979). Second, errors in copying hierarchical letters (e.g., the letter H made up of As) produced by adult patients with brain lesions are related to the hemisphere of damage. Patients with right-sided damage reproduce the small letters (i.e., As) accurately but they cannot arrange them to form the correct larger letter, whereas patients with left-sided damage copy the correct larger form but tend to omit the smaller letters (e.g., Delis, Robertson, & Efron, 1986). A similar pattern has been found in 5-year-olds diagnosed at birth with brain damage. When asked to draw a picture of a house (Stiles-Davis, Janowsky, Engel, & Nass, 1988), children with damage to the right hemisphere produce the appropriate components of a house, such as the door, windows, and chimney, and are able to name each of those components. However, unlike normal controls and children with damage to the left hemisphere, the patients with right-sided damage fail to arrange the components in a correct layout for a house, e.g., by positioning the chimney and smoke beneath, rather than above, the house.

The global shape task was designed to evaluate holistic processing of shapes—which would be revealed by global superiority. However, subjects could also show global superiority, not because holistic processing created an overall Gestalt, but rather because they processed only a large chunk of the external contour. From the literature on children's bias for face recognition based on external cues (Campbell et al., 1995; Diamond & Carey, 1977) and the results of Experiment 6, I expected that might be the case for normal 6-year-olds. I thought it might also be the case for patients, if, as I speculated in Experiment 6, patients identify faces by the shape of a large piece of the external contour (e.g., the chin region).

Method

Stimuli

Facial Stimuli

Selecting faces. I used the photographs of faces from Experiment 6 that had been photographed with a neutral pose, with a neutral facial expression and with the head and eyes en face. The faces were different from those used in Experiment 6 so as to prevent subjects from recognizing the stimuli, except that I used some of the eyes in faces from Experiment 6 to create different versions of a face for Experiment 7.

Manipulating face halves. I created "fused" facial composites consisting of the top half of one face and the bottom half of another face based on the procedure from Young et al. (1987) and Hole (1994). I used Photoshop to remove the bottom half (7.5 cm) of an original face, which effectively split the face at a point halfway down the nose, and then replaced that area with the bottom half of a new face. The faces making up the composite were of the same sex, with similar colouring of complexion and face width (at their widest points). There were subtle differences between the two halves in their colouring and shape along the outer contour, and so I blended the colouring near the middle of the face and joined the lines on the two sides near the cap (ear) regions to make the photograph look natural.

Three faces were used to create a pairing of fused faces that was identical in their top halves and different in their bottom halves: I first duplicated one of the faces, removed the bottom halves of both versions, and then replaced the bottom with those from the other two faces. To make a pairing of fused faces that differed both in their top halves and in their bottom halves, I switched the bottom segments of two different faces. Each of the pairings was shown either with the halves fused together to form a realistic face or with the halves misaligned horizontally.[9] Misalignment was produced by shifting the bottom 7.5 cm of the image 5 cm to the left or to the right. See Figure 18 for examples of fused facial composites presented fused and intact (a) or with

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[9] Pairings were also shown inverted but the results are not discussed because there were only four inverted trials and subjects at all ages made the most errors with inverted fused faces (see Results), a pattern which is opposite to that found in previous studies (see Carey, 1992). I suspect that subjects require many more trials to get used to looking at upside-down faces before their performance becomes sufficiently above chance for differences between conditions to be revealed.

the halves misaligned (b). (Refer to Figure 18 [c] for inverted fused faces, and Footnote 9.)

Manipulating eye size and shape. I created two versions of each face that differed on the basis of eye size or eye shape using procedures modelled on Deruelle & de Schonen (1998). To manipulate eye size, I used Photoshop to remove the eyes from a face, and pasted each eye onto a separate image. I then measured the width (i..e., distance from inner to outer corner) and height (i.e., distance from top lid to bottom) of each eye, and enlarged their sizes by 25 percent, a process that also caused proportional changes in the area of the iris and pupil. The enlarged eyes were then repasted onto a duplicated photograph of the original to create a second version of the face with larger eyes. To manipulate eye shape, I duplicated a face, removed the eyes from one of the duplicated faces, and then replaced the eye region with the eyes of a different face. The eyes chosen as replacements came from a photograph of the same sex as the original face and were similar in eye colouring and eye width, from inner to outer corner, but not in eye height. In this way, the outer contour of the eyes was approximately similar in size to that of the original face, but the shape of the eyelid contour relative to the pupil and the cornea differed from the original eyes. Figure 19 illustrates pairs of faces used on a typical trial in which the two versions of faces were identical (a), were different in eye shape (b), and were different in eye size (c).

Figure 18.

Illustrations of pairs of "fused" facial composites from the task in Experiment 7 that required same/different judgments of faces' eyes when the composites were presented intact (a) and with their halves misaligned horizontally (b). For each example shown, the target face is depicted on the left and the test face is on the right. The examples are from trials in which the bottom halves of each pairing are different and the top halves are the same (i.e., same trials). The example of misaligned composites is from a typical trial in which the bottom halves are shifted to the right. (For comparison, an example of fused faces presented inverted is shown in [c].)

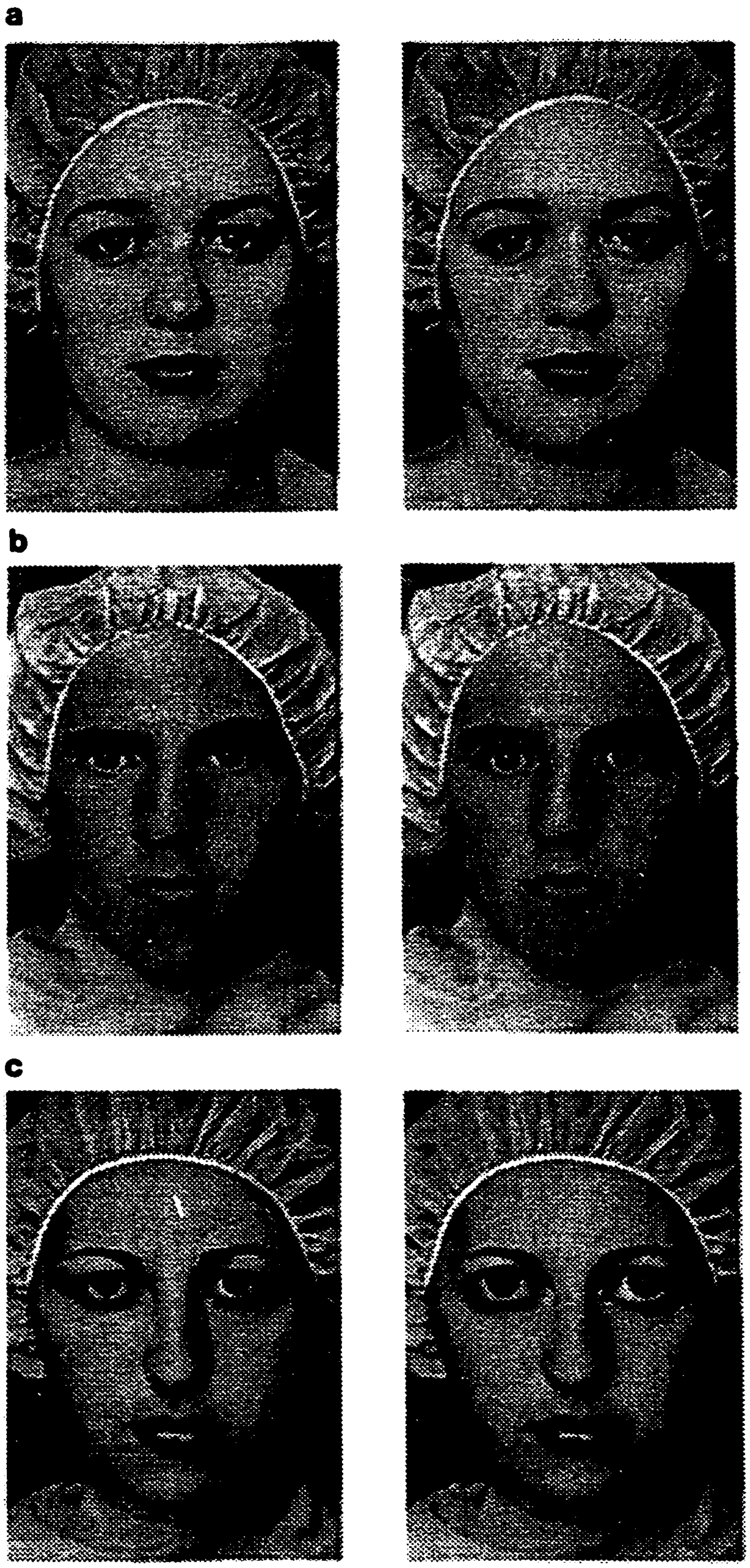
a

b


c

Figure 19.

Illustrations of pairs of faces from the task in Experiment 7 that required same/different judgments of faces' eyes when the faces were identical (a), when the faces varied in eye shape (b), and when they varied in eye size (c).


a
b
c

To prevent subjects from differentiating between two faces simply because one version appeared as though it had been tampered with, I used Photoshop to make the manipulated faces look realistic. I did so by blending the colouring of the complexion near the lower regions of the eyes and the lighter regions of the upper cheek and nose. I also blended the colouring of the top of the eye with the darker brow region without altering the shape or colour of the eyebrows and lashes. In addition, I created a new version of faces not only from natural photographs but also from manipulated faces. For example, to increase eye size in a manipulated face, I took a natural photograph and substituted the eyes with those from a different face, and then made a final version of it by enlarging the eyes.

Shape Stimuli

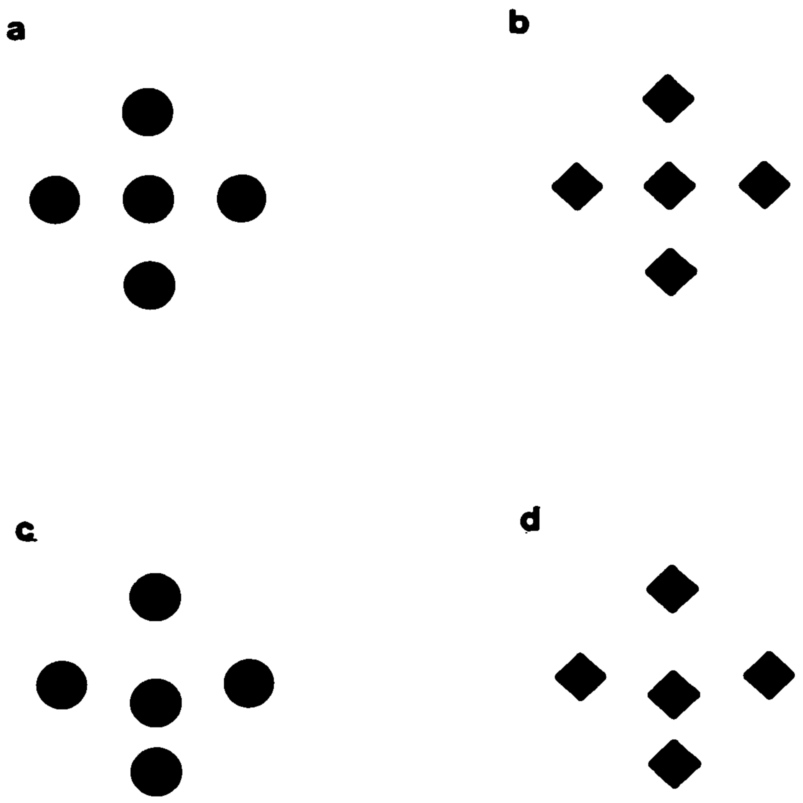
Creating hierarchical shapes. I used Canvas software to create hierarchical figures, each consisting of a larger geometric shape produced by the arrangement of smaller black shapes. The larger shapes were made to be no larger than five visual degrees wide and high when viewed from 100 cm. This was a small enough image size to discourage subjects from encoding the patterns solely on the basis of the individual elements. Previous studies indicate that adults do not show global superiority when viewing hierarchical alphabetical letters extending more than about six or seven visual degrees (e.g., Kinchla & Wolfe, 1979).

To be sure that patients would be able to detect each element that made up the larger figure and could discriminate between elements, I calculated the necessary minimum size of elements and their spacing based on previous measurements of grating acuity and vernier acuity in a similar cohort of patients. Grating acuity, which is a good estimate of the ability to discriminate between the black elements and light-coloured background, is 10 minutes of arc or better in at least one eye (Maurer & Lewis, 1993; also see Experiment 6 on calculations of faces' eyes). Vernier acuity measures the minimum offset between two contours that can be resolved, and is a good estimate of how far apart each element had to be for patients to discriminate between them. For 95% of the cohort, vernier acuity is approximately 3.5 minutes of arc or better in at least one eye (Tytla, Lewis, Maurer, & Brent, 1990). Therefore, I made the width and height of each element and the distance between elements large enough that they would be well above patients' thresholds (i.e., 60 minutes of arc [or 1°] in the local/configural task; 30 minutes of arc in the global shape task).

Manipulating the shape of elements and the positioning of the internal element. For the local/configural task, geometric figures differed in the shape of the individual elements or the positioning of the internal element. The stimuli, modelled on Deruelle and de Schonen (1995), consisted of four cross forms made by the arrangement of five black circles or black diamonds. See Figure 20 for an illustration of the four cross forms, reduced in size. In "good" forms, the internal element used to construct the cross was positioned in the center (Figure 20 a and b). The height and width of each smaller element, and the spacing between elements, extended one visual degree. This gave the entire form an image size of 5° wide by 5° high. Crosses defined as "bad" forms had the internal element positioned so that it was closer to the bottom element, i.e., 0.5° above the bottom element (Figure 20 c and d).

Figure 20.

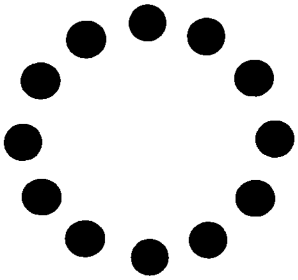
The four geometric figures from the local/configural task in Experiment 7 that required same/different judgments of pairs of figures that were identical, that differed in the shape of individual elements, and that differed in the positioning of their internal element. Figures a and b illustrate a pair of good cross forms and figures c and d illustrate a pair of distorted cross forms, both of which varied only in the shape of elements (i.e., circles and diamonds, respectively). Figures a and c and figures b and d represent pairings of figures that varied only in the positioning of their internal element (i.e., good vs. bad cross, respectively).

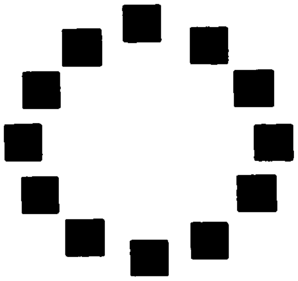

a
b
c
d

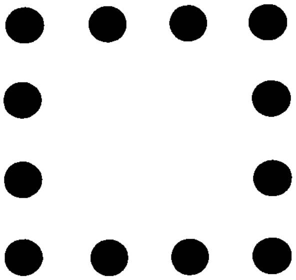
Manipulating the shape of elements and the positioning of the external elements. For the global shape task, four hierarchical figures were produced by the arrangement of 12 individual elements, which could either be black squares or black circles. The elements were positioned so that they formed either a large square or a circle. The size of the elements and the size of the spaces between elements was .51 visual degrees (i.e., 30 minutes of arc). This gave the entire form a size of 4.2° wide by 4.2° high. See Figure 21 for an illustration of the four hierarchical figures, reduced in size.

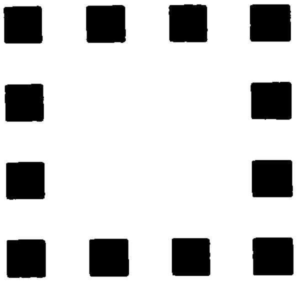
Figure 21.

The four hierarchical figures from the global shape task in Experiment 7 that required same/different judgments of pairs of figures on the basis of either their individual elements (ignoring global shape) or their global shape (ignoring individual elements).









Tasks

General Design

The order of the tasks was the same for all subjects: one practice task of face matching, followed by two tasks of face matching, and finally two tasks of shape matching. During each trial, a target stimulus appeared for a short duration in the center of the computer screen (see below), and following a 200 millisecond interstimulus interval, was replaced by the test stimulus for the same duration.[10] The subject was asked to signal whether the two stimuli were the same or different by moving the joystick forward toward the screen (for same) or backward toward himself/herself (for different). As in Experiment 6, Superlab was used to initiate the trials, to score the correctness of responses, and to calculate reaction time.

The order of the trials within each task was the same for all subjects. All tasks began with practice trials. The number of practice and test trials varied across tasks (see below). For each, the correct response was same for 50 percent of the trials. Same and different trials were presented in random order with the constraint that no more than three trials of each type appeared consecutively. For face tasks, the target and test faces were always of the same sex, with 50 percent male trials. The order of faces' sex was random with the

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[10] The extremely short exposure times of the stimuli (i.e., 360 ms and 180 ms for face tasks; 150 ms for shape tasks) were based on similar short exposures used in previous studies (e.g., Hole, 1994; Paquet & Merikle, 1984) and the results of pilot work with normal 6-year-olds, 10-year-olds, and adults (n = 10 per group). Pilot subjects at each age were given one task, using three different exposure times (e.g., 120 ms, 180 ms, 360 ms). Within each age group, I compared the results of the different exposures across conditions of the task. I then chose the exposure duration for the task that, for all three age groups, revealed the largest differences between conditions.

constraint that no more than two trials of the same sex appeared consecutively.

Description of Tasks

The tasks are described in the same order in which they were presented to subjects.

Practice Task: Same/different judgments of faces varying in the orientation of eyes, nose, or mouth. The practice task used faces in which the orientation of the mouth, nose or eyes had been greatly changed. Using Photoshop, I varied the angle of the longer axis of the nose by orienting it either 20° to the left or to the right from the center of an original face. The angle of the longer axis of the mouth or eyes were varied by orienting them either 16° upwards or downwards. For the eye manipulation, the orientation chosen for one of the eyes was always mirrored in the other eye.

The tester explained the instructions for the practice task as follows: "You will see one person's face in the center of the screen for a very short time, and then that face will disappear. Then a second face will appear in the center, also for a short time. Your job is to decide whether the two faces are the same or different. If the two faces are the same, move the joystick upwards to show me that they are the same. If you think the faces are different, move the joystick downward. Remember that the faces will appear for only a short time, and so it is important to always look at the center of the screen."

Figure 22 illustrates pairs of faces used on a typical practice trial in which they were the same (a) or were different on the basis of mouth orientation (b) or eye orientation (c). The practice task began with four trials during which the two faces were presented simultaneously, one to the left and the other to the right of the visual field, so that subjects could easily compare the faces to see how they differed. On those trials, the tester gave feedback on accuracy and explained on what basis the faces were the same or different. The remaining trials presented the faces sequentially, and the subject was not informed about his/her correctness. Any subject who failed the criterion of at least 75% correct on the practice task was allowed to repeat it up to three times. No subject took three attempts. Only seven normal 6-year-olds and three normal 10-year-olds had accuracy below 75 percent on their first attempt, and all passed on their second attempt.[11]

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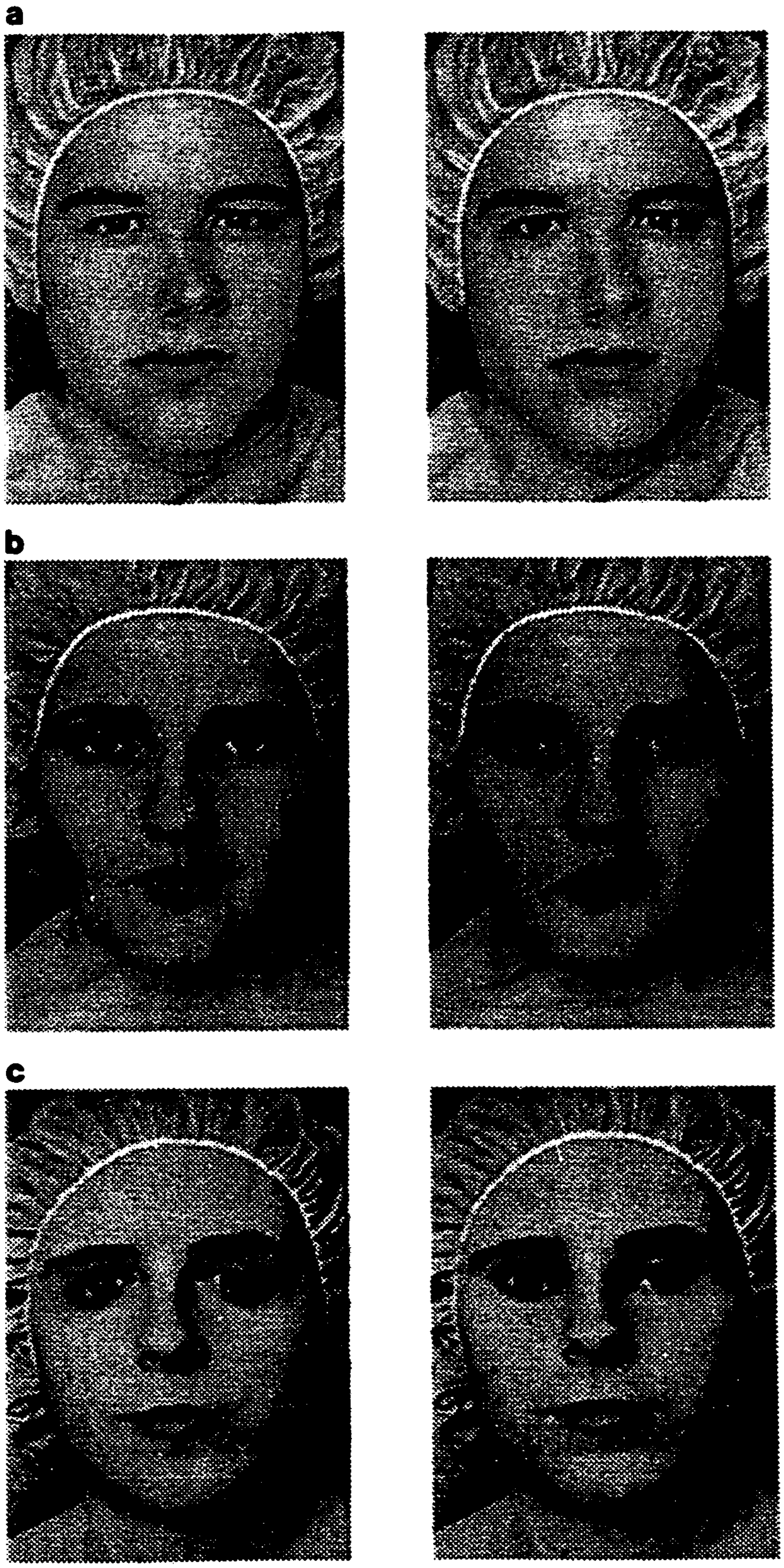
[11] The criterion for passing the practice task was not as stringent as that in Experiment 6 based on pilot data from adults who made no errors in Experiment 6 but some errors in Experiment 7 (i.e., M accuracy = 92 percent; range = 83 to 100 percent).

Figure 22.

Illustrations of pairs of faces from the practice task in Experiment 7 that required same/different judgments of faces when the faces were identical (a), when the faces were different in mouth orientation (b) and when they were different in eye orientation (c).


a
b
c

Task 1: Same/different judgments of eyes varying in size or shape. Task 1 used faces that differed in eye shape (by substituting the eyes of a different face) and eye size (by enlarging the eyes). For each of 32 test trials, subjects viewed two faces sequentially for 360 ms each, and decided whether the eyes of the two faces were the same or different. The tester explained the task by saying "As before, you will see one person's face in the middle of the computer screen for a short time. Then a second face will appear, also for a short time. Your job is different than before because now you will need to decide whether the eyes of the two faces are the same or different."

There were eight pairings of faces that differed only in eye shape, eight pairings of faces that differed only on in eye size, and 16 pairings in which the two faces were identical. Within each of the three types of pairing (i.e., same, different in eye size, different in eye shape), half contained natural photographs and the other half contained modified faces. The number of same and different trials, and natural and modified faces, were equally represented in the first half of the procedure and in the second half. The task was preceded by four practice trials consisting of two different trials (one for each type) and two same trials. Refer to Figure 19 for typical trials of this task in which two versions of faces were the same (a), and two versions were different on the basis of eye shape (b) or eye size (c).

Task 2: Same/different judgments of eyes in fused faces. Task 2 used fused facial composites that were presented upright, inverted, or with their halves misaligned horizontally. For each of 16 test trials, subjects viewed two fused faces shown sequentially in the center of the screen for 180 ms, and then decided whether the eyes of the fused faces were the same or different.

In blocks of four test trials each, fused faces were presented in the following order: inverted, upright, upright again, and misaligned. Within each block, two pairings of fused faces differed from each other in both their top and bottom halves, and the other two pairings differed from each other only in their bottom halves. The first, second, and fourth block of trials were preceded by practice trials of the same two types of pairings. In the block of trials containing misaligned faces, half of the trials contained the bottom segments displaced to the right. Figure 18 illustrates pairs of fused faces with the same top halves and different bottom halves, and presented either upright and intact (a), misaligned horizontally, with the bottom segment displaced to the right (b), or inverted (c).

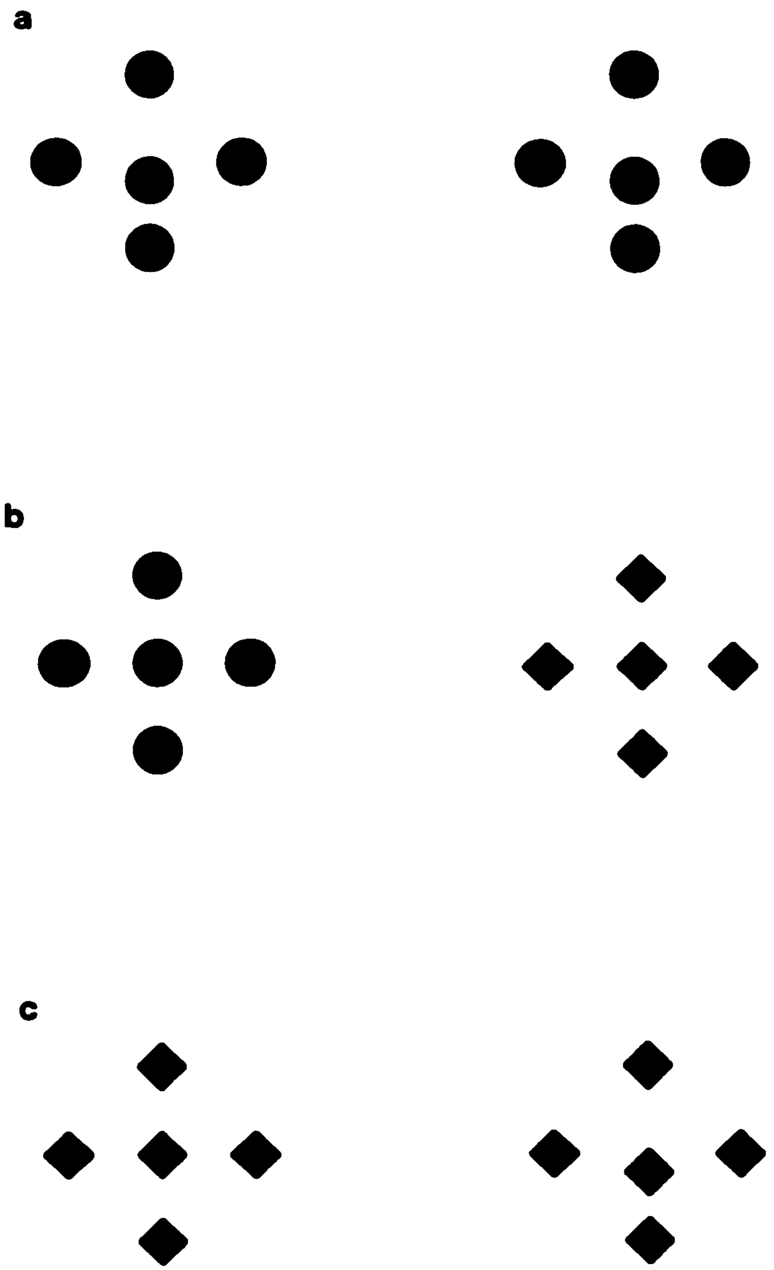
The instructions for matching were given to the subject before the first, second and fourth block of trials. Before the first block with inverted faces, the tester said "As in the last task, you will see one face in the middle of the screen for a short time, and then a second face in the middle also for a short time. Again, your job is to decide whether the eyes of the two faces are the same or different. This time, both faces will be upside-down. As you look at them, you must not turn your head sideways, but always keep it straight." Before the second block of trials, the subject was told that the faces would be shown in their normal orientation, but that the job was the same because he/she would need to decide whether the eyes of the two faces were the same or different. Before the last block of trials with misaligned faces, the tester said "Each face will look funny because it is cut in half (demonstrating with hands). Even though the faces are split, your job is the same because you will need to decide whether the eyes of the two faces are the same or different."

Task 3: Same/different judgments of geometric figures varying in the shape of the elements or the positioning of the internal element. Task 3 used the four geometric figures consisting of good and bad cross forms (Figure 20). For each of 16 test trials, the subject viewed two figures shown sequentially in the center of the computer screen for 150 ms, and then decided whether they were the same or different. Before testing, the subject was told that the new task involved looking at shapes instead of people's faces. The shapes were described as funny-looking because they consisted of a larger pattern that was made from a set of smaller shapes. The tester described the task as follows: "You will see one shape in the center of the screen for a short time, and then a second shape also in the center for a short time. The time that each shape appears is much shorter than it was for faces and so it is important to look carefully in the middle. Your job is to decide whether the two shapes are the same or different."

There were four pairings of patterns that differed only in the spacing of their elements, four pairings that differed only in the shape of the elements, and eight pairings in which the two patterns were identical. The same and different trials were equally represented in the first half of the procedure and in the second half. All were preceded by two practice trials consisting of one trial in which figures were identical and one trial in which they were different on the basis of the positioning of the internal element. Figure 23 shows two versions of figures that were the same (a), different in the shape of elements (b), and different in the positioning of the internal element (c).

Figure 23.

Illustrations of the pairs of geometric figures from the task in Experiment 7 that required same/different judgments when the figures were the same (a), when the figures varied in the shape of the elements (b), and when they varied in the positioning of their internal element (c).


a
b
c

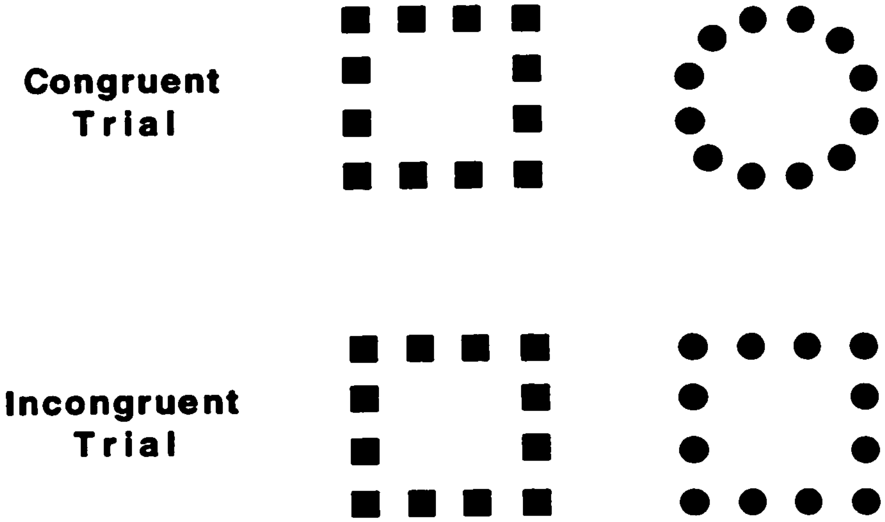
Task 4: Same/different judgments of figures on the basis of the individual elements or the global shape. Task 4 used the four hierarchical figures consisting of squares and circles (see Figure 21). For each of 32 test trials, the subject saw two figures shown sequentially in the center of the screen for 150 ms. On half the trials, the subject was asked to decide whether the pair of figures were the same or different on the basis of the individual elements, and to ignore any possible differences between them in the positioning of the elements. For the remaining trials, the subject was asked to decide whether the figures were the same or different on the basis of their global shapes, and to ignore any differences between them in their elements.

In blocks of eight test trials each, subjects indicated their same/different judgments of individual elements and global shape in the following order: global shape, elements, elements again, and global shape. Within each block, two shape pairs were the same and two were different on the basis of both the elements and the global shape. These four pairs of trials are called congruent trials because the similarity or difference between two shapes at one level (e.g., in global shape) is consistent with that occurring at the other level (i.e., in individual elements). Within each block, two additional pairs of figures were the same at the level at which subjects were asked to respond and different at the level they were asked to ignore, and two pairs were different only at the level at which subjects were asked to respond. These four pairs of trials are called incongruent trials because correct judgments were different from those occurring at the level at which subjects were required to ignore. The order of the congruent and incongruent trials was random across the eight trials that made up each block. The first, second, and fourth block of trials were preceded by two practice trials, each containing one congruent and one incongruent trial. Figure 24 illustrates congruent and incongruent trials when responding to figures in global shape or in the individual elements.

The instructions for matching figures were given immediately before the first, second, and fourth block of trials. Before the first block, the tester explained that the shapes used in this task looked like a square or a circle, and that each one was made by the arrangement of smaller squares or circles. The subject was told that his/her job was to decide whether the larger shapes were the same or different. The subject was asked to ignore the smaller shapes with an example: "If the two shapes look like squares but one is made from small circles and the other is made from small squares, then the two shapes are the same. It does not matter that the smaller shapes are different." Before the second block of trials, the subject was given new instructions. The tester said "Now you must focus on the smaller shapes rather than the larger forms. Your job is to decide whether the smaller shapes in the two patterns are the same or different." Before the last block of trials, the tester explained that the task was like that from the beginning—to decide whether the larger shapes were the same or different and to ignore the smaller shapes.

Figure 24.

The pairs of hierarchical figures from the task in Experiment 7 that required responding same/different based on either the individual elements or the global shape. The examples represent congruent and incongruent trials. On the congruent trial, the correct response at one level is the same as the correct response occurring at the level at which subjects were asked to ignore. On the incongruent trial, the correct response at one level is not the same as that for the other level.


Congruent Trial
Incongruent Trial

Procedure

Each participant was tested after completion of the tasks in Experiment 6 and a 5- to 10-minute break away from the screen. Before testing, the tester explained that the joystick would be moved in only two directions, forwards or backwards. The younger subjects were allowed to handle the joystick before testing to learn how to move it correctly.

When the subject appeared ready, the tester initiated the first trial of the practice task. Following the practice task, participants were tested with the two tasks of face matching and the two tasks of shape matching, in the order described earlier (see Tasks). For all tasks, the tester emphasized accuracy in response but asked that the subject try to respond quickly.

Data Analyses

The analyses of accuracy and reaction time data were the same as in Experiment 6 except as noted below.

First, because the mean accuracy scores on the shape tasks were significantly different for normal 10-year-olds and adults (see Results), and to make the comparison between normal controls and patients on those tasks as conservative as possible, I used the scores from the 10-year-olds as the norm for patients. (On the tasks of face matching, mean accuracy in 10-year-olds and adults did not differ significantly, and so I used their combined scores as the norm [as in Experiment 6]).

The best choice for the normative group in the analysis of reaction time was not so obvious. For all tasks, I used the combined scores from normal 10-year-olds and adults as the norm for patients (just as I had done in Experiment 6). I did so because, although 10-year-olds were slower than adults in each task, their patterns of reaction times across conditions were not significantly different (See Results). If I had used the data from 10-year-olds alone as the comparison it was likely to reveal uninteresting differences in speed between normals and patients because the patients were older (M age: 16 years), and hence, would be expected to be faster. Using the combined scores of normal 10-year-olds and adults probably was a better comparison for the face tasks because it meant that the comparison group was the same for both the analysis of reaction time and accuracy. For the shape tasks, I used different norms for the analyses of accuracy (i.e., 10-year-olds) and reaction time (i.e., 10-year-olds and adults), and did so despite the fact that in normals the interaction between age and one shape task approached significance ($p = .06$). However, as reported in footnotes 15 and 16, the pattern of results is not affected by the choice of comparison group.

Second, I did not analyse the reaction times when the median was based on too few trials to get an accurate estimate. This happened in task 2 which required same/different judgments in fused faces because there were only two trials per condition. It also happened for normal 6-year-olds who made many errors on all tasks. Third, for subjects included in the analyses of reaction times who did not have any correct trials in a particular condition, I assigned a score for that condition based on the mean reaction time from the group (uncorrected for a subject's overall speed).

Results

Same/Different Judgments of Faces with Eyes Varying in Size or Shape

For Normal Participants. The normal participants' mean proportion of correct responses for identical faces and for faces with eyes varying in shape or size are shown in Figure 25. The mean proportion scores were subjected to an ANOVA, with one within-subjects factor (same, different eye shape, different eye size) and one between-subjects factor (3 ages). There was a significant main effect of age and a significant interaction between age and trial type, but no significant main effect of trial type (see Table 8). Analyses of simple effects revealed an effect of age when faces varied in eye shape or in eye size, but not when faces were identical. They also showed an effect of trial type in 6-year-olds, but not in 10-year-olds or adults. Whether responding to faces differing eye size or eye shape, 10-year-olds were as accurate as adults (Dunnett t-test, $\underline{p} > .05$), and 6-year-olds made significantly more errors than adults ($\underline{p} < .01$). Furthermore, unlike adults and 10-year-olds who showed high accuracy regardless of trial type, the 6-year-olds made significantly more errors on the two types of different trials than on same trials (Tukey, $\underline{p}\text{s} < .05$), though errors on the two types of different trials were not significantly different from each other ($\underline{p} > .05$). As shown in Figure 25, the mean accuracy scores on the two types of different trials were only slightly above chance in 6-year-olds, but they were over 75 to 85 percent in the older subjects.

Figure 25.

Normal participants' mean proportion of correct responses (+1 SE) on the task in Experiment 7 that required same/different judgments of faces' eyes in three conditions: when the faces were the same, when the faces differed in eye shape, and when the faces differed in eye size. Refer to Figure 19 for illustrations of the three types of face pairings.

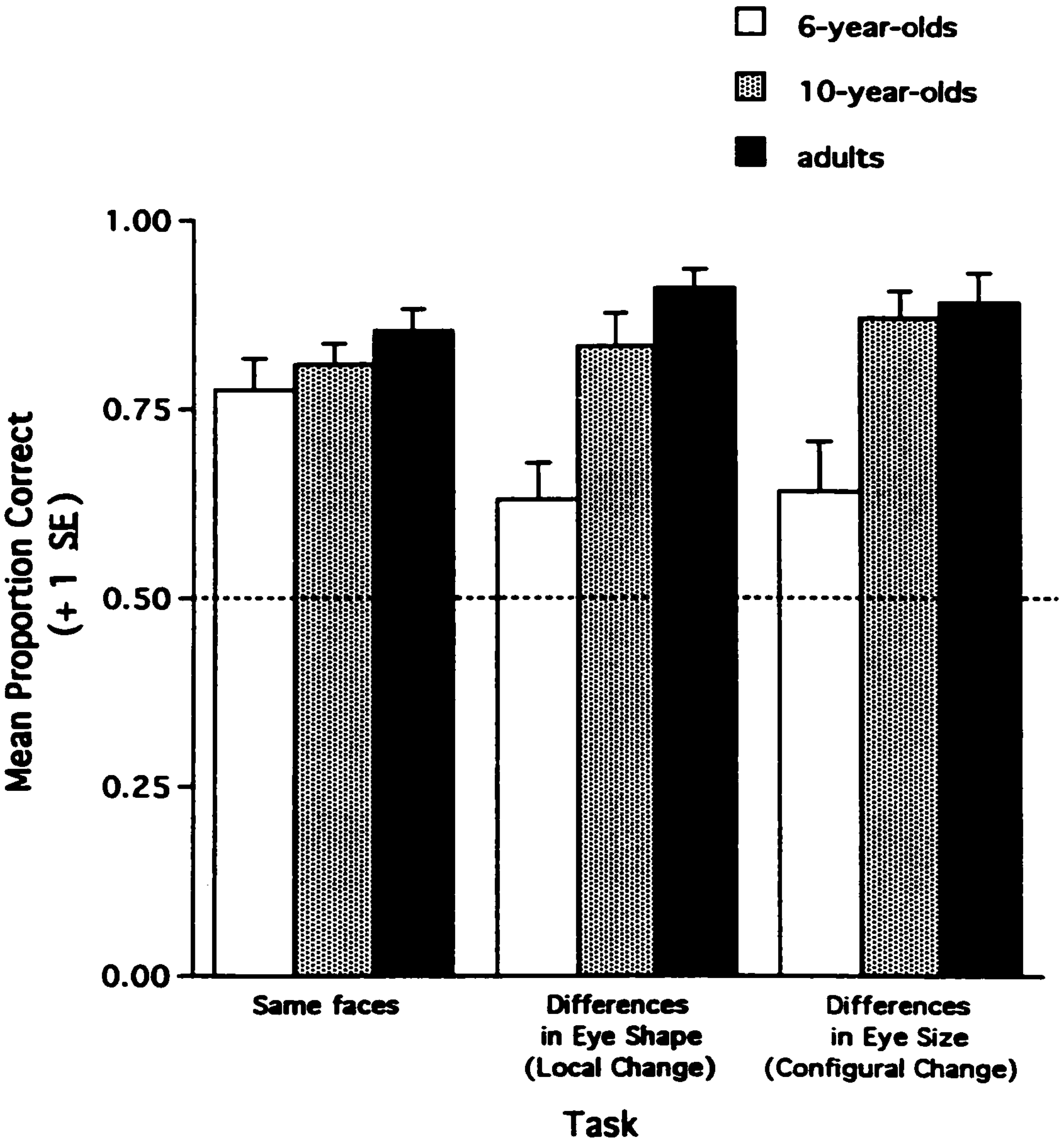

6-year-olds
10-year-olds
adults
1.00
0.75
0.50
0.25
0.00
Mean Proportion Correct
(+1 SE)
Same faces
Differences in Eye Shape (Local Change)
Differences in Eye Size (Configural Change)
Task

Table 8.

Results of the 2-way ANOVA on normals' mean proportion of correct responses on the task requiring same/different judgments of faces that were identical or that varied in eye shape (local change) or eye size (configural change)—with age group (6, 10, adults) and task type (same, different eye shape, different eye size), and the analyses of simple effects (indent).

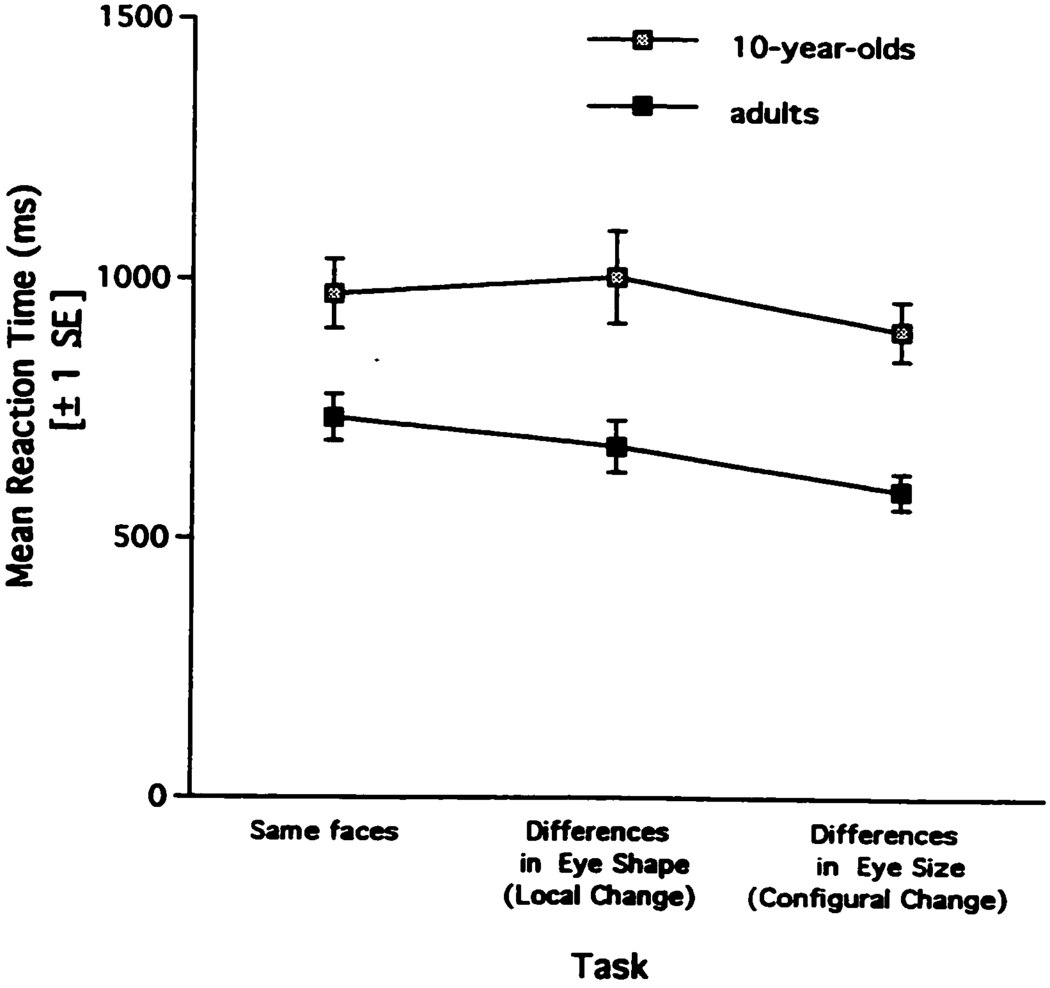
Effect	F	df	p
Age group	**24.05**	**2, 69**	**< .0001**
Type of task	1.07	2, 138	.347
Age group x type of task	**4.34**	**4, 138**	**.0025**
Age group at same faces	0.48	2, 207	.621
Age group at eye shape	**15.74**	**2, 207**	**.000**
Age group at eye size	**16.93**	**2, 207**	**.000**
Task type at age 6	**8.82**	**2, 138**	**.000**
Task type at age 10	0.52	2, 138	.595
Task type at age adult	0.41	2, 138	.666

The mean (of the median) reaction times for the three trial types are shown in Figure 26. An ANOVA, with one within-subjects factor (3 trial types) and one between-subjects factor (2 ages), revealed a significant main effect of age, $\underline{F}\ (1,46) = 16.59$, $\underline{p} < .001$, a significant effect of trial type, $\underline{F}\ (2,92) = 4.60$, $\underline{p} < .05$, but no significant interaction, $\underline{F}\ (2,92) = 0.76$, $\underline{p} > .10$. In both 10-year-olds and adults, reaction times were significantly shorter for trials with different eye size than for trials with different eye shape or same trials (Tukey, $\underline{p}$s $< .05$), which did not differ from each other ($\underline{p} > .05$). Reaction times were also significantly longer in 10-year-olds than in adults.

For Patients vs. Normal Controls. The mean proportion of correct responses in patients and normal controls (10-year-olds and adults) are shown in Figure 27. The figure shows that patients' accuracy for both types of different trials were at chance. An ANOVA on the accuracy scores showed significant main effects of subject group and trial type and a significant interaction between group and trial type (see Table 9). Further analyses revealed a significant effect of group when faces varied in their eyes and their size, but not when faces were the same. They also showed an effect of trial type in patients, but not in normal controls. While the normal group showed high accuracy across all trial types, the patients were no different from normal on same trials but they made significantly more errors than normal when they viewed faces differing in eye size and eye shape. Furthermore, the patients' errors for faces differing in eye size and shape were not different from each other (Tukey, $\underline{p} > .05$), but both were significantly greater than their errors on same trials (both $\underline{p}$s $< .01$).

Figure 26.

Normal 10-year-olds' and adults' mean reaction times (±1 SE) on the task in Experiment 7 that required same/different judgments of faces' eyes in three conditions: when the faces were the same, when the faces differed in eye shape, and when they differed in eye size. Reaction times for each condition were based on the median reaction time for test trials with correct responses.



1500
1000
500
0
Mean Reaction Time (ms) [± 1 SE]
10-year-olds
adults
Same faces
Differences in Eye Shape (Local Change)
Differences in Eye Size (Configural Change)
Task

Figure 27.

The mean proportion of correct responses (+1 SE) in patients with a history of early visual deprivation and in the normal group (10-year-olds and adults) on the task in Experiment 7 that required same/different judgments of faces' eyes when the faces were the same, when the faces differed in eye shape, and when they differed in eye size.

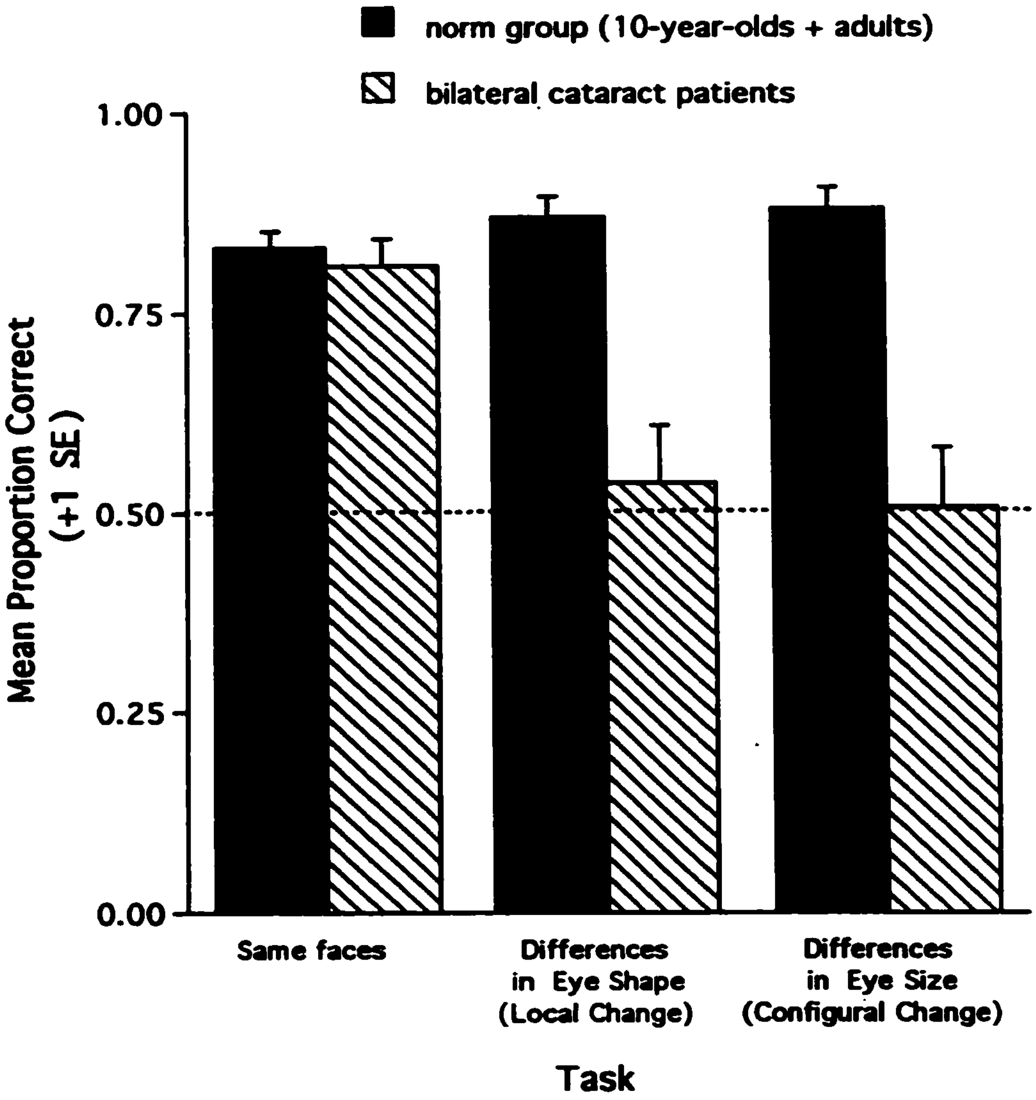

■ norm group (10-year-olds + adults)
▨ bilateral cataract patients
1.00
0.75
0.50
0.25
0.00
Mean Proportion Correct (+1 SE)
Same faces
Differences in Eye Shape (Local Change)
Differences in Eye Size (Configural Change)
Task

Table 9.

Differences between patients with a history of early visual deprivation and the normal comparison group of adults and 10-year-olds on the task requiring same/different judgments of pairs of faces that were identical or that varied in eye shape (local change) or eye size (configural change). Results of the 2-way ANOVA on mean proportion of correct responses with subject group and task type (same, different eye shape, different eye size), and the analyses of simple effects (indent).

Effect	F	df	p
Subject group	**41.66**	**1, 63**	**< .0001**
Type of task	**8.35**	**2, 126**	**< .001**
Subject group x type of task	**15.37**	**2, 126**	**< .0001**
Subject group at same faces	0.18	1, 174	.674
Subject group at eye shape	**36.87**	**1, 174**	**.000**
Subject group at eye size	**46.22**	**1, 174**	**.000**
Task type at normal group	1.03	2, 126	.360
Task type at patient group	**15.69**	**2, 126**	**.000**

There was no significant relationship between patients' duration of visual deprivation and their accuracy on trials containing identical faces, nor on trials containing differences in faces' eye shape or eye size (rs = .12 to .43, ps > .05). There was also no relationship between Snellen acuity in patients' better eye and their accuracy on same trials, nor on trials with different eye size (rs = .23 and .32, respectively, ps > .10). However, patients' Snellen acuity and their accuracy on trials with different eye shape were significantly negatively correlated, $r = -.66$, $p < .01$, and remained significantly correlated when the score from the patient (Z.C.) with the poorest acuity was excluded ($r = -.52$, $p < .05$). See Appendix 12 (a and b) for the scatterplots of individual proportion scores.

The patients' and normals' (10-year-olds and adults) mean reaction times for the three trial types are shown in Figure 28. The ANOVA comparing normals' and patients' mean reaction times showed a significant main effect of trial type and a significant interaction between trial type and group, but no main effect of group (see Table 10). Analyses of simple effects showed an effect of group for trials with different eye size or eye shape, but not for same trials. Patients' reaction times were significantly longer than those of normal controls when they responded to differences in eye shape or eye size, but were no different from normals when they responded to identical faces.

Regression analyses showed no significant relationship between patients' duration of visual deprivation or Snellen acuity and their median reaction times on trials with identical faces, nor on trials with different eye shape or size (rs = .06 to .45, ps > .05) (see Appendix 12 c and d).

Figure 28.

The mean reaction times (±1 SE) in patients with a history of early visual deprivation and in the normal group (10-year-olds and adults) on the task in Experiment 7 that required same/different judgments of faces' eyes when the faces were the same, and when the faces differed in eye shape or eye size. Reaction times were based on the median reaction time for test trials with correct responses.

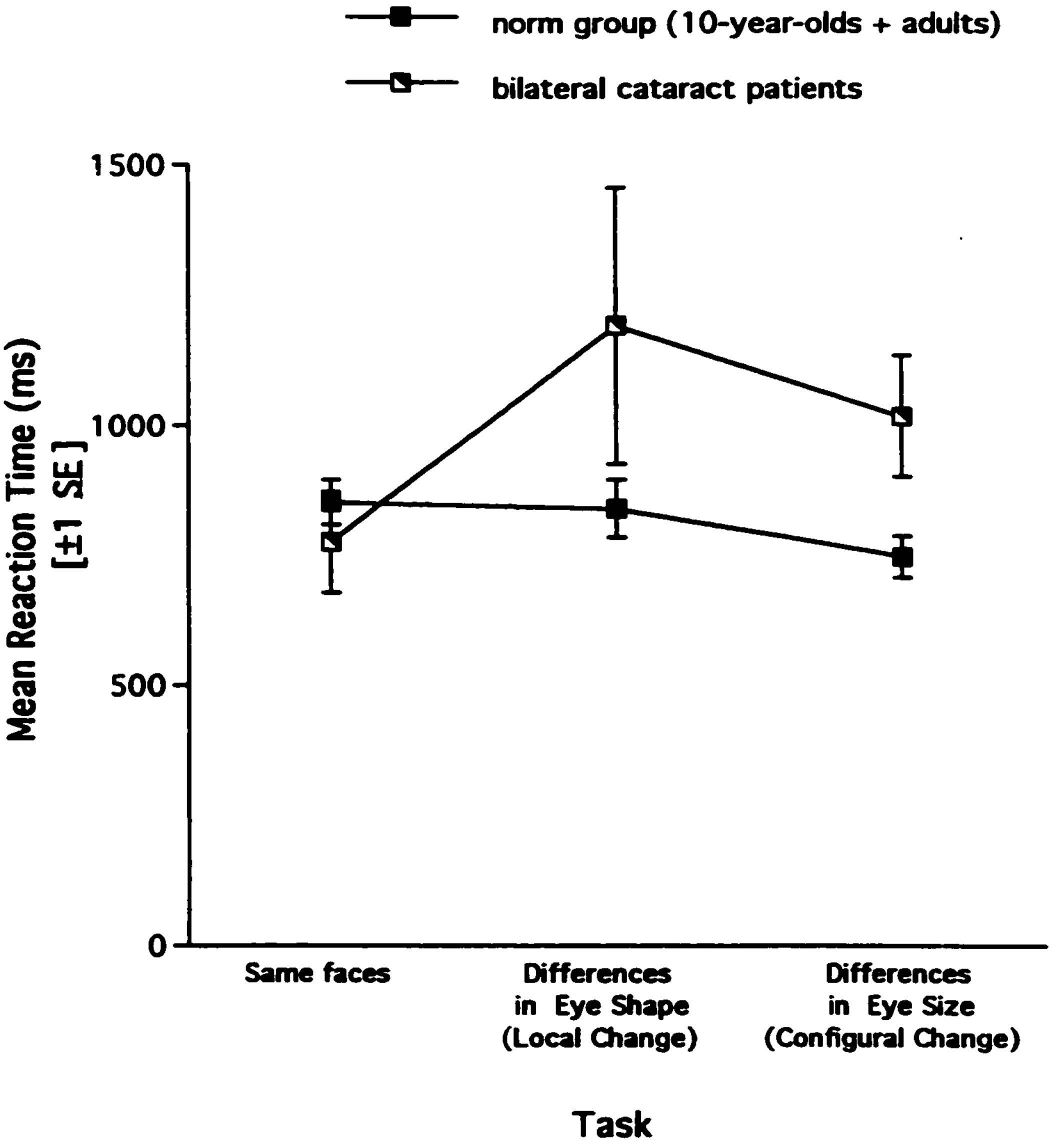

norm group (10-year-olds + adults)
bilateral cataract patients
Mean Reaction Time (ms)
[±1 SE]
1500
1000
500
0
Same faces
Differences in Eye Shape (Local Change)
Differences in Eye Size (Configural Change)
Task

Table 10.

Results of the 2-way ANOVA on patients' and normals' mean reaction times on the task requiring same/different judgments of pairs of faces that were identical or that varied in eye shape (local change) or eye size (configural change)—with subject group and task type (same, different eye shape, different eye size), and the analyses of simple effects (indent).

Effect	F	df	p
Subject group	3.09	1, 63	.084
Type of task	**4.49**	**2, 126**	**.013**
Subject group x type of task	**5.53**	**2, 126**	**.005**
Subject group at same faces	0.35	1, 135	.556
Subject group at eye shape	**7.29**	**1, 135**	**.008**
Subject group at eye size	**4.33**	**1, 135**	**.039**
Task type at normal group	1.34	2, 126	.265
Task type at patient group	**6.31**	**2, 126**	**.002**

Same Judgments of Eyes in Fused Faces Presented Intact or Misaligned

For Normal Participants. As expected if they process faces holistically, subjects at all ages made more errors when fused faces differed only in their bottom halves (same trials) than when fused faces differed in both the top and bottom halves (different trials). Analyses were based on proportion correct for the same trials, averaged across the two blocks of trials with intact faces and across the block with misaligned faces.

The normals' mean accuracy scores for intact and misaligned faces are shown in **Figure 29**. Those scores were subjected to an ANOVA with age as the between-subjects factor and type of presentation of face (intact, misaligned) as the within-subjects factor.[12] The ANOVA showed significant main effects of age, $\underline{F}$ (2,69) = 4.75, $\underline{p} < .05$, and type of face, $\underline{F}$ (1,69) = 83.39, $\underline{p} < .0001$, but no significant interaction between age and face type, $\underline{F}$ (2,69) = .06, $\underline{p} > .10$. Regardless of whether pairs of fused faces were shown intact or with their halves misaligned horizontally, 10-year-olds were as accurate as adults in judging that their eyes were the same (Dunnett t-test, $\underline{p} > .10$), and 6-year-olds made significantly more errors than adults ($\underline{p} < .05$). However, normal participants at every age made significantly more errors when the fused faces were shown intact than when they were shown with their halves misaligned.

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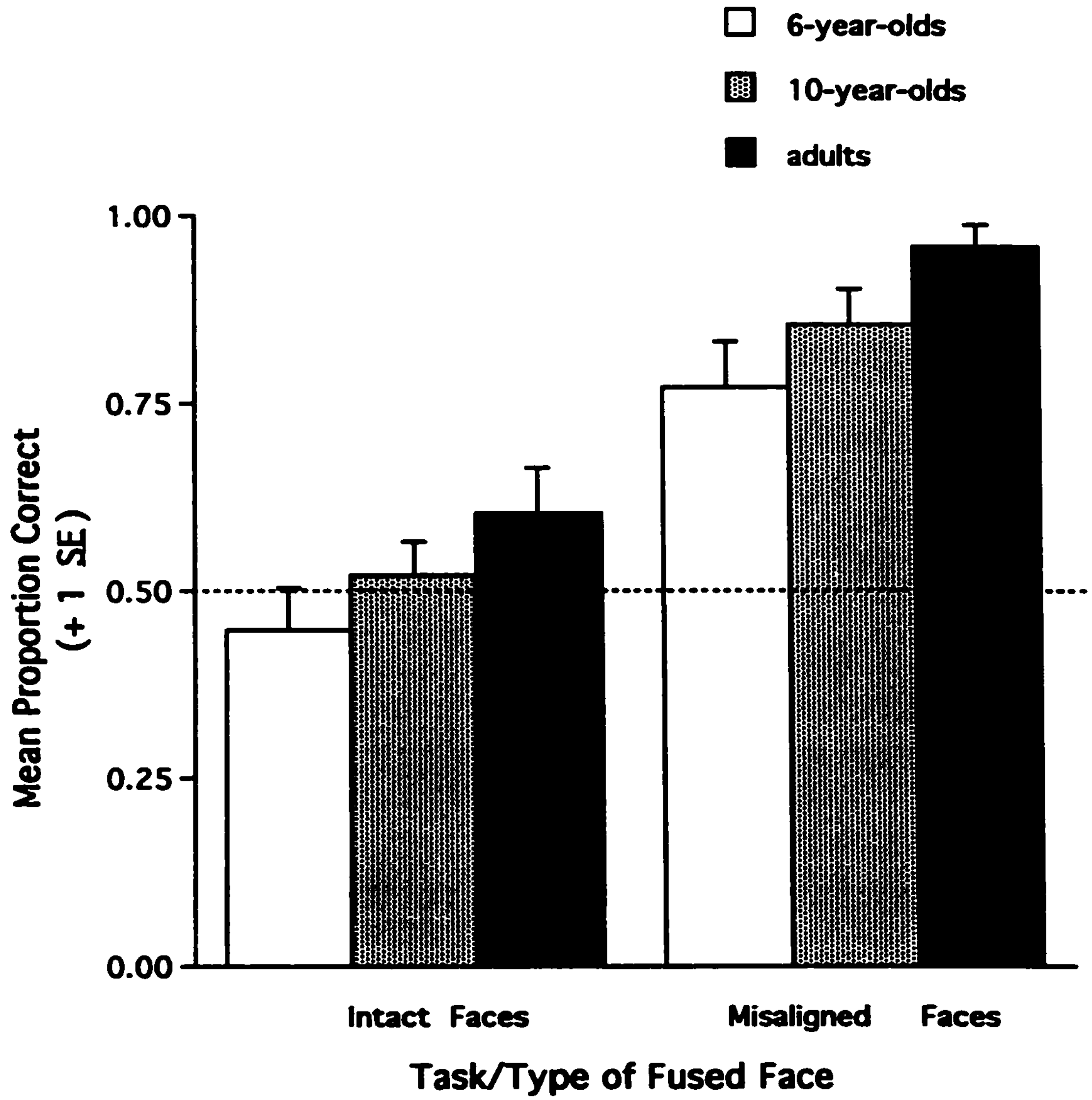
[12] Scores on inverted trials were excluded because they were at chance at all ages (15%, 25%, and 50% for 6-year-olds, 10-year-olds, and adults, respectively). Such errors may have been the result of too few trials to practice encoding inverted faces and/or the face examples being particularly difficult to distinguish.

Figure 29.

Normal participants' mean proportion of correct responses (+1 SE) on the task in Experiment 7 that required same/different judgments of fused facial composites presented intact and presented with their halves misaligned horizontally. Proportion scores were based on trials in which the faces' upper halves were the same and their bottom halves were different. Refer to Figure 18 a and b for examples of pairs of fused faces with the same top halves and different bottom halves, and presented intact or misaligned, respectively.



□ 6-year-olds
▨ 10-year-olds
■ adults
1.00
0.75
0.50
0.25
0.00
Mean Proportion Correct
(+ 1 SE)
Intact Faces
Misaligned Faces
Task/Type of Fused Face

For Patients vs. Normal Controls. The ANOVA comparing patients' and normals' (10-year-olds and adults) mean accuracy scores showed a significant main effect of type of presentation of face and a significant interaction between type of presentation and group, but no main effect of group (see Table 11). The analysis of simple effects showed a significant effect of group for trials with misaligned fused faces but not for trials with intact faces: patients made significantly more errors than normal controls when viewing misaligned faces, but they were not significantly different from normal when viewing intact faces. The analysis of simple effects also showed a significant effect of face type in normal controls, but not in patients. As shown in Figure 30, patients' errors were no different for the two types of faces, unlike normals who made significantly more errors for intact faces.

There was no significant relationship between patients' Snellen acuity and their mean proportion of correct responses on trials that presented fused faces intact or misaligned (rs = .21 and .11, respectively, ps > .10). Nor was there a relationship between patients' duration of visual deprivation and their mean accuracy scores on misaligned trials, $r = .12$, $p > .10$. However, patients' duration of deprivation and mean accuracy scores on trials with intact fused faces were negatively correlated, $r = -.48$, $p = .05$. As shown in Appendix 13 (a), the relationship between duration of visual deprivation and mean proportion score for intact faces was produced by one patient (S.G.) with the longest duration of deprivation, and was not maintained after removing his score from the analysis, $r = .18$, $p > .10$.[13]

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[13] The results of the ANOVA comparing patients' and normals' accuracy scores were the same when repeated without the data from S.G.

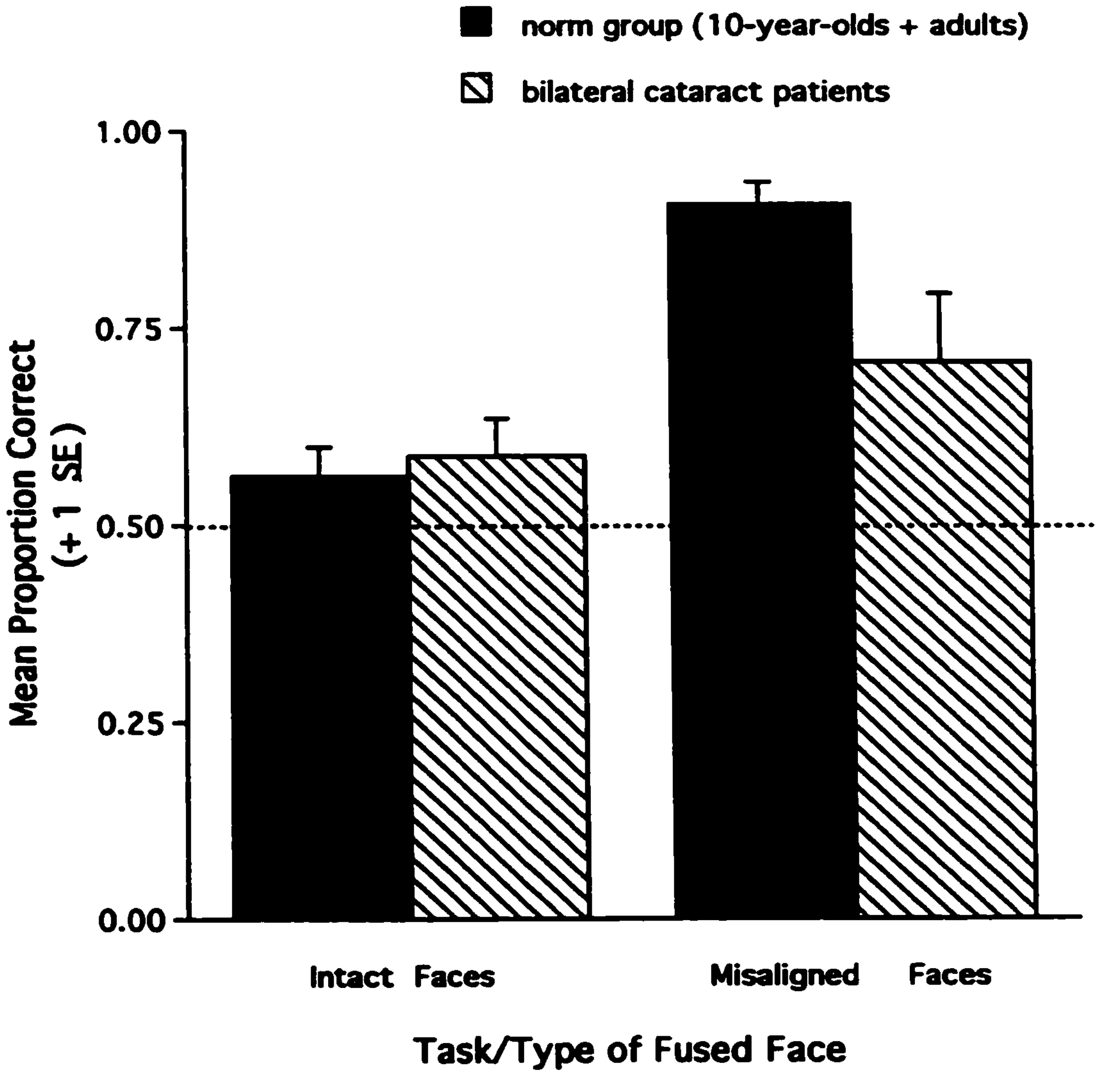
Table 11.

Differences between patients with a history of early visual deprivation and the normal group (10-year-olds and adults) in same judgments of "fused" facial composites presented intact and with the halves misaligned horizontally. Results of the 2-way ANOVA on mean proportion of correct responses with subject group and type of task (intact, misaligned), and the analyses of simple effects (indent).

Effect	F	df	p
Subject group	3.07	1, 63	.09
Type of fused face	44.42	1, 63	< .0001
Subject group x type of fused face	5.41	1, 63	.023
Subject group at intact faces	0.14	1, 63	.712
Subject group at misaligned faces	8.23	1, 63	.006
Fused face type at normal group	47.85	1, 63	.000
Fused face type at patient group	1.99	1, 63	.164

Figure 30.

The mean proportion of correct responses (+1 SE) in patients with a history of early visual deprivation and in the normal group (10-year-olds and adults) on the task in Experiment 7 that required same/different judgments of the eyes in pairs of fused faces presented intact and presented with their halves misaligned horizontally. Proportion scores were based on trials in which the upper halves of the faces were the same and their bottom halves were different.


■ norm group (10-year-olds + adults)
▨ bilateral cataract patients
Mean Proportion Correct (+ 1 SE)
1.00
0.75
0.50
0.25
0.00
Intact Faces
Misaligned Faces
Task/Type of Fused Face

Same/Different Judgments of Figures Varying in Shape of Elements or in Positioning of the Internal Element

For Normal Participants. Figure 31 shows the normal participants' mean proportion of correct responses on trials in which geometric figures differed in the shape of elements, on trials in which figures differed in the positioning of the internal element, and on trials in which the figures were identical. An ANOVA on mean accuracy, with one within-subjects factor (3 trial types) and one between-subjects factor (age), showed significant main effects of age and trial type and a significant interaction between age and trial type (see Table 12). Analyses of simple effects revealed a significant effect of age when figures differed in the shape of elements and in the positioning of the internal element, but no effect of age on same trials. Normal subjects at every age were accurate at detecting that two figures were the same. However, when responding to differences based on the shape of elements or their positioning, 6-year-olds made significantly more errors than adults (Dunnett t-tests, $\underline{p}s < .05$) and 10-year-olds and adults did not differ significantly from each other ($\underline{p}s > .10$). The analysis of simple effects also showed an effect of trial type in 6-year-olds and 10-year-olds, but not in adults. Adults made similar errors in all conditions. While 6- and 10-year-olds' errors were no different on same trials and on trials with different elements (Tukey, $\underline{p}s > .05$), both made significantly more errors on trials with different positioning of the internal element than on trials with different elements ($\underline{p}s < .05$). Also, 6-year-olds made significantly more errors on trials with different positioning of the element than on same trials ($\underline{p} < .01$), but 10-year-olds did not ($\underline{p} > .05$).

Figure 31.

Normal participants' mean proportion of correct responses (+1 SE) on the task in Experiment 7 that required same/different judgments of pairs of geometric figures that were the same, that differed in the individual elements, and that differed in the positioning of their internal element. See Figure 23 for illustrations of the three types of pairings.

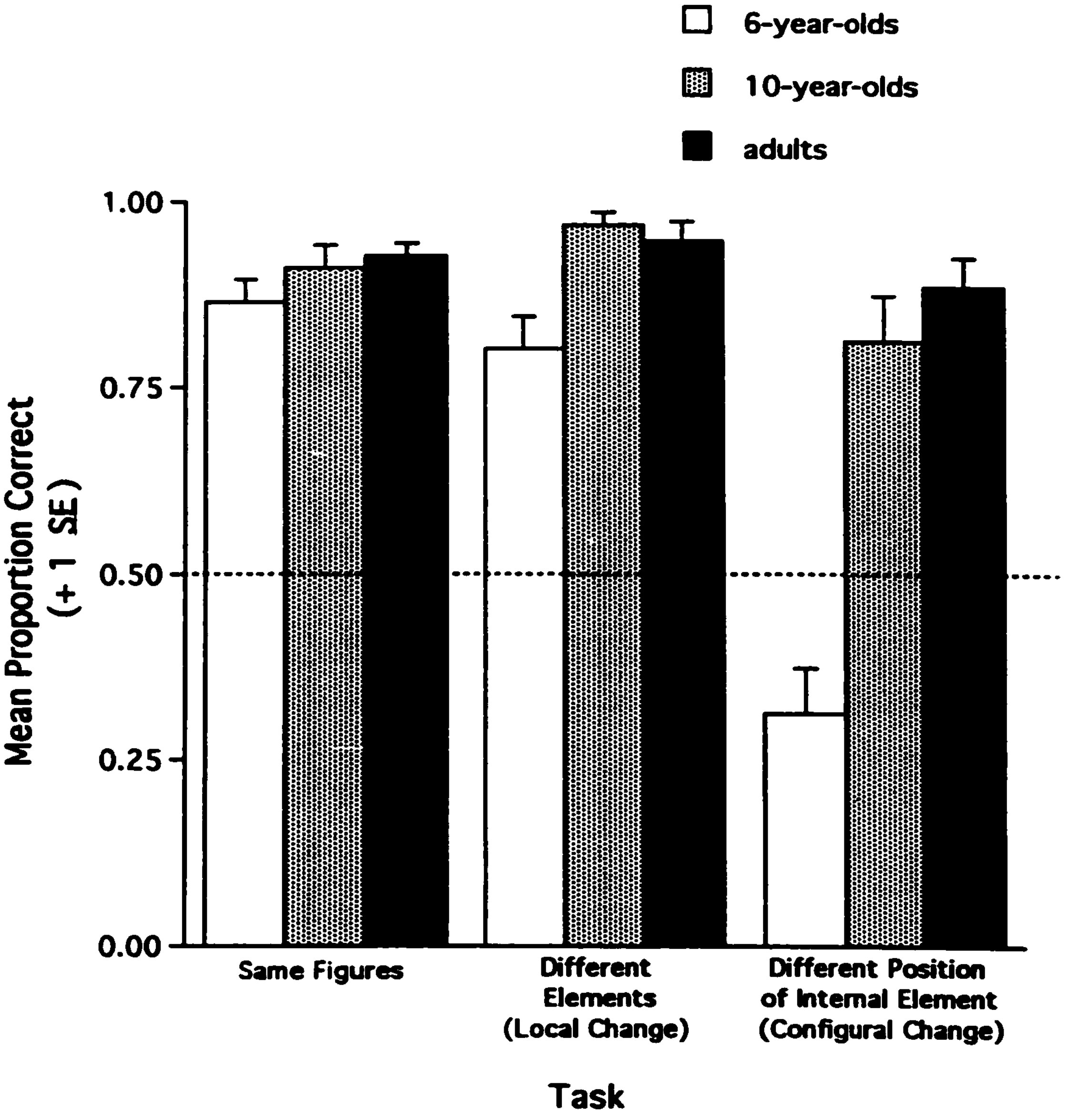

6-year-olds
10-year-olds
adults
Mean Proportion Correct
(+ 1 SE)
1.00
0.75
0.50
0.25
0.00
Same Figures
Different Elements (Local Change)
Different Position of Internal Element (Configural Change)
Task

Table 12.

Results of the 2-way ANOVA on normals' mean proportion of correct responses on the task requiring same/different judgments of pairs of geometric figures that were identical, that varied in elements (local change), and that varied in the positioning of the internal element (configural change)—with age group (6, 10, adults) and task type (same, different elements, different positioning), and the analyses of simple effects (indent).

Effect	F	df	p
Age group	**44.21**	**2, 69**	**< .0001**
Type of task	**32.95**	**2, 138**	**< .0001**
Age group x type of task	**13.32**	**4, 138**	**< .0001**
Age group at same figures	0.67	2, 206	.512
Age group at elements	**5.24**	**2, 206**	**.006**
Age group at positioning	**61.77**	**2, 206**	**.000**
Task type at age 6	**55.21**	**2, 138**	**.000**
Task type at age 10	**3.77**	**2, 138**	**.025**
Task type at age adult	0.61	2, 138	.544

Figure 31 shows that 6-year-olds were below chance when figures varied in the positioning of the internal element. This occurred because 6-year-olds did not respond randomly—they failed to notice the change in positioning, and consequently, had a bias to give the incorrect response of "same" on these trials.

Adults' and 10-year-olds' mean reaction time scores in the three conditions are shown in **Figure 32**. The ANOVA showed a significant main effect of age, $\underline{F}$ (1,46) = 20.67, $\underline{p} < .0001$, but no significant effect of trial type, $\underline{F}$ (2,92) = 1.49, nor a significant interaction between age and trial type, $\underline{F}$ (2,92) = 2.25, both $\underline{p}$s > .10. Reaction times were significantly longer in 10-year-olds than in adults.

For Patients vs. Normal Controls. The patients' and normal 10-year-olds' mean accuracy for the three trial types are shown in **Figure 33**. The ANOVA showed only a significant main effect of task type, $\underline{F}$ (2,78) = 6.39, $\underline{p} < .01$. There was no significant main effect of group, $\underline{F}$ (1,39) = .21, nor an interaction between group and task, $\underline{F}$ (2,78) = .51, both $\underline{p}$s > .10. Like normals, patients made significantly more errors on trials with different positioning of the internal element than on same trials or trials with different shape of elements.

Figure 32.

Normal 10-year-olds' and adults' mean reaction times (±1 SE) on the task in Experiment 7 that required same/different judgments of pairs of geometric figures that were the same, and that differed in their individual elements or the positioning of their internal element. Reaction times were based on the median reaction time for test trials with correct responses.

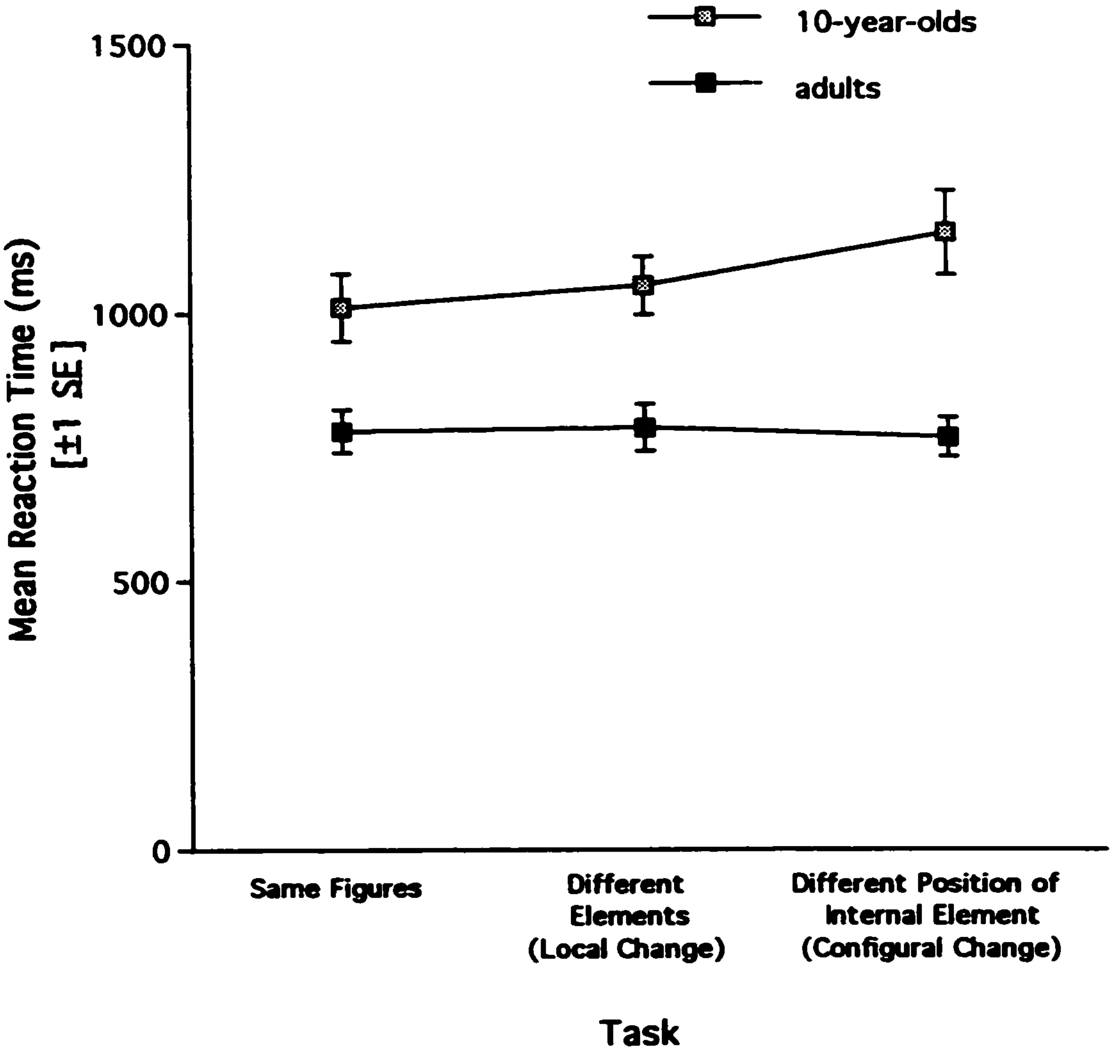
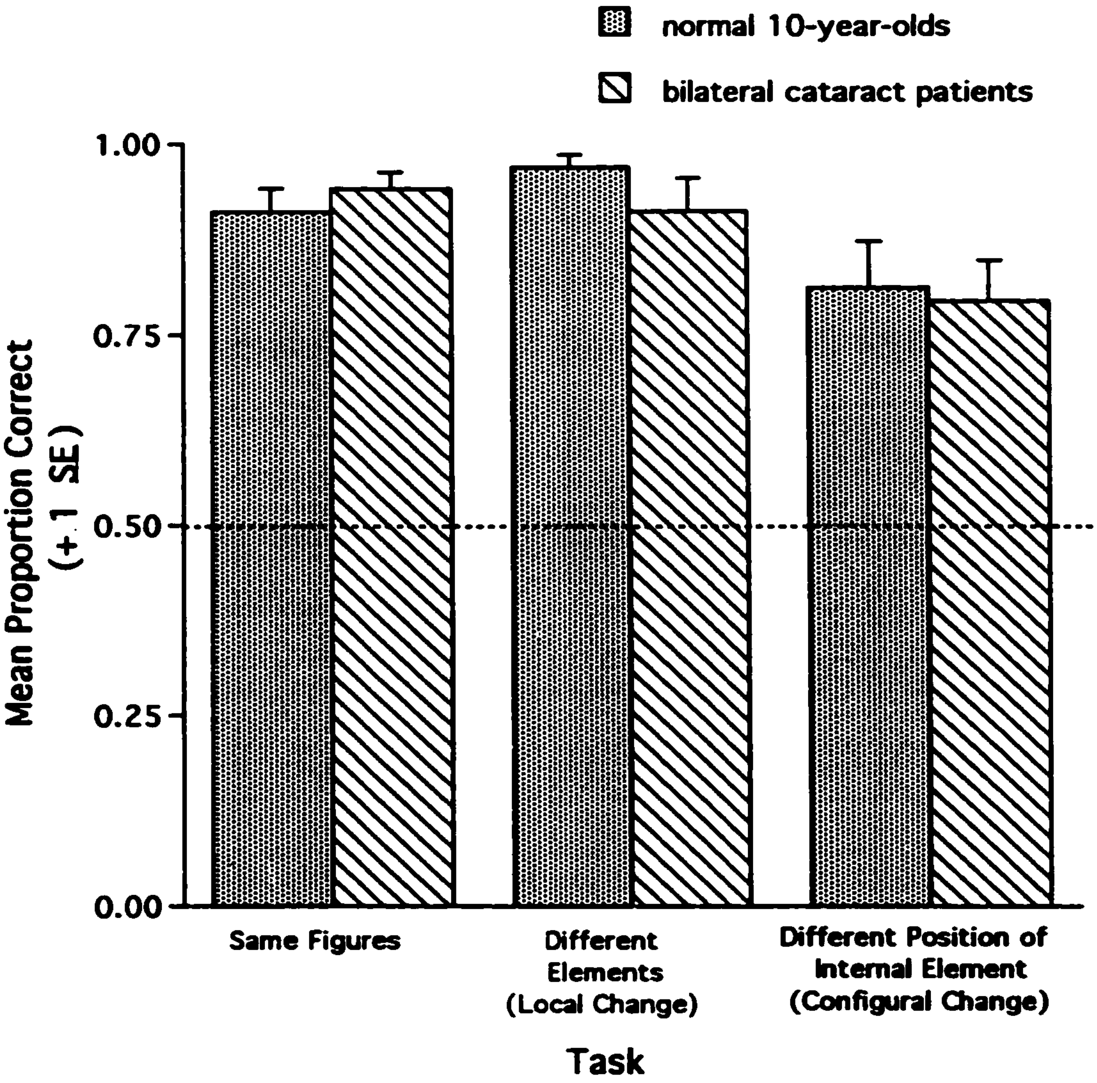

10-year-olds
adults
Mean Reaction Time (ms)
[±1 SE]
1500
1000
500
0
Same Figures
Different Elements (Local Change)
Different Position of Internal Element (Configural Change)
Task

Figure 33.

The mean proportion of correct responses (+1 SE) in patients with a history of early visual deprivation and in normal 10-year-olds on the task in Experiment 7 that required same/different judgments of pairs of geometric figures that were the same, that varied in the individual elements, and that varied in the positioning of the internal element.


normal 10-year-olds
bilateral cataract patients
Mean Proportion Correct
(+ 1 SE)
1.00
0.75
0.50
0.25
0.00
Same Figures
Different Elements (Local Change)
Different Position of Internal Element (Configural Change)
Task

There was no significant relationship between patients' duration of visual deprivation or Snellen acuity and their accuracy for any of the three types of trials (range of rs = .033 to .345, ps > .10) except that patients' Snellen acuity and their accuracy were negatively correlated on trials containing element changes, $r = -.52$, $p < .05$ (see Appendix 14 a and b). However, that correlation did not achieve significance when the score from the patient (Z.C.) with the poorest acuity was excluded ($r = .14$, $p > .10$).[14]

The patients' and normals' (10-year-olds and adults) mean reaction time scores were subjected to an ANOVA, with one within-subjects factor (3 trial types) and one between-subjects factor (2 groups). There was no significant effect of group, F (1,63) = 0.13, or trial type, F (2,126) = 1.99, nor a significant interaction between group and trial type, F (2,126) = 0.16, all ps > .10.[15]

---

[14] The results of the ANOVA comparing patients' and normals' accuracy scores were the same when I excluded the data from this patient with the poorest vision (Z.C.), and when I also excluded the data from the patient (D.D.) for whom there was no information on acuity.

[15] The results are the same when 10-year-olds alone are used as the normative group.

Same/Different Judgments about Figures' Elements or Global Shape

For Normal Participants. Each subject had a mean proportion of correct response on congruent trials—responding that two figures were the same or different at one level (e.g., global shape) that matched the response for the ignored level (e.g., individual elements), and on incongruent trials—responding either same or different that did not match the correct response at the other level. Figure 34 shows that all normal participants were accurate on congruent trials. Therefore, I examined only the accuracy on incongruent trials because it is these trials that indicate whether conflicting information from the local or global level interferes with accuracy.

To obtain an estimate of subjects' accuracy based on a larger sample of trials, their accuracy scores were averaged across the two blocks of each type of trial: responding to figures' global shape and responding to figures' individual elements (see Figure 35). An ANOVA, with age as the between-subjects factor and type of trial (responding to global shape or elements) as the within-subjects factor, showed significant main effects of age and trial type, and a significant interaction between age and trial type (see Table 13). Analyses of simple effects revealed a significant effect of age at each trial type and a significant effect of trial type in 6-year-olds and 10-year-olds, but not in adults. Regardless of trial type, 6- and 10-year-olds made significantly more errors than adults (Dunnett t-tests, all ps $< .01$). While adults made a similar number of errors in both tasks, 6-year-olds and 10-year-olds made significantly more errors in the task requiring that they respond to the individual elements (and ignore the global shape) than in the task requiring that they respond to the global shape (and ignore elements).

Figure 34.

Normal participants' mean proportion of correct responses (+1 SE) on the task in Experiment 7 that required same/different judgments of pairs of hierarchical geometric figures based on the individual elements (ignoring global shape) or the global shape (ignoring individual elements). The results are shown separately for congruent and incongruent trials.

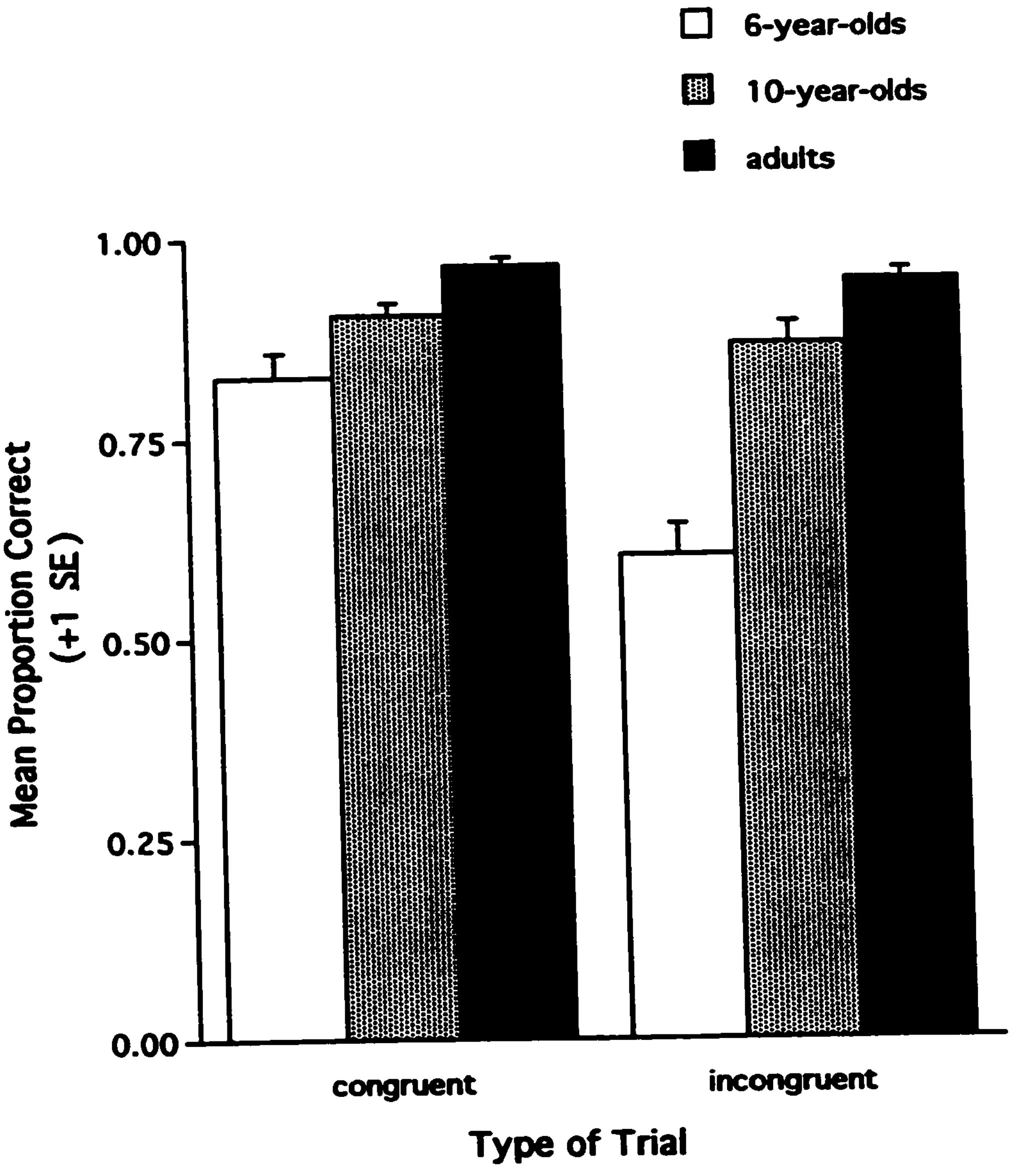

6-year-olds
10-year-olds
adults
Mean Proportion Correct
(+1 SE)
1.00
0.75
0.50
0.25
0.00
congruent
incongruent
Type of Trial

Figure 35.

Normal participants' mean proportion of correct responses (+1 SE) on the task in Experiment 7 that required same/different judgments of pairs of hierarchical geometric figures based on either the individual elements (ignoring global shape) or the global shape (ignoring individual elements). Proportion scores were based on incongruent trials only.

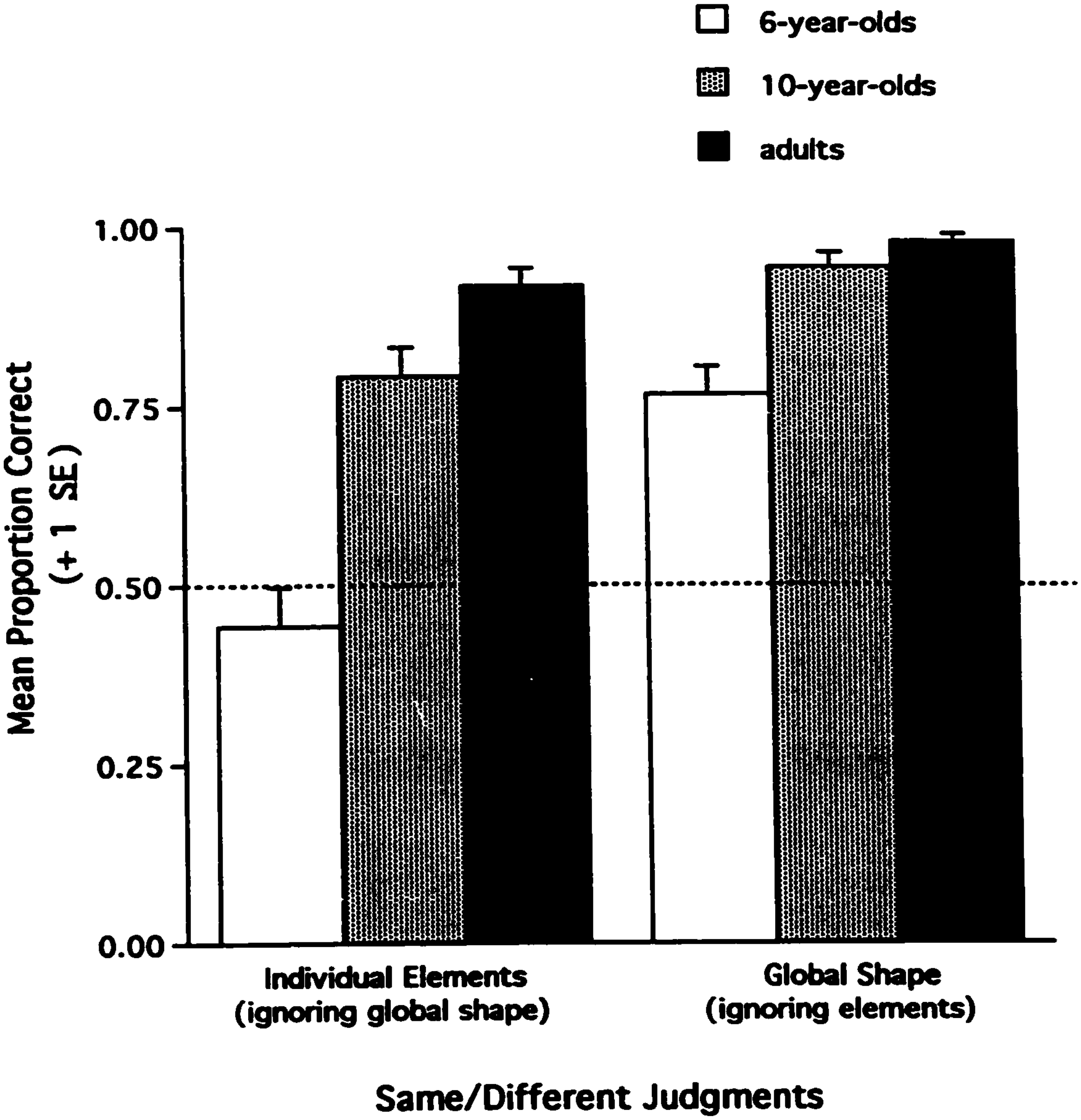

6-year-olds
10-year-olds
adults
1.00
0.75
0.50
0.25
0.00
Mean Proportion Correct
(+ 1 SE)
Individual Elements
(ignoring global shape)
Global Shape
(ignoring elements)
Same/Different Judgments

Table 13.

Results of the 2-way ANOVA on normals' mean proportion of correct responses on the task requiring same/different judgments of pairs of figures based on individual elements or global shape (on trials with conflicting information at the other level)—with age group (6, 10, adults) and task type (individual elements, global shape), and the analyses of simple effects (indent).

Effect	F	df	p
Age group	**41.35**	**2, 69**	**< .0001**
Type of task	**55.93**	**1, 69**	**< .0001**
Age group x type of task	**10.22**	**2, 69**	**.0001**
Age group at individual elements	**34.27**	**2, 69**	**.000**
Age group at global shape	**19.78**	**2, 69**	**.000**
Task type at age 6	**60.79**	**1, 69**	**.000**
Task type at age 10	**13.30**	**1, 69**	**.001**
Task type at age adult	**2.28**	**1, 69**	**.136**

The ANOVA on adults' and 10-year-olds' mean reaction times showed a significant main effect of age, $\underline{F}$ (1,46) = 48.31, and type of task, $\underline{F}$ (1,46) = 24.10, $\underline{p}$s < .0001. However, an interaction between age and task just missed significance, $\underline{F}$ (1,46) = 3.69, $\underline{p}$ = .06 (see **Figure 36**). The reaction times in 10-year-olds were significantly longer than those in adults. In both groups, reaction times were significantly longer on the task requiring that they respond same/different based on elements than on the task requiring that they respond based on global shape. Inspection of the figure suggests that the interaction approached significance because the 10-year-olds tended to be more different from adults on trials that involved responding to individual elements (and ignoring global shape) than on trials that involved responding to global shape (and ignoring elements).

For Patients vs. Normal Controls. The ANOVA comparing patients' and normal 10-year-olds' accuracy showed a significant main effect of task and a significant interaction between task and group, but no main effect of group (see **Table 14**). Analyses of simple effects showed a significant effect of task type at each group: patients and 10-year-olds made significantly more errors when asked to respond to individual elements (and ignore global shape) compared to when they were asked to respond to the global shape (and ignore elements). The interaction arose because there was a significant effect of group only for the task that involved responding to the individual elements: patients made significantly more errors than normals when asked to respond to the individual elements and ignore global shape, but they were no different from normals when asked to respond to global shape (see **Figure 37**).

Figure 36.

Normal 10-year-olds' and adults' mean reaction times (±1 SE) on the task in Experiment 7 that required same/different judgments of pairs of hierarchical geometric figures based on either the individual elements (ignoring global shape) or the global shape (ignoring individual elements). Reaction times were based only on correct responses from incongruent trials.

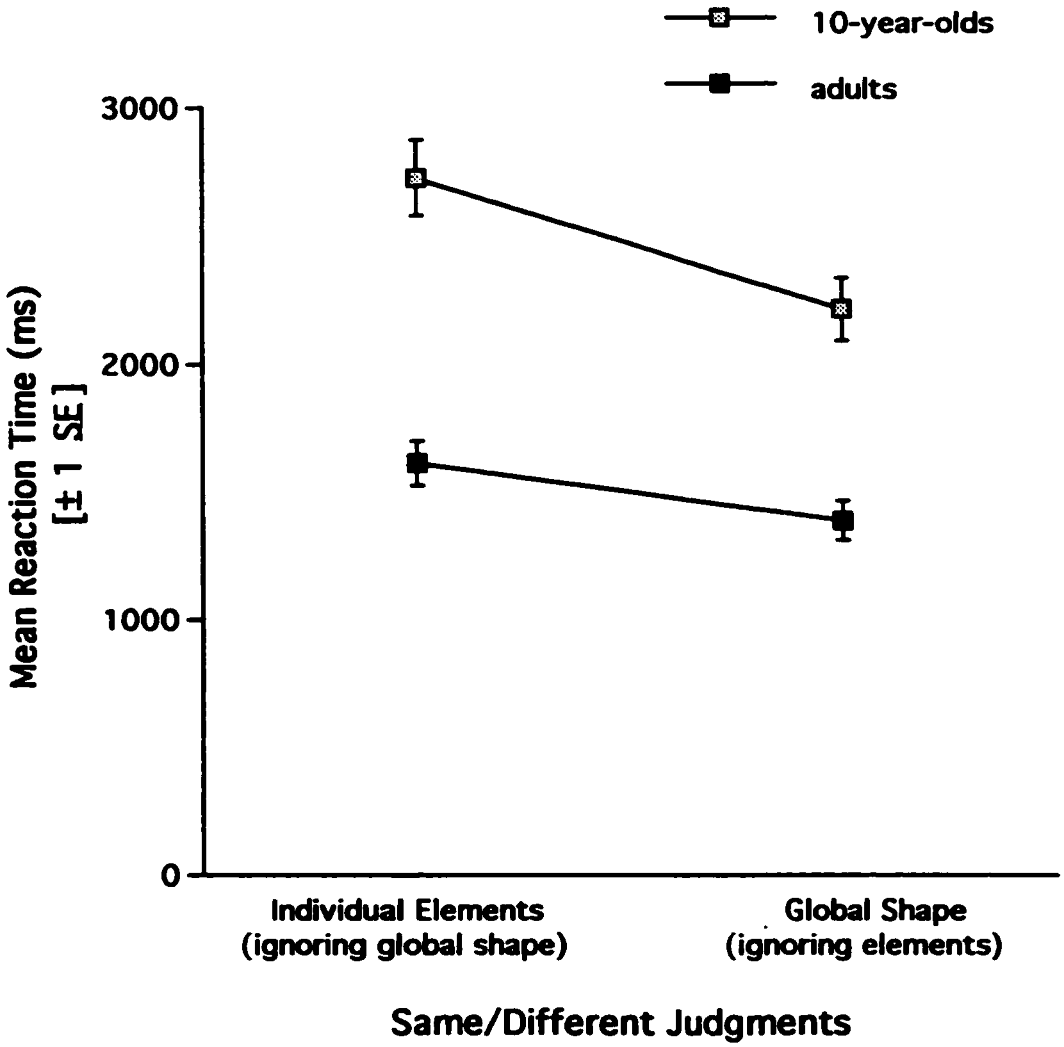

10-year-olds
adults
3000
2000
1000
0
Mean Reaction Time (ms)
[± 1 SE]
Individual Elements
(ignoring global shape)
Global Shape
(ignoring elements)
Same/Different Judgments

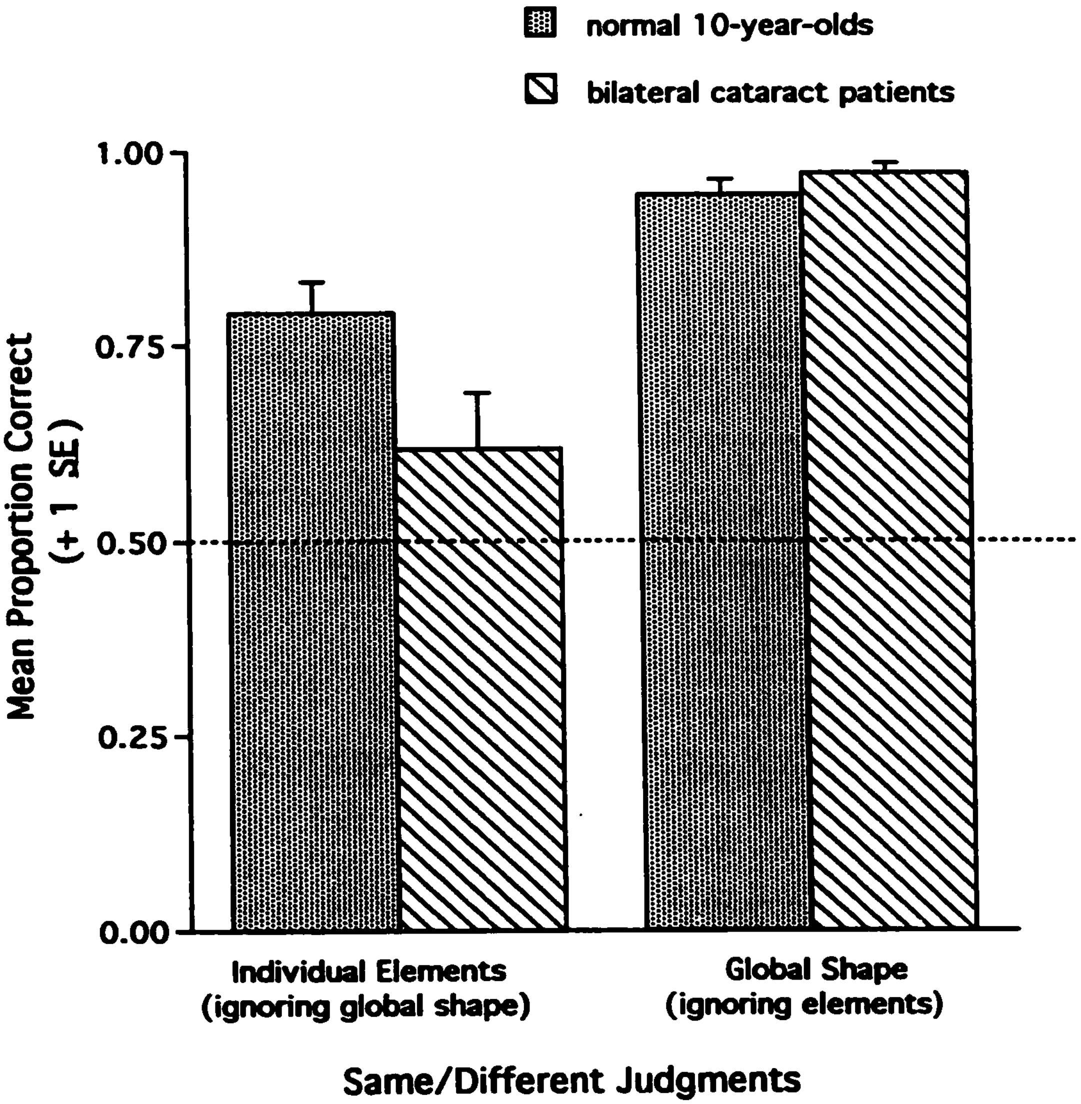
Table 14.

Differences between patients with a history of early visual deprivation and normal 10-year-olds on the task requiring same/different judgments of pairs of figures based on individual elements or global shape (on trials with conflicting information at the other level). Results of the 2-way ANOVA on mean proportion of correct responses with subject group and task type (individual elements, global shape), and the analyses of simple effects (indent).

Effect	F	df	p
Subject group	2.68	1, 39	.110
Type of task	41.34	1, 39	< .0001
Group x type of task	7.42	1, 39	.009
Group at individual elements	8.99	1, 75	.004
Group at global shape	0.23	1, 75	.632
Task type at normal 10-year-olds	10.02	1, 39	.003
Task type at patient group	38.74	1, 39	.000

Figure 37.

The mean proportion of correct responses (+1 SE) in patients with a history of early visual deprivation and in normal 10-year-olds on the task in Experiment 7 that required same/different judgments of pairs of hierarchical geometric figures based on either the individual elements (ignoring global shape) or the global shape (ignoring individual elements). Proportion scores were based on incongruent trials only.


normal 10-year-olds
bilateral cataract patients
Mean Proportion Correct
(+ 1 SE)
1.00
0.75
0.50
0.25
0.00
Individual Elements
(ignoring global shape)
Global Shape
(ignoring elements)
Same/Different Judgments

There was no significant relationship between patients' duration of visual deprivation or Snellen acuity and their accuracy on trials of responding to figures' individual elements or global shape (range of rs = .05 to .17, ps > .10) except that patients' Snellen acuity was correlated negatively with accuracy in responding to elements and ignoring global shape, $r = -.63$, $p < .01$, and remained correlated when the score from the patient with the poorest acuity was excluded, $r = -.54$, $p < .05$ (see Appendix 15 b).

The ANOVA comparing patients' and normals' (10-year-olds and adults) mean reaction times showed a significant main effect of trial type and a significant interaction between trial type and group, but no significant effect of group.[16] (See Table 15.) Patients did not differ significantly from normals in their reaction times to individual elements or global shape: in both patients and normals, reaction times were significantly longer when responding to figures' elements than when responding to their global shape. Inspection of Figure 38 suggests that the interaction arose because the differences in reaction time for global versus local trials was slightly larger for patients than for normal controls.

There was no significant relationship between patients' duration of deprivation or Snellen acuity and their reaction times (range of rs = .31 to .36, ps > .10) except that patients' acuity was correlated with reaction time in responding to elements, $r = .62$, $p < .05$, and remained correlated when the outlier was removed, $r = .70$, $p < .01$ (see Appendix 15 d).

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[16] When 10-year-olds alone are used as the normative group, the results are the same except that reaction times are significantly longer in 10-year-olds than in patients (ANOVA main effect of group, $p < .01$).

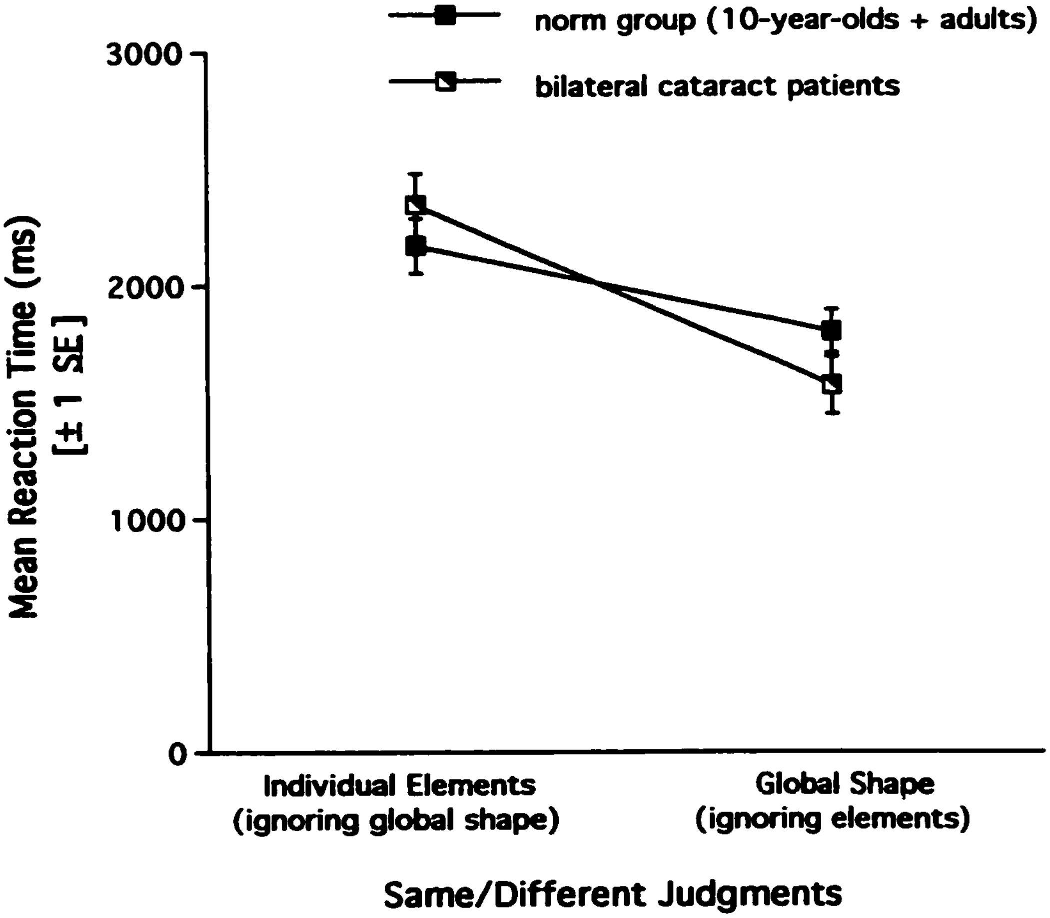
Table 15.

Results of the 2-way ANOVA on patients' and normals' (10-year-olds and adults) mean reaction times on the task requiring same/different judgments of pairs of figures based on individual elements or global shape (on trials with conflicting information at the other level)—with subject group and task type, and the analyses of simple effects (indent).

Effect	F	df	p
Subject group	0.12	1, 63	.726
Type of task	54.37	1, 63	< .0001
Group x type of task	5.07	1, 63	.028
Group at individual elements	0.28	1, 84	.598
Group at global shape	1.40	1, 84	.241
Task type at normal controls	25.08	1, 63	.000
Task type at patient group	31.36	1, 63	.000

Figure 38.

The mean reaction times (±1 SE) in patients with a history of early visual deprivation and in the normal group (10-year-olds and adults) on the task in Experiment 7 that required same/different judgments of pairs of hierarchical geometric figures based on either the individual elements (ignoring global shape) or the global shape (ignoring individual elements). Reaction times were based on correct responses from incongruent trials.


norm group (10-year-olds + adults)
bilateral cataract patients
3000
2000
1000
0
Mean Reaction Time (ms) [± 1 SE]
Individual Elements (ignoring global shape)
Global Shape (ignoring elements)
Same/Different Judgments

Discussion

The results from normal participants suggest that the specialized strategies used for face processing become adultlike after six years of age. Normal 10-year-olds were adultlike on all tasks of face matching in Experiment 7, just as they were in Experiment 6. In contrast, normal 6-year-olds made more errors than normal adults and 10-year-olds in judging differences between faces that varied either in individual features or in the spatial relationships among the internal features, but were above chance on both tasks. The results also suggest that strategies used for the processing of shapes, unlike those used for face processing, may take longer than 10 years to mature, at least as indexed by the tasks of Experiment 7. Both 6- and 10-year-olds were less accurate than adults in the task that required matching geometric figures based on individual elements while ignoring global shape, a finding which suggests that they relied more than adults on the figures' global shape. Moreover, the 6-year-olds performed below chance in the task that required matching figures that differed on the basis of the positioning of the elements.

This was the first study to examine these same capabilities in patients with a history of early visual deprivation caused by bilateral congenital cataracts. The findings from patients suggest that the development of specialized strategies for face processing is influenced by early visual experience, at least as indexed by the tasks in Experiment 7. Patients made more errors than normal controls whether they were judging differences in the individual features of faces or the spatial relationships among the features. Patients also performed abnormally in a task that measured holistic processing of faces. They performed normally on tasks that measured similar capabilities for the processing of shapes, except for one condition in which patients, particularly those with poor acuity, were less accurate than normals in matching figures based on individual elements while ignoring global shape.

Normal Development

Normal adults and 10-year-olds made few errors in judging differences between two faces that varied only in the size or the shape of the eyes. On that task, changes in eye size produced differences between faces primarily in the spatial relationships among the features, whereas changes in eye shape (created by replacing the eyes with those of a different person) produced differences in a small, single feature. The results are consistent with previous reports that adults can match faces or recognize individual faces based either on small changes in one or more individual features (i.e., local cue) or very slight changes in the spacing between those features (i.e., configural cue) (e.g., Bruce et al., 1991; Sergent, 1984; Tanaka & Sengco, 1997). They are also consistent with studies showing that children over seven years of age are capable of recognizing the identity of a face when the individual feature(s) and/or the positioning of the features has been altered (Baenninger, 1994; Pedelty et al., 1985).

However, both adults and 10-year-olds responded slightly, but significantly, faster when faces varied in eye size compared to when they varied in eye shape or when they did not differ at all. Longer reaction times on same trials is a well-known phenomenon in adults (see Sergent, 1984) and probably occur because subjects must search all of the facial features for differences before they respond "same." In this experiment, subjects' longer reaction times on trials with different eye shape than on trials with different eye size perhaps was the result of having to search longer for a single change produced by the different eye shape than to find one of several changes produced by the change in eye size (e.g., change in spacing between the eyes, between eye and external contour, between eye and brow, etc.). It may also arise because seeing the differences in eye shape required local processing, which may be less efficient than a strategy of configural processing which could be used to detect the differences in eye size. In addition, 10-year-olds were significantly slower than adults across all conditions, and that may be because children are less efficient at perceptual processing, in making decisions about whether two stimuli are the same or different, and/or in making a motor response.

Six-year-olds were less accurate than adults in judging differences between faces on the basis of either changes in eye size or eye shape, although they were above chance on both. In a previous study that used the same manipulations (Deruelle & de Schonen, 1998), infants as young as four months of age demonstrated right hemisphere specialization for processing faces that differed in eye size and left hemisphere specialization for processing faces that differed in eye shape. The findings from Experiment 7 suggest that skills in local and configural processing of faces, that are controlled by separate cortical mechanisms from as early as infancy, become adultlike after six years of age. Those cortical mechanisms make young infants sensitive to both small, local cues and to configural cues, but it may be only after they are shaped by years of experience that they can mediate expertise like that found in adults (see Carey, 1992). The improvement in these skills may also be related to children's ability to overcome a bias to attend to external/ paraphernalia cues (see Campbell et al., 1995 and Diamond & Carey, 1977) so that they can use the internal cues to distinguish between faces. The immaturities in configural processing are consistent with previous reports that young children are especially immature at detecting changes in faces' identity caused by changes in the spacing of the features (e.g., Baenninger, 1994; Freire, 1997). According to Carey (1992; Carey & Diamond, 1994), part of the perfection of configural processing is that children become skilled at recognizing individual faces by comparing them against a mental prototype.

The findings also provide support for the interpretation of the children's pattern of errors with faces in Experiment 6. The 6-year-olds' relatively poorer performance in tasks involving matching faces' identity and decoding direction of gaze likely occurred because good performance on those tasks requires configural processing and the 6-year-olds are relatively less skilled than the older subjects in using that strategy. In contrast, the 6-year-olds' near adultlike performance in lip reading and matching faces in emotional expression occurred presumably because they were able to rely on large, local features and did not need to use less-developed strategies based on small, local cues or configural cues.

However, there was one condition in which even 6-year-olds were adultlike in face matching. Subjects at every age showed evidence of relying on "holistic" processing in the task with fused facial composites consisting of identical top halves and different bottom halves: They made more errors in deciding that the eyes were the same when the facial composites were shown intact then when they were shown with their halves misaligned horizontally. The subjects' accuracy was worse with intact faces presumably because it was difficult for them to perceptually isolate one individual feature—the eyes—from the facial gestalt. Accuracy was better when the two halves of the faces were misaligned horizontally because in this case the facial gestalt was eliminated, and so it was easier for subjects to switch from a strategy of holistic processing to a strategy of local processing that was more appropriate for the task. Although 6-year-olds made more errors than older subjects in both conditions, the differences between conditions was the same as in adults. The results complement those of Hole (1994) who found that adults' decisions about whether the top halves of two fused faces are the same are slower when faces are presented upright than when they are presented inverted. They are also like those previously found for adults and children as young as six years of age who were less accurate and slower to name familiar people in the top halves of a composite when they were presented intact and upright than when they were presented inverted or with their halves misaligned (Carey & Diamond, 1994; Young et al., 1987). The findings from my task indicate that even when viewing unfamiliar faces, and when matching as opposed to recognizing faces, children as young as six years of age find it difficult to switch from holistic processing to effective local processing, just as adults do.

The conditions under which young children show adultlike strategies in face processing may be those that involve distinguishing faces from other classes of objects. Carey and Diamond (1994) have suggested that the holistic encoding evoked by fused faces allows the perceiver to see the image as a face rather than as a non-face object. It is contrasted with the more sophisticated configural processing that involves detecting subtle differences between individual faces in the spacing among the internal features. The pattern of results from the two face tasks in Experiment 7—one showing that 6-year-olds are immature in determining differences between faces based on configural cues and the second showing that 6-year-olds rely on holistic cues in the same way as adults—supports the view that there are different types of face processing, with different developmental time courses.

In Experiment 7, adults showed expertise in tasks measuring different aspects of shape processing, just as they had done for face processing, but the 6-year-olds did not perform as well as adults. While adults made minimal errors in their same/different judgments of geometric figures that varied in the elements (i.e., circles or diamonds) and in the positioning of the internal element (i.e., good vs. bad cross), the 6-year-olds were less accurate for both types of changes, and they were especially poor (below chance) at detecting changes in the positioning of the elements (see Figure 31). The pattern of results for 6-year-olds provides additional evidence that they are especially immature in determining differences between patterns in the spacing among the internal elements. It is interesting to note that even 10-year-olds, though making infrequent errors, made more errors on trials with different positioning of the internal element than on trials with different individual elements. These results are unlike those found for an analogous task of face matching on which 10-year-olds were equally proficient (and adultlike) in determining differences in individual features (created by changed eye shape) and in differences in the spacing between the features (created by changed eye size), and on which 6-year-olds were equally immature. Perhaps a mechanism of configural processing that underlies pattern processing, and that is specialized in the right hemisphere from as early as infancy (Deruelle & de Schonen, 1995; 1998), develops more quickly for the processing of human faces than for non-face objects because of children's greater exposure to faces and need to use configural processing to distinguish among them (Carey, 1992; 1996). That hypothesis is supported by the finding that adults' reliance on configural processing for stimuli other than faces (e.g., dogs, greebles) increases with increasing training with those stimuli (Diamond & Carey, 1986; Gauthier & Tarr, 1997; Rhodes & Tremewan, 1996).

As expected, adults demonstrated global superiority on the second shape task. Although adults were equally and highly accurate in their same/different judgments of hierarchical figures based only on one level—the individual elements (i.e., circles or squares) or the global shape formed by the elements along the external contour—when the correct decision conflicted with the answer at the other level, they were slightly, but significantly, slower when responding to individual elements than when responding to global shape. Adults' pattern of reaction times provides evidence that conflicting information from the global level interfered with their ability to process the smaller components, an effect previously reported with hierarchical alphabetical letters (e.g., Navon, 1977).

Children showed a much larger effect of global superiority. This was true both in accuracy, where the size of the effect in adults may have been limited by their nearly perfect performance on global shape trials, and in reaction time, where no such ceiling effect limited the comparison. Although

6- and 10-year-olds performed more poorly than adults on both types of incongruent trials, they were especially poor on trials that involved responding to individual elements. Figure 35 reveals that 6-year-olds were at chance levels on trials that involved responding to elements while ignoring global shape. In Figure 36, it is evident that 10-year-olds' reaction times were affected in the same way as their accuracy because they took longer to make same/different judgments about individual elements than they did to make judgments about global shape. This figure also shows that differences in reaction time for global versus local trials was slightly, but significantly, larger for the 10-year-olds than for adults. The children appear to have a stronger bias than adults to attend to patterns' global shape and/or more difficulty shifting attention away from global shape. This interpretation is consistent with the literature showing 6-year-olds' bias to recognize faces on the basis of features located outside the face (i.e., hair) (Campbell et al., 1995) and their difficulty in differentiating between faces in the presence of irrelevant cues, such as hats or glasses (Diamond & Carey, 1977). It is also supported by studies that have found stronger effects of distractors on children aged 5 to 10 than in adults (e.g., Akhtar & Enns, 1989; Ridderinkhof & van der Molen, 1995). In one study, 10-year-olds showed adultlike skills in using a cue to orient their attention to one spatial location, but they were hurt more than adults when the subsequent target was surrounded by distractors that signalled an incorrect response (Goldberg, Maurer, & Lewis, 1997).

In the discussion so far, I have assumed that the differences between children and adults reflect differences in perceptual skills. However, it is possible that the differences might instead reflect differences in motivation, attention, and/or memory. For example, the 6-year-olds might have been less interested in the tasks and/or might have had more difficulty maintaining their attention during the procedure. As a result, 6-year-olds might have encoded the stimuli less accurately, especially in Experiment 7 when the target stimuli were presented very briefly (i.e., 150 to 360 ms), and especially for the shape tasks administered towards the end of the test battery. These problems could have been exacerbated by 6-year-olds' relatively poor memory, although I note that there was essentially no delay between the target and test stimuli. Although poorer memory, motivation, and/or attention may have contributed to young children's errors, they are not likely to have caused the overall pattern of results: the 6-year-olds showed good performance on some tasks, and good performance was not related to presentation time of the stimuli, nor to when the tasks appeared in the procedure. In Experiment 6, 6-year-olds were close to adultlike in tasks involving lip reading and matching facial expressions, but not in matching facial identity, and all had the same presentation time of two seconds. In Experiment 7, the children showed good performance on one of the two shape tasks that involved determining changes in individual elements, and both used the same exposure durations of 150 milliseconds. Also in Experiment 7, 6-year-olds exhibited an adultlike difference in errors for fused faces presented intact versus with their halves misaligned horizontally and with exposures of 180 milliseconds. The same pattern did not hold true for the other face task that required determining differences in faces' eye shape and eye size, despite a longer presentation time (i.e., 360 ms). In general, the differences in the pattern of results between adults and children are likely to reflect differences in processing skills rather than differences in attention, motivation, and/or memory.

Overall, the findings from normal participants in Experiments 6 and 7 provide evidence that various aspects of face processing, including local and configural processing, become adultlike sometime after six years of age and by age 10. The development may be related, at least in part, to children's ability to ignore irrelevant information about large facial features located on the external contour. It is important to emphasize that what may be developing with age is not simply being skilled in a particular aspect of face processing, but being skilled under conditions that demand (rapid) configural processing. Even young children might show adultlike capabilities in recognizing people's faces if given the opportunity in the real world to differentiate between faces using cues such as the presence/absence of glasses, moustache, hair, etc. Conversely, young children might be quite poor in recognizing expressions of emotion and speech if in typical face-to-face interaction those expressions change subtly and quickly, and therefore, necessitate the encoding of faces based on configural cues.

The results of Experiment 6 and 7 provide evidence that local and configural processing of geometric shapes also become adultlike sometime after six years of age. The pattern of results suggests especially slow development of sensitivity to configural cues—at least as measured by the tasks used in Experiment 7—and of the ability to process individual elements while ignoring patterns' global shape. Even the 10-year-olds were not adultlike on the tasks measuring these skills. As was suggested for face processing, these developments may be related to the ability to overcome a bias to attend to large, local elements located on the external contour. It would be interesting to test the ability to detect changes in figures' individual elements (while ignoring conflicting information about global shape) in children older than 10 years of age to see when the skill becomes adultlike. One could also examine whether 6- and 10-year-olds' greater bias than adults for global shape persists with longer exposures, especially since longer exposure is known to eliminate global superiority in adults (e.g., Paquet & Merikle, 1984). What may be developing is efficiency of local processing and/or a greater ability to ignore distracting global information. Additionally, capabilities in processing shapes and other non-face objects on the basis of small, local cues, configural cues and global shape could be explored in adults or children with extensive training with those stimuli so as to gain more insight about the role of experience in the development of the strategies underlying object processing.

Effects of Early Visual Deprivation

Patients with a history of early visual deprivation did not reveal the same face processing strategies as normal individuals of the same age. For example, the patients did not show evidence of holistic processing in the task with fused facial composites. Patients' accuracy in deciding that faces' eyes were the same did not differ for fused faces presented intact and with their halves misaligned horizontally, unlike normal 10-year-olds and adults who made significantly more errors for intact faces. Greater errors for intact faces than for misaligned faces was expected if holistic processing caused the patients to perceive a facial Gestalt—a form not easily broken into individual features (in this case, the eyes). Patients' abnormal performance on this task is not likely to be related to task difficulty because, unlike their immature performance on all other tasks, normal 6-year-olds showed adultlike reliance on holistic processing with intact faces (also see Carey & Diamond, 1994 for a similar report). The results from this task suggest that early visual deprivation has an adverse effect on the development of holistic processing—a strategy that is useful for distinguishing between faces and non-face objects, and that is normally mature by early childhood. Patients' abnormalities may be related to the fact that they had no exposure to faces during the period when Conlern, the cortical mechanism used for face processing, emerges (Johnson & Morton, 1991) and when infants' preferences for faces over non-faces become increasingly differentiated (e.g., Mondloch et al., 1999).

Nor did patients show evidence of (efficient) configural processing of faces. The patients made significantly more errors than normal 10-year-olds and adults in same/different judgments of faces varying in eye size. The patients' difficulty was shown by their chance performance, unlike normal controls who had about 85 percent accuracy. It was also evident by their longer-than-normal reaction times on trials with different eye size, despite normal reaction times on same trials and despite the fact that the normal controls were fastest on trials with different eye size. Overall, the findings suggest that patients have deficits in processing the configural cues that distinguish between faces. That conclusion supports my interpretation that in Experiment 6 patients had difficulty recognizing facial identity despite changes in point of view, because that task required configural processing and could not be solved on the basis of large, local cues. Suprisingly, however, in Experiment 6 patients did show normal competence in matching direction of gaze despite changes in identity and head orientation, a task that required encoding the relationship between individual eye features. Perhaps their greater difficulty in Experiment 7 arose because of the extremely short presentation times of the faces (i.e., 360 ms), though I note that the identity task of Experiment 6 on which they performed abnormally used the longer presentation time of two seconds.

Patients also had problems with local processing of faces, at least when the facial features to be encoded were small and were presented for a short duration. First, patients made significantly more errors, and took significantly longer, than normal 10-year-olds and adults in same/different judgments of faces varying in eye shape. Second, patients' accuracy in deciding that the eyes were the same in misaligned faces was significantly worse than normal controls. Some of the patients' difficulties in local processing may be related to their poor visual acuity: Patients with worse Snellen acuity made more errors in deciding that two faces were different on the basis of eye shape. The poor performance on that task may not be related to face processing per se, but rather to an inability to see the exact shape of each eye. (A similar pattern was found in the global shape task in which patients with worse acuity made more errors on same/different judgments of figures based on the individual elements while ignoring global shape.) In contrast, patients may be better in local processing when those features are larger and/or are presented for longer exposures, as suggested by their normal performance in Experiment 6 for matching faces on the basis of emotional expression or vowel sound. Alternatively, the large variations in speech and emotion expressed by the models in Experiment 6 might have made it easy for the patients to achieve success simply by attending to the faces' outer contour. For example, patients might have found the face pronouncing the vowel "u" because it has a unique chin shape that is quite different from the chin shape for "a" or "e." Patients might have difficulty reading lips and matching facial expression if they change rapidly and produce more subtle changes in the shape of the external contour.

In general, the findings from Experiments 6 and 7 support the hypothesis that errors in matching facial identity were caused by patients' poor ability to use configural processing, and perhaps a greater reliance than normals on an ineffective strategy based on large, local features. Those deficits may be restricted to face processing, at least as suggested by patients' performance on one of the shape tasks in Experiment 7. In that task, patients performed normally in detecting differences between two geometric figures in the positioning of the interior element (i.e., good vs. bad cross). They also performed normally in detecting differences between figures in the individual elements (i.e., circles vs. diamonds). Their good performance on this shape task is probably not simply the result of its being an easier task than the ones with face stimuli because normal 6-year-olds performed as badly on this task as on the face tasks. Using these same stimuli, Deruelle and de Schonen (1995) found that 4- to 9-month-old infants learned to distinguish the individual elements faster in the right visual field (i.e., left hemisphere) and learned to distinguish the internal positions faster in the left visual field (i.e., right hemisphere). My finding that patients performed normally in this shape task, whereas they did not show comparably good performance in the tasks designed to measure similar specialized strategies for the processing of faces (Deruelle & de Schonen, 1998), suggests that early visual experience may have a special influence on the development of the cortical mechanisms necessary for face processing. If this interpretation is correct, it would not support de Schonen and Mathivet's (1989) claim that early visual experience is necessary for the development of all object processing.

However, the findings from the second shape task suggest that patients' deficits are not restricted to face processing because they had more difficulty than normals in ignoring global shape in making judgments about the individual elements of hierarchical figures, especially if their visual acuity was poor. Thus, patients with poor acuity may not have been able to see the individual features easily, and that likely contributed to their errors about the individual elements. For those patients, poor vision affects their shape processing abilities not only by making them insensitive to small, local cues but perhaps also by encouraging them to adopt alternate strategies based on a large, local feature, such as parts of the external contour. This interpretation does not account for patients' normal proficiency on the other shape task that required attending to differences between small elements (i.e., circles vs. diamonds), but that may be because those elements were larger and easier to resolve and/or because that task did not include distracting information from the external contour. Nevertheless, the findings from the global shape task provide hints about why patients did poorly in Experiment 6 in matching faces' identity despite changes in head orientation—a task that likely could be solved most successfully by attending to the spatial relationships among the features and least successfully by attending primarily to the external contour. It may be that in absence of efficient configural processing of faces, patients used a familiar, yet ineffective, strategy based on the global shape of the face (near the chin).

I have argued so far that patients' deficits were caused by the effects of early visual deprivation on the neural circuitry responsible for the processing of faces. It is important to rule out the alternative possibility that patients performed poorly in Experiments 6 and 7 because the poor visual acuity caused by the early visual deprivation (see Table 4) prevented them from seeing the stimuli clearly during the tests. Nevertheless, the patients performed well on some tasks. In Experiment 6, they performed normally in matching direction of gaze, and hence, appeared to be able to resolve the small details in the eye features—the pupil/iris and the sclera—well enough to find the correct match. In addition, there was no significant correlation between patients' acuity and their accuracy scores for any of the five tasks in Experiment 6, nor for any of the face tasks in Experiment 7, with one important exception—judging differences between briefly presented faces based on eye shape. This evidence suggests that patients' poor acuity at the time of the test did not interfere with their performance on the face tasks, at least on most of the tasks.

Other problems during the test, such as nystagmus (i.e., jiggly eye movements) and strabismus (i.e., misalignment of the eye), might have degraded the facial images. Nevertheless, the patients viewed the stimuli binocularly, and hence, with the dominant or fixating eye. Also, a look the individual data from patients revealed that deficits were not related to the presence/absence of nystagmus or strabismus. The few patients in my study with glaucoma (i.e., raised intraocular pressure) were included only if their condition was being controlled by medication and if there were no signs in their medical record of retinal damage. Thus, it is unlikely that patients' poor vision caused by the presence of nystagmus, strabismus, and/or glaucoma at the time of the test affected their performance on my tasks.

A second alternative interpretation is that the patients' abnormalities were caused not by early visual deprivation, but rather by abnormalities in visual input after treatment of the cataracts. Because surgery involved removing the natural lens, the contact lens fit after treatment focused input to each eye perfectly for only one distance, until it was supplemented by bifocal glasses at school age. However, during infancy, the power of the patient's contact lenses was chosen to focus visual input at arm's length—the distance for normal face-to-face-interaction between the infant and adult. After infancy, it was usual to leave one eye focused for near objects, and thus, to receive normally-focused input from faces. Therefore, the fixed focus is unlikely to have compromised facial input after treatment.

It is also unlikely that the abnormalities arose from growing up with poor acuity, and hence, compromised visual input, at least for the period from treatment until about 18 months of age. Immediately after treatment, patients' visual acuity is more similar to that of newborn infants than to infants of the same age (Maurer, Lewis, Brent, & Levin, 1999). This restricts processing of objects to the lower spatial frequencies, but it is no different than the biased visual input that normal babies receive during the first month after birth. Moreover, the visual acuity of patients treated for bilateral congenital cataracts is known to improve rapidly after treatment and to reach normal limits by the first birthday (Lewis, Maurer, & Brent, 1995; reviewed in Maurer & Lewis, in press). Thus, over the first year following treatment patients receive the same range of spatial frequencies as normal infants. Of course, visual input may be compromised in other ways or at later ages, either because of the development of associated eye conditions (e.g., nystagmus, strabismus, glaucoma) or because their visual acuity fails to improve at the same rate as that of normal controls after age two (Lewis et al., 1995). Nevertheless, patients have had years of experience viewing human faces binocularly—with the dominant or fixating eye. Furthermore, growing up with reduced acuity and poor contrast sensitivity after infancy (Ellemberg et al., 1999; Tytla et al., 1988) would compromise input necessary to see small details in faces, but not the low spatial frequencies specifying the spacing between features. Such visual input biased toward low spatial frequencies should in turn promote a proficiency in configural processing, unlike the results found in Experiments 6 and 7. Taken together, the evidence suggests that patients' deficits in face processing were caused by early visual deprivation rather than by later mild deprivation caused by poor acuity, poor contrast sensitivity, and/or the presence of nystagmus, strabismus, and glaucoma. Regardless of the contribution of these other factors, the results indicate that visual input is necessary for the normal development of expertise in face processing.

Theoretical Implications

The findings from Experiments 6 and 7 indicate that patients with a history of early visual deprivation perform normally on some aspects of face processing, but not on others. The findings add support to theories arguing for separable components of face processing (Bruce & Young, 1986). The findings also suggest that early visual deprivation caused by bilateral congenital cataracts, just as early insult to the brain (Gepner et al., submitted; Mancini et al., 1994), has a long-term effect on the ability to process many aspects of faces, even after many years of viewing human faces following treatment.

For none of the tasks was there a relationship between the patients' performance on the tasks and the duration of the visual deprivation, which varied from about two months to two years. Although it is not known whether visual deprivation shorter than two months allows better performance, the more interesting result is that deprivation lasting as little as two months was sufficient to prevent the normal development of face processing. This result provides support for theories emphasizing the importance of visual experience during the first few months of life for the development of the specialization for face processing (de Schonen and Mathivet, 1989; Johnson & Morton, 1991).

In one of those theories, Johnson and Morton (1991) propose that newborns begin life with a subcortical mechanism, Conspec, that gives them abundant exposure to human faces in the environment with which to influence an emerging cortical mechanism, called Conlern, to learn about faces. The learning mechanism is thought to rely on that early experience in order to be able to encode and differentiate between faces in terms of their identity, emotional expression, and direction of gaze, all of which have been demonstrated in infants two to four months of age (e.g., Barrera & Maurer, 1981; de Schonen, Gil de Diaz, & Mathivet, 1986; Vecera & Johnson, 1995). For the patients in my study, the Conlern mechanism that developed in the absence of biased input with faces during early infancy might not have been able to learn about faces' identity in a normal way.

de Schonen and Mathivet (1989) argue that infants' poor visual acuity and contrast sensitivity limit the information available to the developing cortical mechanism and lead it to become specialized for configural processing. These visual limitations are thought to influence the emerging cortical circuitry to be influenced more by the spatial relationships among features than by small, facial details so that it ultimately becomes specialized for configural processing. My findings suggest that in the absence of visual input during the first weeks of life, the circuitry does not develop in the normal way. I have speculated that immediately after their treatment for cataracts, patients probably process objects on the basis of lower spatial frequencies because their visual acuity is similar to that of newborns (Maurer et al., 1999). Although the patients may begin to encode faces on the basis of the spatial relationships among large features, the input occurs after the cortex in the right hemisphere has begun to develop on the basis of non-visual input, and therefore, when it may no longer be available to become specialized for configural visual processing.

However, my patients also showed deficits in tasks that required local processing of faces. Thus, unlike the predictions of de Schonen and Mathivet (1989), the findings suggest that early visual input may be as important for the development of the mechanisms located in the left hemisphere for local processing as for the mechanisms in the right hemisphere for configural processing. Perhaps it is the case that by the time the patients' acuity improves to the level of normal age mates, sometime around the first birthday (Lewis et al., 1995), the cortex in the left hemisphere has begun to specialize in other ways and is no longer available to become specialized for local processing.

Overall, the findings presented in Chapter 3 support the hypothesis that there is an influence of early visual experience on the development of face processing. This was the first study to examine it by testing children with a history of early visual deprivation. It complements many previous studies that have revealed an influence of early visual deprivation on the development of aspects of sensory vision that are immature at birth and that develop postnatally (e.g., Maurer et al., 1989). Taken together, the findings suggest an important role for early visual experience in the development both of sensory vision and of higher-level function such as face perception.

CHAPTER 4

GENERAL DISCUSSION

The studies in this dissertation examined the role of experience in the development of face perception. The studies were guided by predictions based on what is known about adults' skills in face processing, the neural mechanisms underlying those skills, and the emergence of face-processing capabilities postnatally.

The research reported in Chapter 2 explored the role of experience in the development of the perception of faces' attractiveness. While previous studies have suggested that adults' perception of beauty does not depend entirely on cultural influences—because there are similarities in aesthetic judgments in adults from diverse cultures (e.g., Cunningham et al., 1995) and because there are similarities in adults' and young infants' preferences for faces (e.g., Langlois et al., 1987), at the time my study began nothing was known about which facial characteristics known to influence adults' perceptions might be rooted in a visual preference during infancy. My studies provided the first examination of the developmental origins of two such influences, namely the faces' eye size and the height of the faces' internal features.

The research in Chapter 3 compared face processing in normal subjects and patients treated for bilateral congenital cataracts to see whether visual input near birth is important for the development of adult skills in lip reading and in processing faces' identity, facial expression, and direction of gaze. It also examined whether early visual experience is important for the development of adult skills in processing faces' identity on the basis of an individual feature (local processing) and the spatial relationships among the features (configural processing). The studies evaluated recent theories on the development of face processing emphasizing an important role for experience with faces during a critical period in the first weeks of life (see de Schonen & Mathivet, 1989; Johnson & Morton, 1991)—a time when babies receive abundant exposure to faces, in large part due to their natural bias for face-like patterns (e.g., Mondloch et al., 1999), and when cortical mechanisms involved in adult face processing (Bruce & Young, 1986) are beginning to form. Visual experience with faces during early infancy when visual acuity and contrast sensitivity are poor may especially influence emerging cortical mechanisms that eventually become specialized for configural processing of faces. My study of patients provided the first examination of whether early visual deprivation affects behaviours in face processing that are normally controlled by those cortical mechanisms. As such, it provided an indirect test of the theories by documenting the effects of deprivation of all patterned input.

The findings from both Chapters 2 and 3 suggest that visual experience from as early as infancy contributes to the development of face perception. In the next section, I integrate the behavioural findings from the two chapters and discuss the developmental implications of the results.

What My Studies Add to Our Knowledge about the Development of Face Perception

The results indicate that visual experience during the first months of life is important for the development of some aspects of face processing. The study on the influence of eye size (Chapter 2) showed similarities between adults' aesthetic preferences for faces with larger eyes and 5-month-olds' visual preferences for faces with larger eyes. This finding indicates that eye size influences reactions to faces from early infancy, before extensive cultural learning. However, other aspects of the results suggest a role for experience with faces: the 5-month-olds exhibited preferences with the colour photographs in Experiment 1 but not with simplified schematic drawings in a previous study (Carney, 1995), despite the fact that the differences between the faces with larger and smaller eyes in area and amount of contour were *smaller* in the photographs. This pattern suggests that, at least by five months of age, babies' preference is not based simply on patterns' physical size or contour—characteristics that are known to influence newborns' preferences (e.g., Fantz et al., 1975)—but rather on their experiences with real faces that more closely resemble photographs than line drawings. I speculated that preferences for faces with larger eyes develop during infancy as a consequence of infants' many experiences with expressive faces containing large eye height and width. Such faces with large eyes may come to seem familiar and preferred. A similar account has recently been proposed for facial averageness (Rubenstein et al., 1999), which influences both adults' aesthetic ratings and 6-month-olds' visual preferences. It has been suggested that the ability to form mental prototypes of faces based on a number of examples (de Haan et al., submitted;

Langlois & Roggman, 1990; Rubenstein et al., 1999) may enable both babies and adults to respond to average-looking faces that resemble the prototype as familiar and appealing. That interpretation, like mine for the findings on eye size, indicates that at least some aspects of aesthetic preferences arise from infants' experiences viewing human faces.

The findings from patients with a history of early visual deprivation (Chapter 3) provide additional evidence that adult capabilities in face processing are influenced by young infants' experiences. Patients showed abnormal performance in matching facial identity despite changes in head orientation, and they tended to show abnormal performance in matching facial identity despite changes in facial expression. Patients also performed abnormally on a task that required configural processing to differentiate between faces, and on a different task that involved holistic processing of faces. All of these abilities have been shown to be controlled by specialized cortical mechanisms in the right hemisphere in normal individuals (e.g., Allison et al., 1994; Deruelle & de Schonen, 1995; Hillger & Koenig, 1991; Sergent et al., 1992). Based on recent theories on the development of face processing (de Schonen & Mathivet, 1989; Johnson & Morton, 1991) and the current results, I speculated that the absence of visual experience during the first weeks of life interrupted the development of cortical mechanisms in the right hemisphere specialized for holistic processing, for recognizing individual faces, and for the configural processing that allows efficient recognition of faces. Delayed visual experience was not sufficient because the cortical mechanisms are not static and had already started to specialize on the basis of non-visual input.

Patients with a history of early visual deprivation also performed abnormally on some tasks that required a strategy of local processing to differentiate between geometric shapes or faces—behaviours that have been shown to be controlled by neural mechanisms in the left hemisphere in normal individuals (e.g., Deruelle & de Schonen, 1995). The patients' deficit in local processing of shapes was evident in only one of the two shape tasks, and was accounted for by a more general deficit in visual acuity. That particular shape task required ignoring distracting information about global shape, and so it may be that some patients—because of their poor ability to resolve the smaller elements—are especially influenced by one large chunk on the pattern's external contour. The patients' deficit in local processing of faces was evident on the two relevant tasks when the local differences were small—eye shape—and the presentation times of the faces were short, and in only one of those tasks was explained by poor acuity. Furthermore, patients did perform normally on some tasks of local processing when the local details were larger and the presentation times of the faces were longer, namely matching facial expression and lip reading. Overall, the results suggest that absence of visual experience during the first weeks of life interfered with the later development of specialized skills in the left hemisphere for recognizing faces efficiently on the basis of small, local cues.

While these findings suggest that the development of adult face processing capabilities is influenced by experience near birth, some of the other findings suggest that additional experience after infancy also plays a role in the development of face perception. The finding that the height of faces' internal features had different effects on 5-month-olds' behavioural preferences and adults' aesthetic preferences (Chapter 2) suggests that this variable begins to shape adultlike aesthetic preferences sometime after early infancy, perhaps with social learning and/or additional experience with faces. Adults rated faces with their features at either a medium or low height as more attractive than faces with their features at a high height, and in most cases they rated faces with medium features as most attractive, but babies looked equally long at faces with their features at various heights except for looking slightly longer at faces with high rather than low features. I suggested that infants' preference may be based on their familiarity with faces as they appear when viewed from below the chin—with a small forehead and a large chin. In adults, it may be based on years of experience viewing faces as they appear at eye level, forming a prototype of an average-looking face, and then responding to a face with its features in an average location as familiar and attractive (e.g., Langlois & Roggman, 1990).

My test of 3-year-olds was aimed at determining whether the adultlike influence of the features' height emerges during early childhood, when children begin to have much more contact with faces from eye level. There was no effect of the features' height on children's perceptions of prettiness, except for a subgroup with more exposure to similar-aged peers who rated faces with low features as more pretty than faces with high features. Thus, children's aesthetic preference for low features appears to be influenced by face-to-face interaction with children, whose features are known to be low in the face (Enlow, 1982). As shown in Experiments 2 to 4, this preference for low over high features persists into adulthood. Nevertheless, the results also suggest that the preference for facial features at an average height emerges after early childhood with more experience viewing adults' faces and older children's faces (containing adult proportions) from an en face perspective.

The studies on normal development (Chapter 3) show that many aspects of face processing are not fully developed by six years of age. Normal 6-year-olds did show adultlike performance on at least one aspect of face processing—holistic processing. However, normal 10-year-olds, but not 6-year-olds, were adultlike in matching faces on the basis of their identity and various facial signals, and in using the specialized strategies of local and configural processing. Normal 6-year-olds showed some competence, but were especially poor at aspects of face processing that involve configural processing. My findings fit well with previous studies showing that the abilities to recognize individual faces and to use configural processing for face recognition emerge during infancy but then improve slowly until reaching adult levels at about 10 years of age (reviewed by Chung & Thomson, 1995). Research with adults has revealed that configural processing of patterns, including faces, is related to the amount of training or expertise in differentiating among members of a particular class of stimuli (e.g., Diamond & Carey, 1986). On this basis, I speculate that the emergence of adult skills in face processing—particularly those skills that require configural processing—may depend on early exposure to faces that sets up cortical circuits that can become specialized for configural processing. Those circuits in turn are shaped by many years of experience in differentiating among faces.

Future Studies on the Role of Experience in the Development of Face Perception

The Role of Experience during Infancy

The deficits I found for processing facial identity, for using the strategies of local and configural processing to efficiently recognize faces, and for holistic processing of faces in patients treated for bilateral congenital cataracts support the hypothesis that the normal specialization of the brain for face processing is affected by visual experience from birth. However, additional research is needed to determine the neural basis of those deficits. Future research should also consider whether visual experience after infancy is as important as experience during the first weeks of life in shaping the specialization of the brain for face processing.

I hypothesized that the abnormalities in the patients reflect deficits in the specialization of the two hemispheres for face processing. The patients' early visual deprivation might have led to no hemispheric specialization for face processing, some specialization in cortical regions that are less affected by deprivation, or a pattern of brain specialization different from normal—a pattern that might explain patients' normal abilities in some face matching tasks in my study. Future studies with patients treated for bilateral congenital cataracts, using behavioural and neuroimaging techniques, may help to differentiate these possibilities.

Lateralized tachistoscopic studies in normal adults have revealed different patterns of hemispheric specialization for different strategies used for face processing (e.g., Hillger & Koenig, 1991). My tasks could be used in a lateralized tachistoscopic paradigm to delineate the contribution of each of the hemispheres to the performance of normal adults and to the patients treated for bilateral congenital cataracts. Functional magnetic resonance imaging (fMRI) and event-related potential (ERP) measures of brain activity could reveal which regions of the brain are activated more or less strongly during the tasks. Such techniques, which differentiate adults' processing of different aspects of faces in different regions of the temporal cortex (e.g., Allison et al., 1994; Puce et al., 1995), would test whether early visual input is important for the development of the mechanisms located in the left hemisphere for local processing and for the mechanisms in the right hemisphere for configural and holistic processing. Based on my findings, I predict that the patients with a history of early visual deprivation do not show the same hemispheric specialization for face processing as do normal individuals.

Lateralization and neuroimaging techniques can also be used to assess whether patients' normal abilities in some aspects of face processing (e.g., recognizing facial expressions, decoding direction of gaze) are controlled by the same neural mechanisms as those in normal subjects. The mechanisms might be the same, as would be expected if the behaviours are mediated by mechanisms that are largely unaffected by visual deprivation and/or that are tuned by many years of experience after infancy. Alternatively, the mechanisms used by the patients may be different from normal despite their similar performance, perhaps because early visual deprivation produces a pattern of specialization for face processing different from normal. These techniques can also be used with my geometric shape tasks in order to determine whether shape processing is controlled by the same neural mechanisms in patients and normals, as would be expected from (at least some of) the behavioural findings.

While the findings from patients with a history of congenital cataracts suggest that experience from the beginning of life is important for the normal development of many aspects of face processing, research is needed to define the "sensitive period(s)" during development in which experience plays a fundamental role. Studies with patients who began life with normal vision and then developed bilateral cataracts later in childhood would indicate the role that visual experience plays at different points in development. If experience is influential only during the first months of life, then there should be no abnormal brain organization, and consequently no face processing deficits, in patients whose deprivation occurred later in life. If experience after infancy plays a role in maintaining the normal specialization for face processing, then deficits in face processing should be observed in patients who developed cataracts after infancy, just as in patients who were born with cataracts. Experience after infancy may be critical in elaborating the brain specialization for face processing, in which case deficits might be greater for patients treated for developmental cataracts than for patients treated for congenital cataracts. A comparison of the types and degree of deficits between these two groups of patients would differentiate among these hypotheses. This type of study can be carried out with my behavioural tasks and with lateralization and neuroimaging procedures of the type discussed above.

Future studies could evaluate whether early visual input affects the development of cortical mechanisms related to other components of face perception, such as the perception of faces' attractiveness. I assumed that babies' preference for faces with larger eyes arises sometime after two to three months of age when infants spend more time scanning the internal features of faces, especially the eyes, rather than the faces' external contours (e.g., Maurer & Salapatek, 1976), and when infants begin to recognize faces on the basis of the internal features alone (e.g., de Schonen & Mathivet, 1990). Nevertheless, such preferences might be an extension of newborns' natural visual preferences for patterns with elements of larger physical size and/or more energy at low spatial frequencies (e.g., Banks & Salapatek, 1981; Fantz et al., 1975). These are the very characteristics that may mediate the visual preferences for "attractive" faces in newborns (Slater et al., 1998), and which may bias the young infant to look at large features in patterns, including faces. Such early biases for larger eyes, perhaps like newborns' biases for face-like patterns (e.g., Mondloch et al., 1999), might cause emerging cortical mechanisms to develop representations of faces with larger eyes and then to show preferences for faces that resemble those representations.

Future studies with newborn infants might shed light on these issues. One type of study could compare visual preferences for faces varying in eye size in newborn infants, older infants and adults. Newborns may look longer at faces with larger eyes regardless of whether they are viewing realistic colour photographs or simple drawings of faces, or even when the eyes are removed from the context of a face. Moreover, these effects may be stronger, the larger the size of the eyes, a pattern opposite to that found for 5-month-olds and adults in Experiment 1. Newborns could also be tested using face-like stimuli of the type that have demonstrated newborns' preference for Config (i.e., 3 blobs placed in the correct locations for the eyes and mouth) over its inverted version (e.g., Mondloch et al., 1999). Those patterns could be manipulated to create versions with larger and smaller eyes. Newborns might look longer at the Config pattern with larger eyes than at either Config with smaller eyes or an inverted Config with larger eyes, a finding which would indicate that newborns' bias for faces is influenced not only by the positioning of the features but also, by the size of the eyes.

There are other reasons to suspect that young infants' experiences might play a role in the development of cortical mechanisms involved in aesthetic preferences for faces with larger eyes. In a lateralization study, Deruelle and de Schonen (1998) found that 4- to 9-month-old infants learned to distinguish between two faces—one with larger eyes and one with smaller eyes—more quickly when those stimuli were presented in the infants' left visual field (right hemisphere) than when they were presented in the right visual field. According to de Schonen and her colleagues (e.g., de Schonen et al., 1993; de Schonen & Mathivet, 1989), the development of a right hemisphere mechanism for configural processing—produced in this case by changes in eye size—is shaped by newborns' experiences viewing patterns on the basis of the spacing between large, individual features. That same mechanism may also influence babies' preference for faces with larger eyes. This hypothesis could be tested by examining whether infants' visual preferences are present (or stronger) when the faces with larger eyes are presented to the left visual field compared to when they are shown to the right visual field. Also, an indirect test would involve comparing the visual preferences in normal infants and in infant patients treated for bilateral congenital cataracts. For the infant patients, deficits in the right hemisphere mechanism caused by their early visual deprivation might prevent the normal preference for larger eyes.

The Role of Experience After Infancy and Early Childhood

The pattern of aesthetic preferences from preschoolers gives support to the hypothesis that experience during early childhood contributes to at least one adult aesthetic preference, namely a preference for faces with their features positioned low on the face. Additional research is needed to distinguish the contribution of visual experience versus social learning on the development of that preference.

One aspect of adult aesthetic preferences that is present by three years of age—preferences for faces with lower features—is correlated with exposure to children's faces, and hence, may be based on familiarity with faces containing low features. It may also reflect learning about societal norms during interactions with other children and adults in preschool and playgroups. Additional testing with children who are given extensive training with faces containing features at medium height may differentiate the role of visual experience versus social learning. If visual experience is critical, it should be possible to induce the adult preference for faces with medium features' height over faces with low height in 3-year-olds.

Future studies could also examine the influence of exposure to faces during middle childhood and adulthood on the development of adult aesthetic preferences. Adults' preference for faces with their features at a medium height may require further physical growth that allows more frequent en face interaction with faces with adults' proportions. It would be interesting to trace the age at which the position of the features in peers' faces approaches medium height and then see whether aesthetic preferences at that age coincide with those in adulthood. Additional research that explores aesthetic preferences in adults with experience viewing faces from a perspective different from eye level (e.g., adults taller or shorter than the average height) may also give us more insight about the effects of exposure.

One could also test the effects of exposure to faces on the development of the ability to perceive faces on the basis of their identity. In Chapter 3 with normal subjects, I found that adults and 10-year-olds were more accurate than 6-year-olds in matching faces' identity (despite changes in head orientation or facial expression), and in matching faces' identity on the basis of either small, local cues or configural cues. The older subjects were also more accurate than 6-year-olds in shape tasks that required matching geometric figures on the basis of the local cues or configural cues. It would be interesting to test whether more frequent exposure to particular objects of the same class (e.g., faces, shapes) produces a change in young children's visual processing capabilities. For example, one could train 6-year-old children to distinguish among homogeneous stimuli (e.g., faces, dogs of the same breed) to see if configural processing improves, as is known to be true in adults (Diamond & Carey, 1986; Gauthier & Tarr, 1997). Training subjects with faces and geometric shapes that could be distinguished only on the basis of small, individual features would indicate whether learning from exposure is as important for the development of the strategy based on local processing as for configural processing. In addition, it would be interesting to use neuroimaging procedures, such as fMRI, in adults and children to determine whether the perfection of skills in face and shape processing that arise with age either reflects greater specialization of the brain or greater efficiency of the underlying neural mechanisms (see Carey, 1981).

Concluding Remarks

Collectively, the findings from my studies support the hypothesis that the development of human face processing is sensitive to experience from as early as infancy. My tests of face perception included capabilities that would typically occur in real face-to-face interactions, such as encoding and remembering people's faces, and perceiving aspects of a face that guide our interactions—faces' attractiveness, direction of gaze, and expression of emotion.

Although my tasks measured real-life skills in face processing, there are some ways in which they do not reflect typical face processing. The tasks involved presenting faces in the absence of several cues that would otherwise be available in real situations: In all of the experiments, faces appeared without glasses and other paraphernalia (e.g., earrings, hats), and facial hair (e.g., moustache, beard, side-burns in men's faces), and were not accompanied by movement or sound. In Chapter 3, the tasks used faces with natural facial markings removed and with their hair and ears covered. In addition, all of the tasks required the processing of unfamiliar faces. Although much of our knowledge about human face perception and its development comes from this type of study, face processing in the real world occurs often when we are interacting with people who are familiar to us. The effects found for unfamiliar faces in my study may be different than those for familiar faces, as would be suggested by one previous report showing differences in children's processing of familiar versus unknown faces (Diamond & Carey, 1977). Future research that examines the development of the processing of familiar faces will indicate the generality of the findings I have elucidated of the role of experience.

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Appendix 1

Photographing Faces

I took photographs of faces (Chapter 2) using procedures that were similar to those of Langlois (e.g., Langlois et al., 1987; Langlois et al., 1991) in her studies showing a relationship between adults' ratings of attractiveness of natural photographs of faces and infants' looking times to the photographs. I took photographs of Caucasian female students, all between the ages of 17 to 25. The models posed with the head and eyes facing the camera and so that the faces' internal features were in full view. All models were asked to pose with a neutral, closed-mouth expression to eliminate any expression of emotion that might influence adults' aesthetic ratings and/or infants' looking times. To eliminate non-facial cues, models wore a cloth draped around their shoulders and chest, and removed glasses, hats or earrings. To eliminate variation in the facial images in size and/or colouring, models were photographed from a standard distance and with identical background and lighting.

Photoshoot Apparatus

The photography equipment was assembled in a room in the psychology building at the University of Toronto. A highback chair, measuring 0.5 meters from its seat to the floor, was positioned 0.5 meters in front of a grey backdrop (0.4 m wide x 0.4 m high). Two meters in front of the model's chair was a tripod stand (1.2 meters high) that supported the camera. I took photographs with an Olympus OM-2 single lens reflex camera fitted with an Olympus OM-2 55 mm lens and loaded with Kodak Ektachrome 100 ASA colour slide film.

For lighting, I used two electronic flash units (Monobloc, Balcar s.a. France 110v. 12.5A) attached to 1.5 m diameter reflecting umbrellas. The flash units and umbrellas were mounted on stands (each 1.3 meters high), and placed 0.5 meters to the right and to the left of the tripod stand. The flash units were positioned to the left and right of the model's face in order to minimize shadows and highlights.

Procedure

Students passing through the lobby of the building were asked if they were interested in earning one dollar to have their pictures taken. I approached Caucasian female students, but willingly took pictures of any person showing interest regardless of age, sex, or race. Models agreeing to participate read and signed a model release/consent form that gave permission for their photograph(s) to be manipulated by the use of computer computer software and to be published for the purpose of scientific reporting. Models were also asked to state their age.

Models were photographed individually. I asked the model to remove articles from the head region (i.e., eyeglasses, earrings, hats) and any make-up that could be removed easily by a tissue (i.e., blush, lipstick). Any model with hair that covered the forehead and/or the cheeks was asked to use his/her own brush or hands to pull away the hair from the face. For some models, I used cotton swabs to apply a skin-tone pressed powder to the oily regions near the cheekbones and the tip of the nose to remove the shine. The model sat in the chair, directed her head and eyes toward the camera, and posed with a neutral expression. I draped a black cloth around the shoulders to cover clothing and accessories around the neckline. I took pictures of the model's face, explained the purpose of the photoshoot and paid the model for participating.

All rolls of film were brought to a professional processing center for development into colour slides. To minimize colour variability across films, all rolls of film were bought in bulk from the same lot number and were developed simultaneously to ensure that slides were developed using identical processing chemicals and methods.

Appendix 2

Adults' Ratings of Attractiveness of Natural Photographs of Faces

I asked adults to rate the attractiveness of each of 97 colour photographs of faces so that I could select a subset of faces for the manipulation of eye size (see Chapter 2, Section 2.2: Experiment 1 for details) and the height of the internal features (see Section 2.3: Experiment 3). The faces selected for manipulation were those that had been rated by adults as "average" rather than as very attractive or unattractive. I expected that natural photographs that had been judged as average might result in greater variability in adults' aesthetic ratings after changes in the eye size or the position of the internal features than if I had begun with faces rated at the extreme values of attractiveness.

Subjects

Thirty (15 male) undergraduate students (M age: 20.0; range: 17 to 32 years) participated for points in a psychology course. Twenty-two adults were Caucasian, four were Asian, two were Oriental and two were Black. The data from an additional four subjects were excluded because they gave no rating of a face or provided more than one rating per face.

Stimuli

The facial stimuli were the 97 colour slides of Caucasian female faces presented individually and in one of three possible random orders. Adults viewed the faces in one of five randomly-selected starting positions within each order. Each face was shown near-lifesize (14 cm wide x 17 cm high), as in Experiment 4 during sequential presentations of faces (see Section 2.3).

Apparatus

Adults stood behind a platform facing a rear-projection screen (64 cm wide x 28 cm high) onto which the faces were projected from a Kodak carousel projector. A remote control device was used by the adults to advance the projector after each rating. The apparatus was the same as for adults in Experiments 1 to 4.

Procedure

Adults were tested individually while standing 75 cm from the projection screen. Adults rated the attractiveness of each face by filling out a form using a 5-point Likert scale (1-very unattractive; 2-somewhat unattractive; 3-average; 4-somewhat attractive; 5-very attractive). So as to obtain their first impressions of faces, I asked adults not to move backwards through the series. When they finished, adults completed a form asking for their age, sex, and race. The attractiveness rating scale was the same as for adults in Experiment 4 during sequential presentations of faces. In all other respects, the procedure was the same as for adults in Experiments 1 to 4.

Selecting Faces for the Manipulation of Eye Size and Features' Height

I computed the means and standard deviations of adults' ratings of the attractiveness of each of the 97 faces. From a smaller group of faces that adults rated as close to average (i.e., 3 on a 5-point scale of attractiveness), I rejected faces posing with a facial expression other than neutral (i.e., happy, surprise), faces from individuals over the age of 25, models with bangs that covered the face and/or wearing large amounts of makeup. I identified a total of 15 faces of females for experimental manipulation. They came from models, aged 17 to 23 (_M_ age = 21), who had a mean attractiveness rating close to average (i.e., _M_ rating = 3.1; range = 2.8 to 3.3) with minimal variability among the raters (_M_ variance = 0.73; range = 0.49 to 0.93).

Appendix 3

Adults' Ratings of Attractiveness of Faces Varying in Eye Size (± 3 Standard Deviations from the Population Mean)

I manipulated eye size in 15 colour photographs of faces to create two versions of each: one face with larger eyes and a second face with smaller eyes, with eye size set at three standard deviations above and below the population mean, respectively. The purpose of this experiment was to obtain adults' ratings of the attractiveness of all 30 faces (i.e., 2 versions of each of 15 faces), and then to select as final stimuli for Experiment 1 (see Section 2.2) eight faces for which adults' aesthetic judgments of the two alternatives varied most widely.

Method

Subjects

Thirty (15 male) undergraduate students (M age: 19.4 years; range: 17 to 26 years) participated for points in a psychology course. Nineteen adults were Caucasian, 10 were Asian, and one was Black.

Stimuli

I used Photoshop to create two versions of each of 15 faces, one with smaller eyes and another with larger eyes, with the sizes defined as in the preliminary study with schematic faces as three standard deviations from the population mean (Carney, 1995). See Experiment 1 (Stimuli) for details of the procedure for creating faces varying in eye size.

The 30 colour slides of faces were shown individually in the center of the screen and near-lifesize. I created 30 random orders and each adult saw the faces in a different order, without replacement. A constraint on the orders was that the two versions of the same face were never shown on consecutive trials.

Apparatus and Procedure

The apparatus and procedure for adults were the same as for adults in Appendix 2.

Results

Adults' mean ratings of attractiveness of the 15 faces with larger and smaller eyes were 2.6 and 2.5, respectively, on a 5-point scale of attractiveness. Separate t-tests on adults' mean ratings of attractiveness for each of the 15 faces showed significant effects of eye size for eight of the 15 faces ($ps < .05$). Of these eight faces, only five faces showed the effect in the predicted direction, with higher ratings of attractiveness given to the version of the face containing larger eyes.

Discussion

As in Carney's (1995) study with drawings, I manipulated the size of the eyes in photographs so that they were three standard deviations from the population mean. In that study, adults rated each of four schematic female faces as more attractive when they had larger eyes. In this experiment with female photographs, adults' higher ratings of attractiveness for faces with larger eyes was significant for only one-third of the sample of faces. Moreover, adults' mean aesthetic ratings of the two versions of faces with smaller and larger eyes were slightly below average and similar (i.e., 2.5 and 2.6, respectively). Thus, neither version was perceived as attractive. The photographs of faces with larger eyes were not rated as attractive perhaps because their eyes were too large and unrealistic. In support of this hypothesis, many raters commented that the photographs with larger eyes looked unnatural. Interestingly, no one commented about the naturalness of the photographed faces with unusually small eyes, perhaps because those faces resembled faces with partly closed eyes that adults have seen often.

I did not select a set of final stimuli from this sample of photographs because so few examples showed a significant effect of eye size on adults' aesthetic ratings, and because any effect that was observed was not strong. Stronger aesthetic preferences for faces with larger eyes may have been masked because the larger eyes looked unnatural to adults. In the preliminary study reported in Appendix 4, I examined adults' ratings of the same 30 photographs in terms of their judgment of how likely each was to have been manipulated or "tampered with" by the experimenter. If adults judged the photographs with larger eyes as likely to have been manipulated, then I planned to reduce their size so that they appeared more natural.

Appendix 4

Adults' Ratings of "Tampering With" Faces Varying in Eye Size (± 3 Standard Deviations from the Population Mean)

The 30 colour photographs of faces with their eye sizes set at three standard deviations from the mean were shown to a group of adults in order to obtain their judgments of the likelihood that each face had been manipulated or "tampered with" by the experimenter. If those photographs looked unnatural to adults, then I planned to manipulate eye size less extremely so as to make them more realistic, and so that they could be used for testing subjects in Experiment 1 (see Section 2.2).

Method

Subjects

Thirty (15 male) undergraduate students (M age: 18.4 years; range: 18 to 23 years) participated for points in a psychology course. Twenty-two adults were Caucasian and eight were Asian.

Stimuli and Apparatus

The stimuli and apparatus were the same as for adults in Appendix 3.

Procedure

The adult viewed each of 30 faces presented sequentially in the center of the projection screen, and rated each face in response to the question "Did the experimenter *tamper with* (i.e., modify, manipulate) the photograph in any way?" using a 3-point scale (1-no, this one is natural; 2-not sure; 3-yes, this one is modified). Afterwards, the subject completed a form asking for his/her age, sex, and race and was debriefed about the manipulation of eye size.

Results

A one-sample t-test comparing adults' mean ratings of tampering with the photographs containing smaller and larger eyes was significant, $p < .05$. The mean ratings were higher for faces with larger eyes (2.6 on a 3-point scale) than for faces with smaller eyes (1.8). A comparison of the means across the 15 examples of faces showed that adults' mean ratings were higher for the version with larger eyes for all but one example.

Discussion

Adults judged it highly likely that the photographed faces with larger eyes had been manipulated by the experimenter, a finding that supports my hypothesis that the larger eyes set at three standard deviations above the mean were too large to look realistic. It seems likely that the faces with smaller eyes did not look natural either: adults' mean rating of tampering with faces containing smaller eyes was close to the midpoint of the rating scale, indicating that the raters were uncertain about whether they had been manipulated. Therefore, to make the faces with both larger and smaller eyes appear more realistic, I re-manipulated the images so that eye size varied by only two standard deviations above and below the population mean. Another group of adults were then asked to rate the attractiveness of the new faces varying in eye size (see Appendix 5).

Appendix 5

Adults' Ratings of Attractiveness of Faces Varying in Eye Size (± 2 Standard Deviations from the Population Mean)

A new group of adults rated the attractiveness of 20 photographs of faces varying in eye size, with eye size set at two standard deviations above and below the population mean. To save time in recreating images, I manipulated eye size in 10 of the 15 original examples of faces. The goal was to select eight faces (i.e., 4 faces x 2 versions) in which the two versions with larger and smaller eyes varied most widely on adults' aesthetic judgments, and to use these as final stimuli in Experiment 1 (Section 2.2).

Method

Subjects

Thirty (15 male) undergraduate students (M age: 19.6 years; range: 18 to 29 years) participated for points in a psychology course. Twenty-two adults were Caucasian, seven were Asian, and one was Black.

Stimuli

From the 15 faces varying in eye size (± 3 standard deviations) that had been rated for attractiveness by adults in Appendix 3, I selected 10 faces for which aesthetic ratings of both versions with enlarged and smaller eyes, when averaged, varied least from the midpoint of the rating scale. These 10 faces were manipulated so that the eye size varied only two standard deviations above and below the population mean. Experiment 1 provides details of the procedures used for constructing faces with eye size ± 2 standard deviations.

The 20 faces (i.e., 2 versions of each of 10 faces) were presented in random order, without replacement, with the constraint that two versions of the same face were never shown on consecutive trials. Each subject received a different order.

Procedure

The procedure was the same as for adults in Appendix 3.

Results

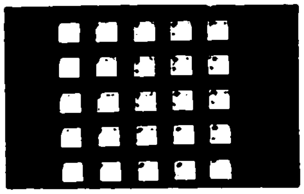
Adults' mean ratings of attractiveness of the 10 faces with larger and smaller eyes were 3.0 and 2.6, respectively, on a 5-point scale of attractiveness. An ANOVA on adults' mean ratings of attractiveness, with two within-subjects factors (eye size, face example), showed significant effects of eye size, $F\ (1,29) = 20.37$, $p < .001$, and face example, $F\ (9,261) = 3.2$, $p < .01$, and a significant interaction between eye size and face example, $F\ (9,261) = 4.37$, $p < .0001$. (A test of homogeneity of variance for the interaction between eye size and face example was not significant, Mauchley's sphericity, $p > .10$.) Analyses of simple effects revealed a significant effect of face at smaller size and at larger size (both $ps < .01$), and a significant effect of size for six of the 10 examples of faces ($ps < .05$). The effect of eye size on adults' aesthetic ratings was in the predicted direction for each of these six faces.

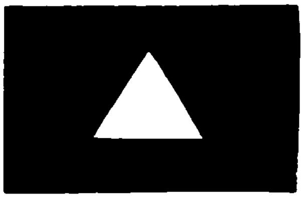
Discussion

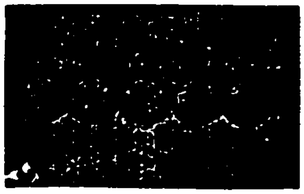
In this experiment, when eye size in photographs of female faces was set at only two standard deviations above and below the population mean, adults gave significantly higher ratings of attractiveness to the faces with larger eyes than to the faces with smaller eyes. The effect of eye size was significant for six of the 10 examples of faces that had been manipulated and was stronger in this experiment than in my previous study with eye size set at three standard deviations from the mean. Thus, it seems that when the size of the eyes was reduced from three to two standard deviations above the mean, more of the photographed faces with larger eyes appeared natural-looking, and hence, more appealing to adults.

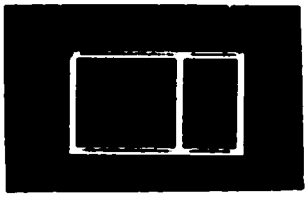
The four faces selected as final stimuli were those from the set of six for which changes in eye size had the strongest effect on adults' aesthetic ratings (mean rating of smaller eyes: 2.4; range: 2.3 to 2.5; mean rating of larger eyes: 3.2; range: 3.0 to 3.5), with minimal variability among the raters (M variance smaller eyes: 0.97; range: 0.9 to 1.0; M variance larger eyes: 0.97; range: 0.82 to 1.1). The four colour photographs of faces with larger and smaller eyes (± 2 standard deviations) were used in Experiment 1 on the influence of eye size on adults' ratings of relative attractiveness and 5-month-olds' proportion of looking times. They are illustrated in Figure 1.

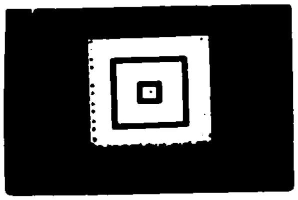
Appendix 6

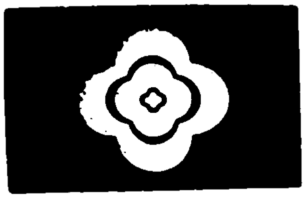


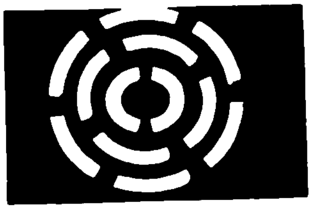












Appendix 7

A

Order #_______________

Pair #

(1)

-2	-1	0	+1	+2
Face on Left Much More Attractive	Face on Left Somewhat More Attractive	The Faces are equal	Face on Right Somewhat More Attractive	Face on Right Much More Attractive

(2)

-2	-1	0	+1	+2
Face on Left Much More Attractive	Face on Left Somewhat More Attractive	The Faces are equal	Face on Right Somewhat More Attractive	Face on Right Much More Attractive

(3)

-2	-1	0	+1	+2
Face on Left Much More Attractive	Face on Left Somewhat More Attractive	The Faces are equal	Face on Right Somewhat More Attractive	Face on Right Much More Attractive

(4)

-2	-1	0	+1	+2
Face on Left Much More Attractive	Face on Left Somewhat More Attractive	The Faces are equal	Face on Right Somewhat More Attractive	Face on Right Much More Attractive

(5)

-2	-1	0	+1	+2
Face on Left Much More Attractive	Face on Left Somewhat More Attractive	The Faces are equal	Face on Right Somewhat More Attractive	Face on Right Much More Attractive

(6)

-2	-1	0	+1	+2
Face on Left Much More Attractive	Face on Left Somewhat More Attractive	The Faces are equal	Face on Right Somewhat More Attractive	Face on Right Much More Attractive

B
INFORMATION SHEET

Subject # _____

Please fill out the following information. This information will enable us to analyze any possible effects that these variables have on ratings of attractiveness of adult female faces.

Feel free to ask any questions.

1. Age: ________

2. Sex: _____________

3. Are you (check one):

Caucasian _____ Asian _____ Black _____ Oriental _____

Other (please specify) ____________________________

4. Have you lived in Canada all of your life? ___________

If not, how long have you been living in Canada? __________________

Where did you live previously? _____________________

C

How attractive is this face?

face #	very unattractive 1	somewhat unattractive 2	average 3	somewhat attractive 4	very attractive 5
1					
2					
3					
4					
5					
6					
7					
8					
9					

D

Baby's Name ________________

HOW LIKELY IS IT THAT THIS FACE WILL LOOK FAMILIAR TO YOUR BABY?

	face #	Very unlikely 1	Unlikely 2	Possibly 3	Likely 4	Very likely 5
	1					
	2					
	3					
	4					
	5					
	6					
	7					
	8					
	9					
	10					
	11					
	12					
	13					
	14					
	15					
	16					
	17					
	18					

E

Scorer: ____________________

Date Scored: ________________

What is your perception of the infant's emotional reaction to the face?

negative (distressed, agitated, actively avoiding)			neutral		positive (happy, excited, seeking interaction)		not scoreable
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—

negative (distressed, agitated, actively avoiding)			neutral		positive (happy, excited, seeking interaction)		not scoreable
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—
1	2	3	4	5	6	7	—

F

Name: **Subject Number:**

Birthdate:

Date of Testing:

Sex:

Order:

PRE-TEST

Test	Number 1	Number 2	Number 3	Number 4
Pass				
No Pass				

TEST

Order	Left	Right
1		
2		
3		

DECODE

	Number	Preference
Low/High		
Medium/ High		
Low /Medium		

POST-TEST

	Yes	No	Frequency
Preschool			
Daycare			
Playgroup			
Other:			

Siblings?
Sibling Ages:

Appendix 8

Adults' Ratings of Attractiveness of Faces Varying in the Height of their Internal Features

I manipulated the height of the internal features in 10 colour photographs of faces to create three versions of each: faces with their features at a low, medium, and high height. The purpose of this experiment was to obtain adults' ratings of the attractiveness of the 30 faces, and then to select as final stimuli 18 faces (i.e., 3 versions of each of 6 faces) for which adults' ratings of the most attractive and unattractive versions of each face were maximally distinct, with minimal variability among the raters.

Subjects

Thirty (15 male) undergraduate students (M age: 25.5 years; range: 17 to 54 years) volunteered to participate for points in a psychology course. Twenty-two subjects were Caucasian, seven were Asian, and one was Black.

Stimuli

The facial stimuli consisted of 30 colour slides of female faces varying in the height of their internal features (i.e., 10 faces x 3 versions). See the text (Section 2.3: Experiment 3, Stimuli) for details of the procedure used to create the faces. Each face was shown lifesize, individually, and in the center of the projection screen. I created 30 random orders and each adult saw the faces in a different order, without replacement. A constraint on the orders was that two versions of the same face were never shown on consecutive trials.

Apparatus and Procedure

The apparatus and procedure were identical to those used in my studies of adults' aesthetic ratings of faces presented individually (e.g., Appendix 2).

Selection of Final Stimuli

Adults' mean attractiveness ratings were subjected to an ANOVA with two within-subjects factors (feature height, face example). The ANOVA showed significant main effects of features' height, $\underline{F}$ (2,58) = 82.36, $\underline{p} < 0.001$ and face example, $\underline{F}$ (9,261) = 9.99, $\underline{p} < 0.001$, and a significant interaction between feature height and face example, $\underline{F}$ (18,522) = 6.08, $\underline{p} < 0.001$, on adults' ratings of attractiveness. Analyses of simple effects did not reveal the source of the interaction between features' height and face example: there was a significant effect of the features' height for each of the 10 faces (all $\underline{p}$s < 0.01) and a significant effect of face example at low height ($\underline{p} < 0.05$), medium height ($\underline{p} < 0.001$), and at high height ($\underline{p} < 0.001$). Adults rated the faces with their features at the medium or low height as more attractive than the faces with their features at the high height, and they rated the faces with their features at the medium height as more attractive than the faces with their features at the low height (Tukey, $\underline{p}$s < 0.01).

The six examples of faces selected as final stimuli were those for which the version with high height received the lowest ratings of attractiveness and the version with medium height received the highest ratings, with minimal variability among raters. They are illustrated in Figure 8.

Appendix 9

Photographing Digitized Faces

Black-and-white computer-digitized images of Caucasian male and female faces were taken for the study of face processing skills (e.g., matching faces' identity, facial expressions, direction of gaze) in patients with a history of early visual deprivation and normal adults and children (Chapter 3). Models were students from McMaster University, all under the age of 28. Models were photographed posing with various expressions of emotion, vowel sounds, and head and gaze orientations. To eliminate external cues that could be used to distinguish between faces, the models wore a cloth draped around their shoulders and chest and a cap to cover their hair and ears, and they removed any paraphernalia (e.g., earrings, glasses). To eliminate differences in the facial images in size and/or colouring, models were photographed from a standard distance and with the same background and lighting.

Photoshoot Apparatus

The equipment for picture-taking was assembled in a room in the psychology building at McMaster University. A chair for the model to sit in was placed one meter in front of a grey backdrop (0.4 m wide x 0.4 m high). Photographs were taken with a Chinon ES-3000 electronic still camera fitted with a 3X zoom lens and preset for maximum superfine resolution quality, 8-bit (640 x 480 pixels) digitized images. The camera, which was held by a tripod stand (one meter high), was positioned one meter in front of the chair.

For lighting, I used one flash bulb (110v) attached to a 10 cm diameter aluminum reflecting umbrella. The flash unit was mounted on a flash stand (one meter high) and placed directly behind the camera. To diffuse the light and minimize shadows and highlights on the model's face, the flash bulb was directed towards a light-coloured wall behind the camera rather than the model's face.

Procedure

Male and female undergraduate students who were Caucasian and under the age of 28 participated as models, either for payment of five dollars or for credit in a psychology course. Male models were asked to be clean-shaven. All models read and signed a model release/consent form. They also read a handout that explained the purpose of the photoshoot.

Models were photographed individually. The photographer asked the model to remove articles from the head region (i.e., glasses, earrings, hats), and female models were asked to remove facial make-up (i.e., blush, lipstick) with a tissue.* When the model was seated, the photographer draped a grey cloth around the shoulders and covered the hair and ears with a light blue surgical cap. As the model directed his/her head toward the camera, the photographer viewed the face through the viewfinder and adjusted its height

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*Due to the large volume of models being photographed, the role of photographer was shared between myself and a research associate at the Vision Laboratory, Dr. Mondloch.

(from the top of the forehead to the bottom of the chin) with the zoom lens. Markers on the viewfinder were used to make the height of all faces the same.

Each model was photographed as he/she posed in one neutral pose, with the head and eyes facing the camera and with a neutral facial expression. Each model was also asked to pose in three or four non-neutral poses that consisted of various head orientations (e.g., 45° to the left, 45° up), gaze/head directions (e.g., eyes and head 30° to the left, eyes en face and head 30° to the right), facial expressions (e.g., surprise, disgust), and expressions of vowel sounds (e.g., pronouncing a or u). Red markers, held by pieces of string from the ceiling, were used to assist the model to orient his/her head 45° to the right, to the left, and above the camera. One marker was taped to the tripod stand 45° below the camera to guide the model to orient the head 45° downwards. Additional markers were used for the poses involving different combinations of gaze and head orientations: one marker was placed 30° to the left of the camera, the other marker 30° to the right. For poses of expressions of emotion (i.e., happy, disgust, surprise) and the pronounciation of vowels (i.e., a, e, u), the photographer modelled each pose before picture-taking. So that surprise would be distinct from the happy expression, the photographer usually repeated these expressions and, in some cases, encouraged the model to not turn the mouth upward (as a smile) for the expression of surprise.

After picture-taking, the model was asked to wait while the digitized images were downloaded from the camera onto the computer and viewed. When one or more images did not turn out, the model was re-photographed. The model was then explained how the pictures were going to be used for study and reimbursed for participating.

Appendix 10

Shoes for the Non-Facial Screening Task

I created a shoe-screening task designed to assess subjects' capabilities to match shoes. The shoe task was administered at the end of faces' testing, and only to those subjects who failed the face screening task and the five tasks of face matching. Details of the shoe stimuli and the task of matching shoes are described below.

Creating Shoe Stimuli

The shoe stimuli were created from black-and-white photographs of shoes taken from a previous study of shoe recognition in autistic children (Gepner et al., submitted). The shoes consisted of various styles of men's loafers, women's pumps, and children's sandals. The shoes were photographed individually, using the same viewing distance, lighting, and background, and displayed in a horizontal orientation—with the toe of the shoe presented towards the left and the heel presented towards the right. Each photograph was computer digitized using a Microtek Color Scanner and Macintosh LC 475 computer. All digitized images were then viewed on a 21" black-and-white Radius 21-GS monitor using Photoshop software. Photoshop was also used to crop the pictures so that each image measured 12.5 cm wide and 7.5 cm high.

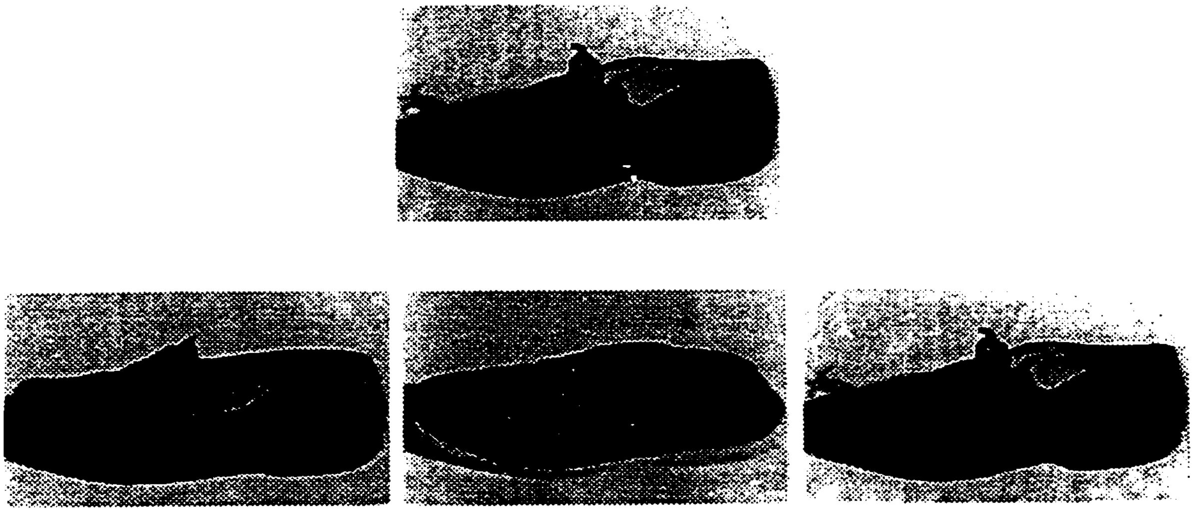
Description of the Shoe Task

There were six test trials. Each trial used three shoes that were matched on the basis of similarity in shading, size, and style (i.e., loafer vs. pump). On each trial, one shoe was shown near the top of the computer screen for two seconds. Following an inter-stimulus interval of 200 ms, three test shoes were presented side-by-side near the bottom of the screen. On each trial, the subject chose the shoe that matched the original by moving a joystick to the left, middle, or right. The test shoes disappeared from the screen once a response was made. See the attached figure for an illustration of the three shoes used on a typical test trial.

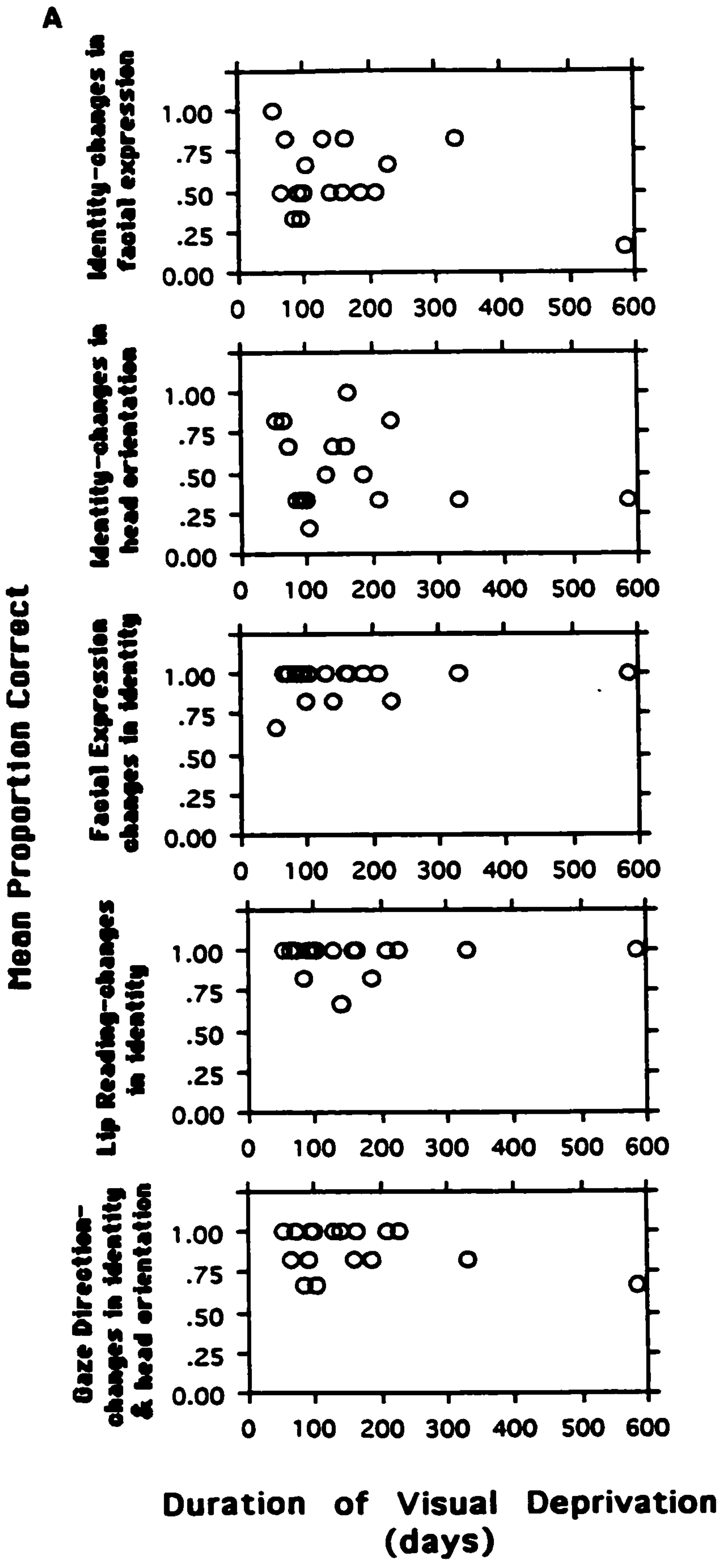
The shoe task began with three practice trials. During the first practice trial, the target shoe was shown until the tester pressed the spacebar, and then called for the test shoes by a second spacebar press. During the second and all subsequent trials, the tester pressed the spacebar only once to call for the target shoe for two seconds and then the test stimuli. The second practice trial was repeated for subjects who had trouble.

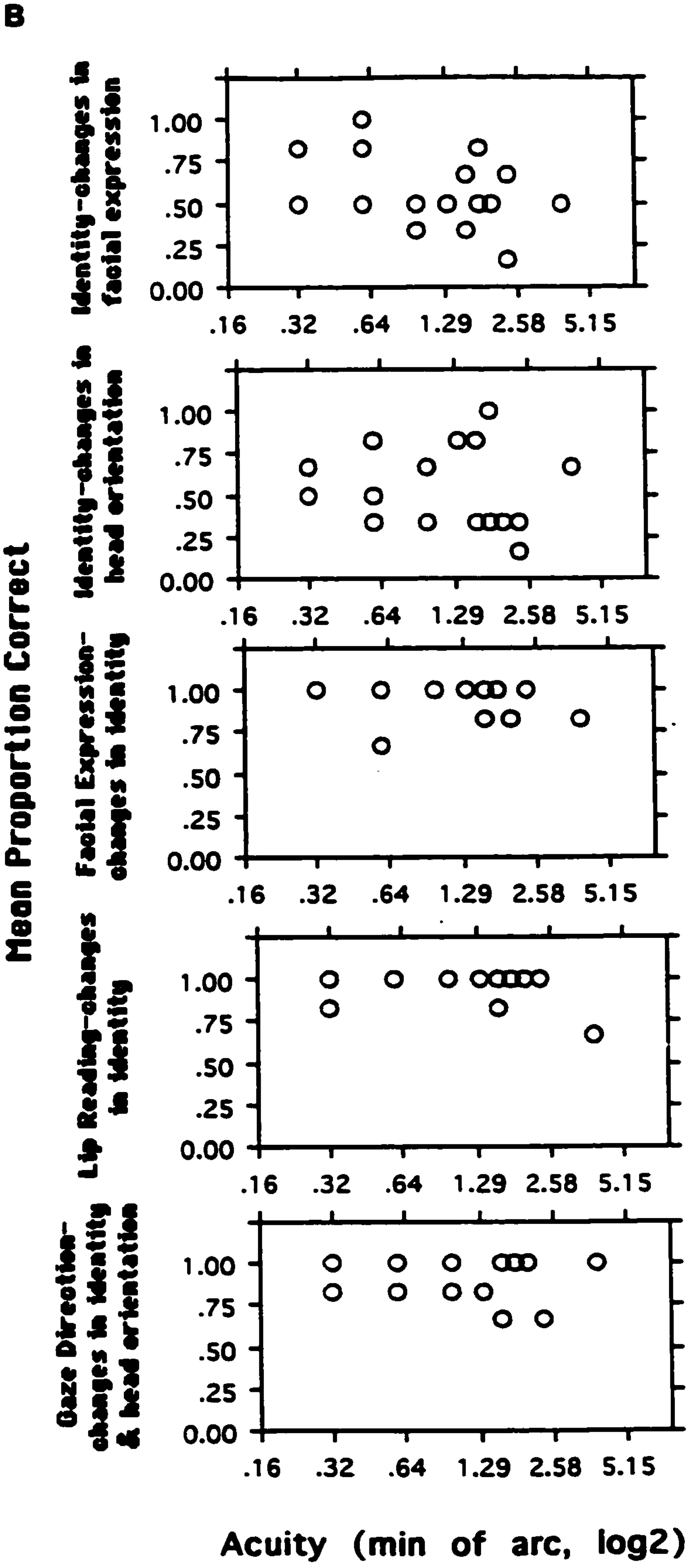
Instructions for Shoe Matching

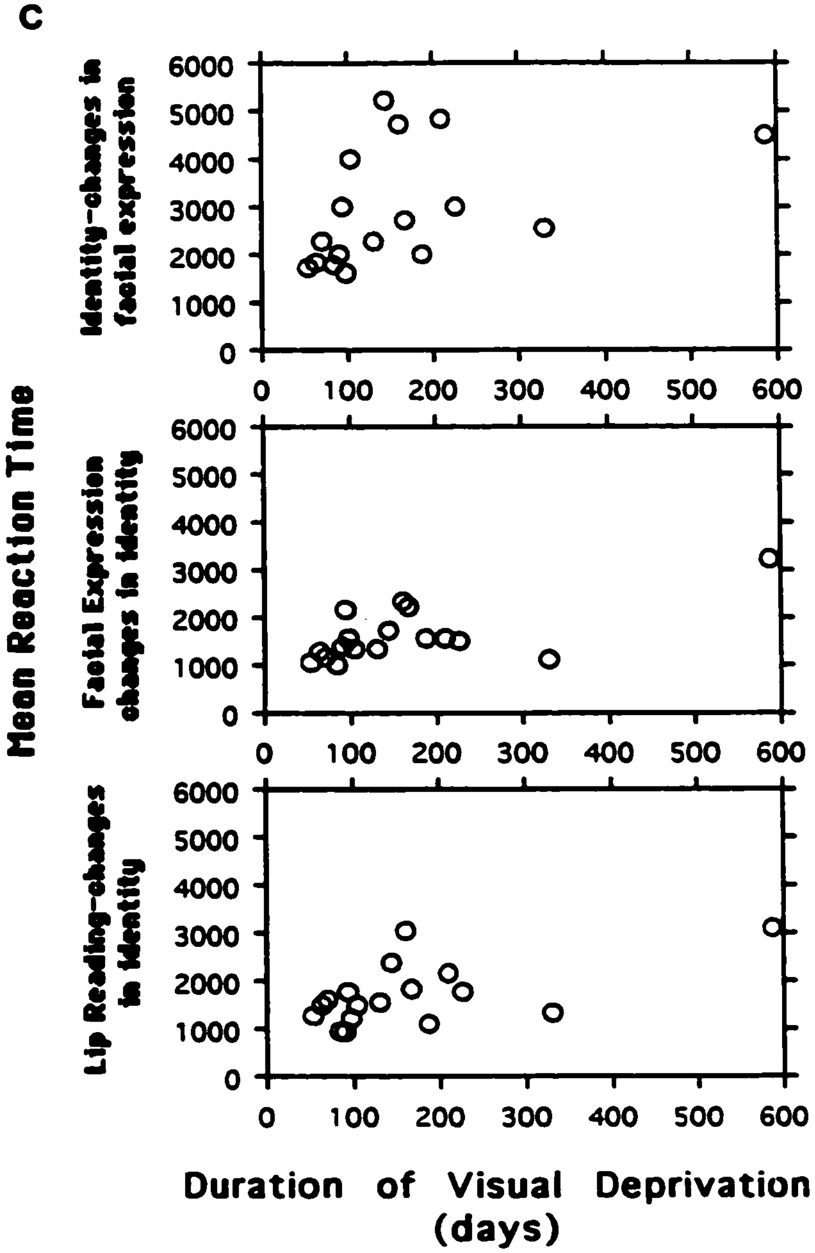
The tester explained that the task involved looking at shoes instead of people's faces. The tester described the task as follows: "You will first see one shoe near the top of the screen for a short time. Then you will see three shoes in a row near the bottom. Your job is to find the same shoe that you saw before. As you did with the other tasks, you will make your response by moving the joystick to the left, middle or to the right." The tester emphasized accuracy but asked that the subject try to respond as fast as possible.

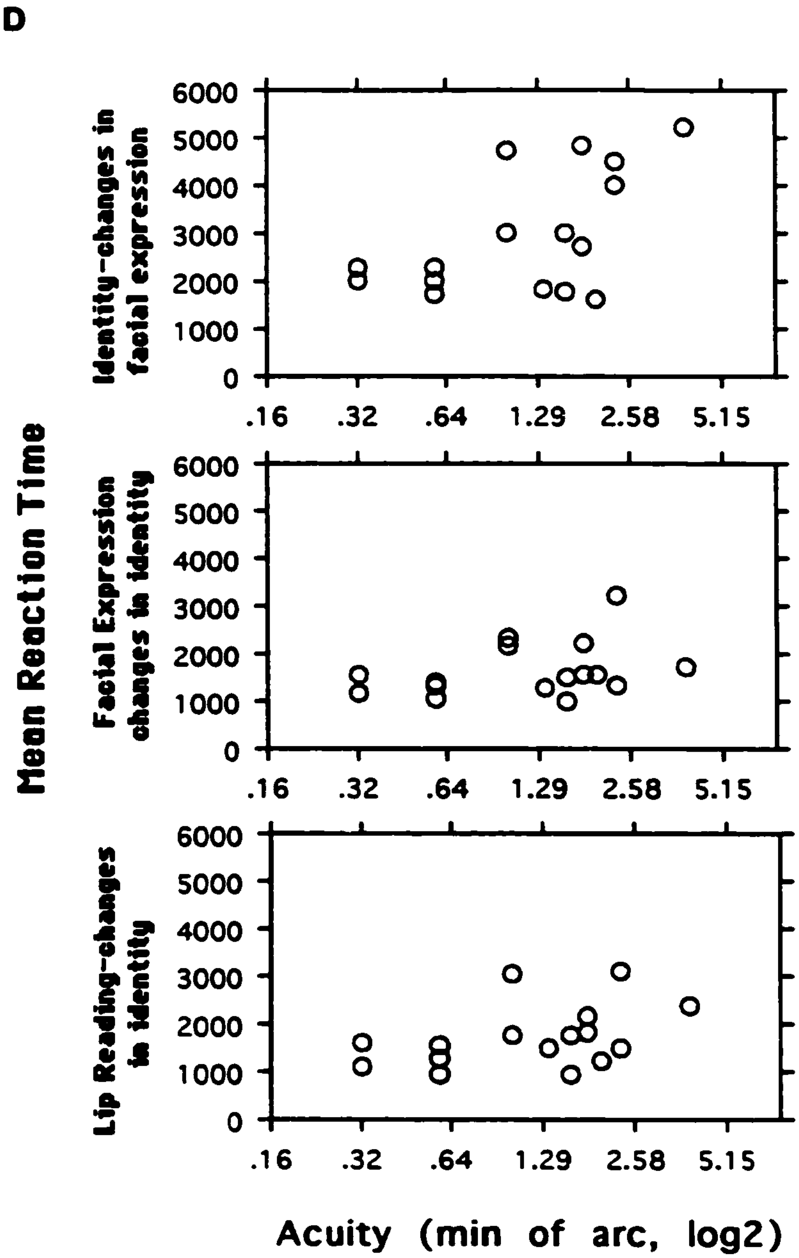


Appendix 11


A
Mean Proportion Correct
Identity-changes in facial expression
Identity-changes in head orientation
Facial Expression changes in Identity
Lip Reading-changes in Identity
Gaze Direction-changes in Identity & head orientation
0.00
.25
.50
.75
1.00
0
100
200
300
400
500
600
Duration of Visual Deprivation (days)

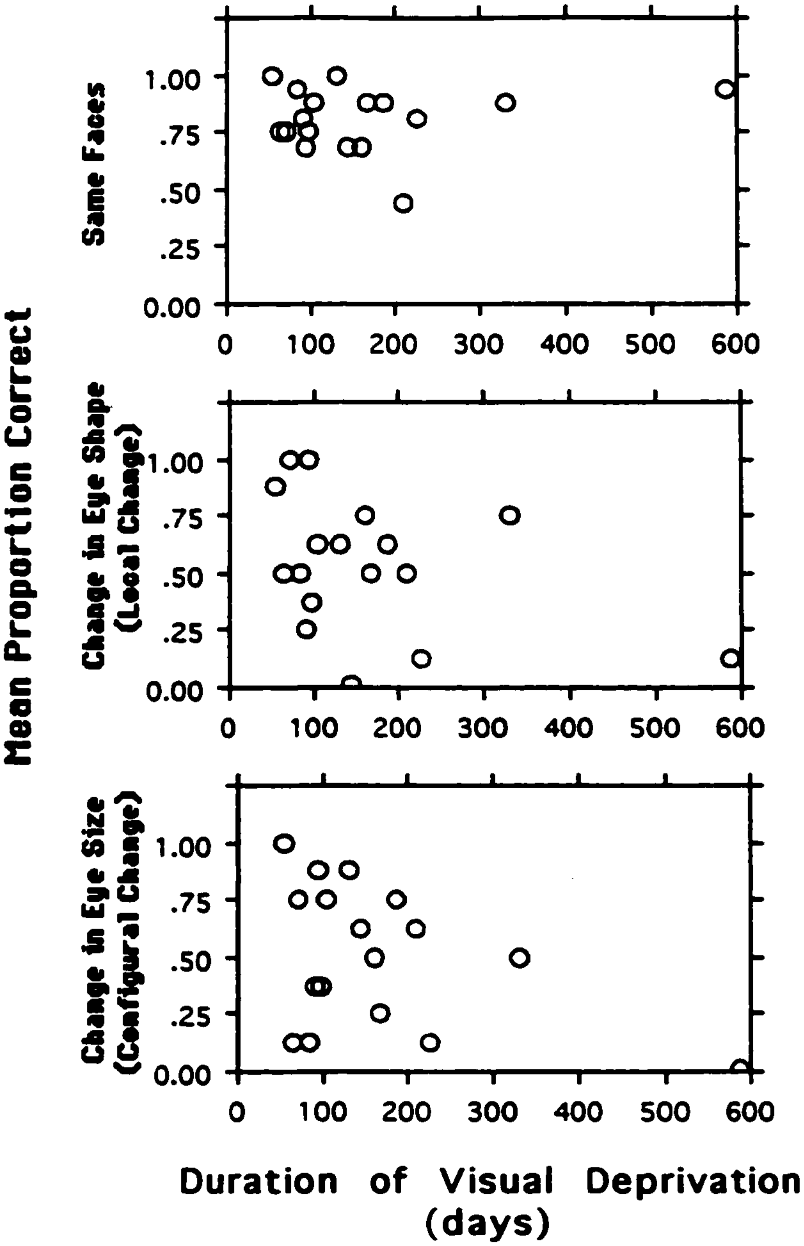

B
Mean Proportion Correct
Identity-changes in facial expression
Identity-changes in head orientation
Facial Expression-changes in identity
Lip Reading-changes in identity
Gaze Direction-changes in identity & head orientation
1.00
.75
.50
.25
0.00
.16
.32
.64
1.29
2.58
5.15
Acuity (min of arc, log2)


C
Mean Reaction Time
Identity-changes in facial expression
Facial Expression changes in Identity
Lip Reading-changes in Identity
0
1000
2000
3000
4000
5000
6000
0
100
200
300
400
500
600
Duration of Visual Deprivation (days)

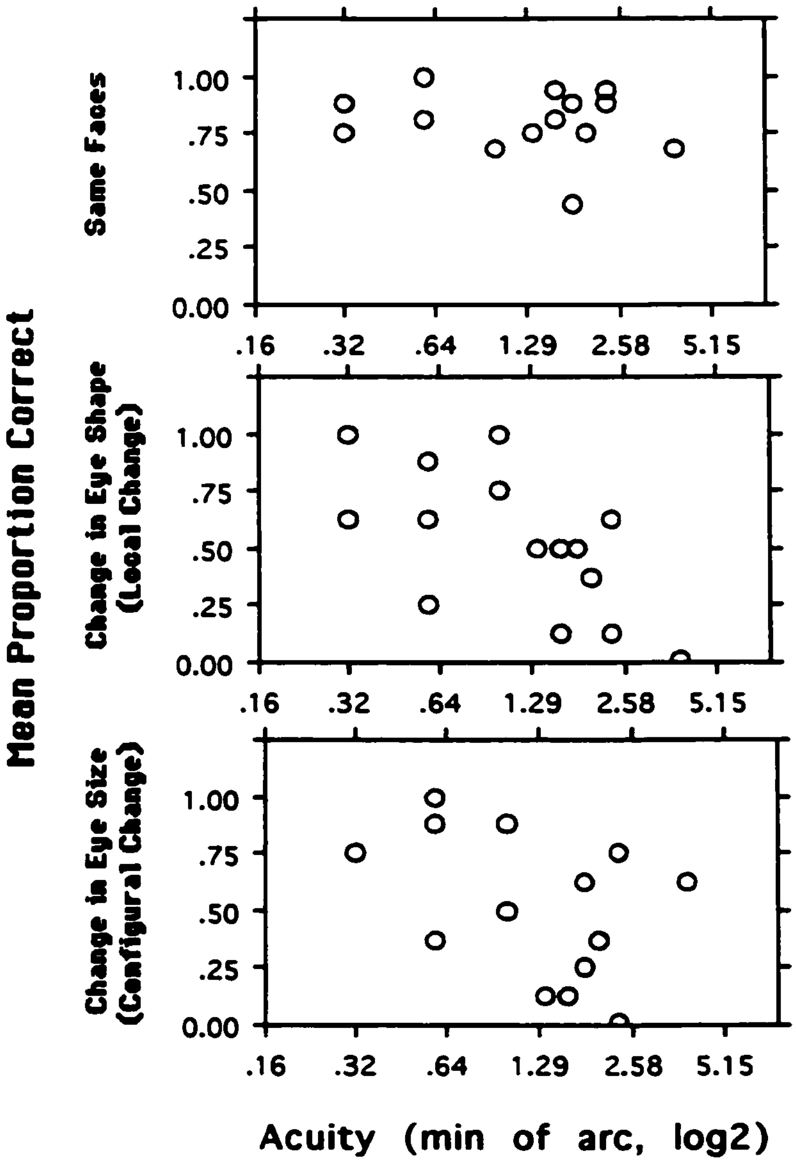

D
Mean Reaction Time
Identity-changes in facial expression
Facial Expression changes in identity
Lip Reading-changes in identity
6000
5000
4000
3000
2000
1000
0
.16
.32
.64
1.29
2.58
5.15
Acuity (min of arc, log2)

Appendix 12

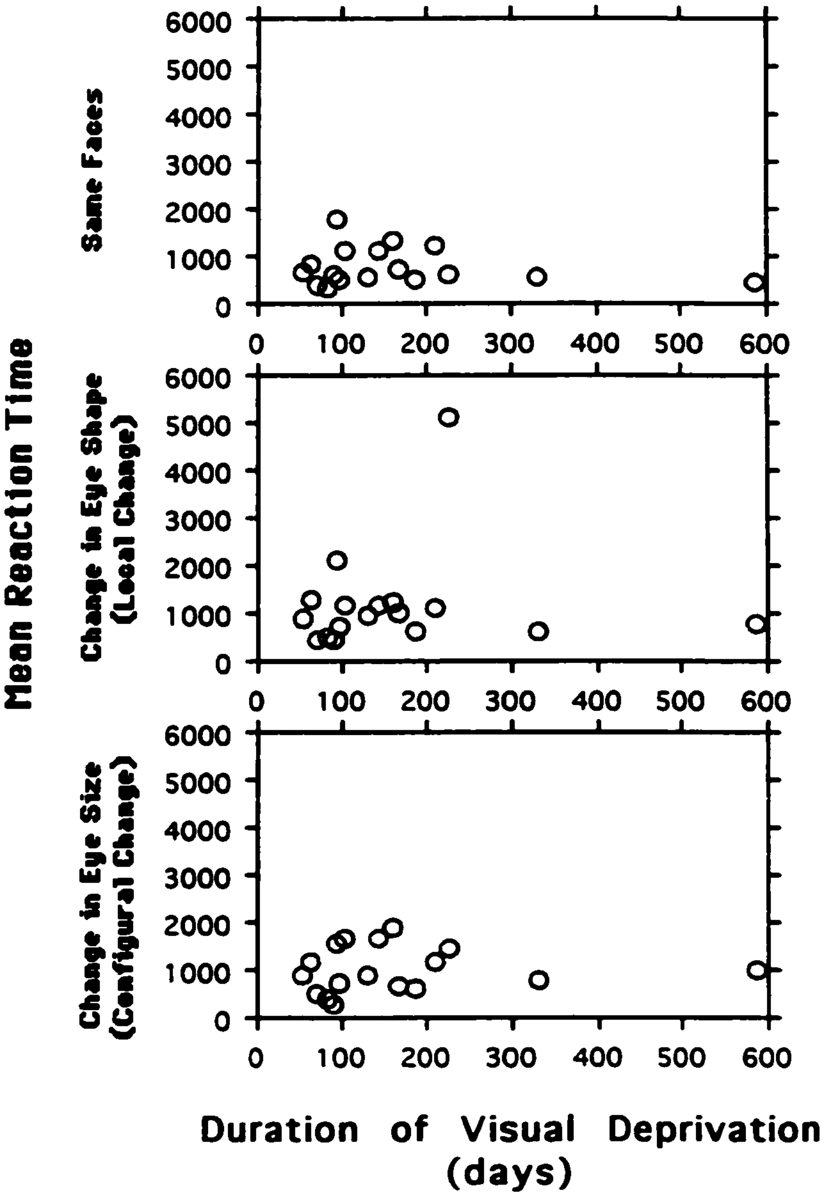
A


Mean Proportion Correct
Same Faces
1.00
.75
.50
.25
0.00
0
100
200
300
400
500
600
Change in Eye Shape (Local Change)
1.00
.75
.50
.25
0.00
0
100
200
300
400
500
600
Change in Eye Size (Configural Change)
1.00
.75
.50
.25
0.00
0
100
200
300
400
500
600
Duration of Visual Deprivation (days)

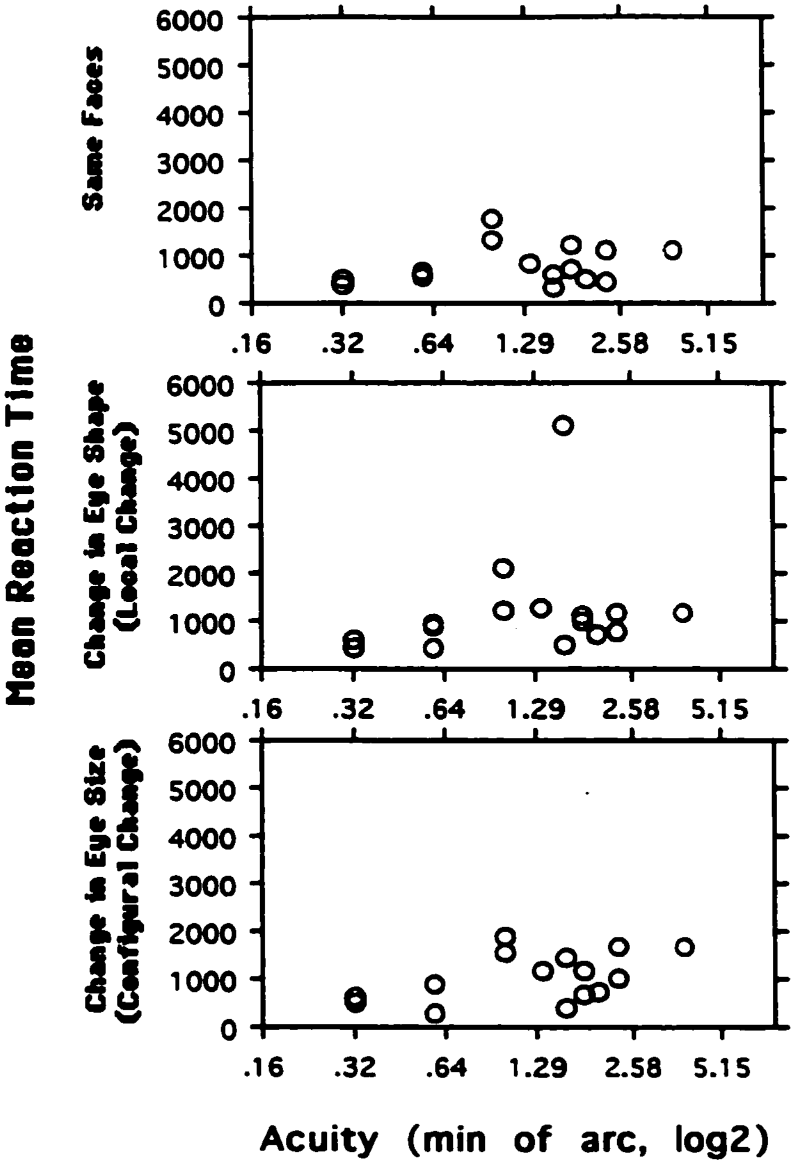
B


Mean Proportion Correct
Same Faces
Change in Eye Shape (Local Change)
Change in Eye Size (Configural Change)
1.00
.75
.50
.25
0.00
.16
.32
.64
1.29
2.58
5.15
Acuity (min of arc, log2)

C

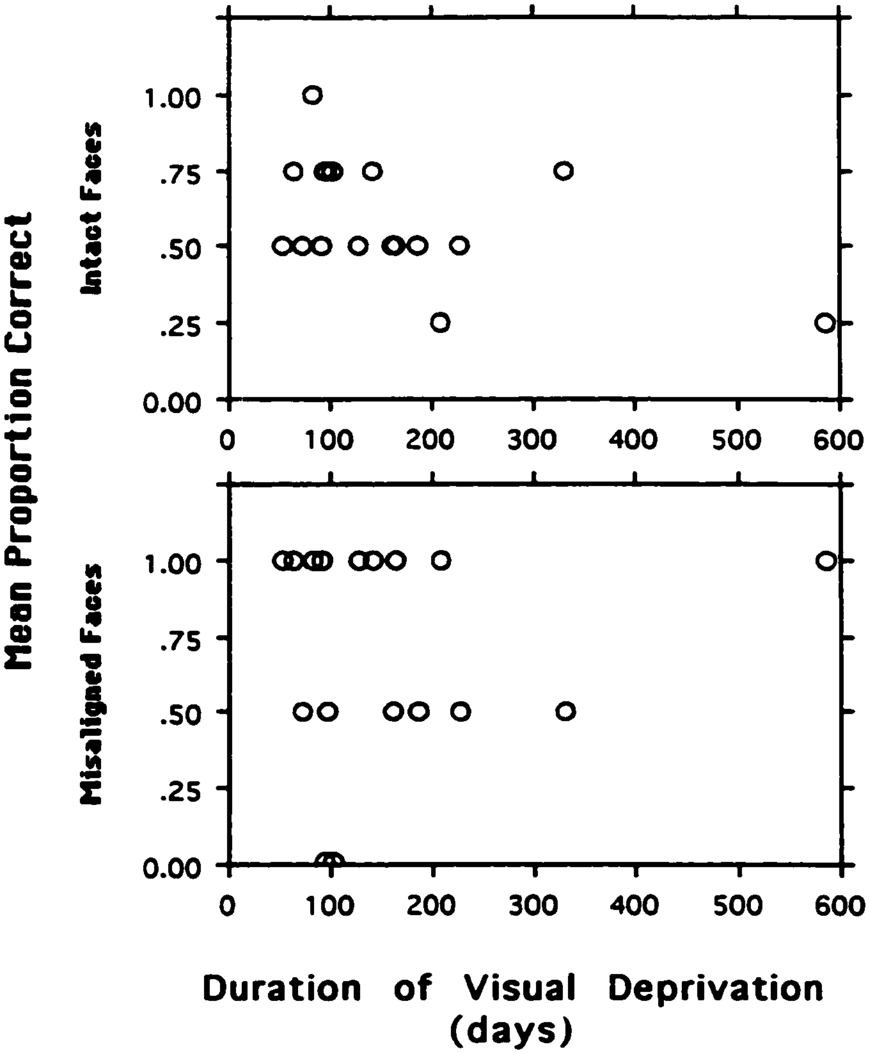

Mean Reaction Time
Same Faces
Change in Eye Shape (Local Change)
Change in Eye Size (Configural Change)
6000
5000
4000
3000
2000
1000
0
0
100
200
300
400
500
600
Duration of Visual Deprivation (days)

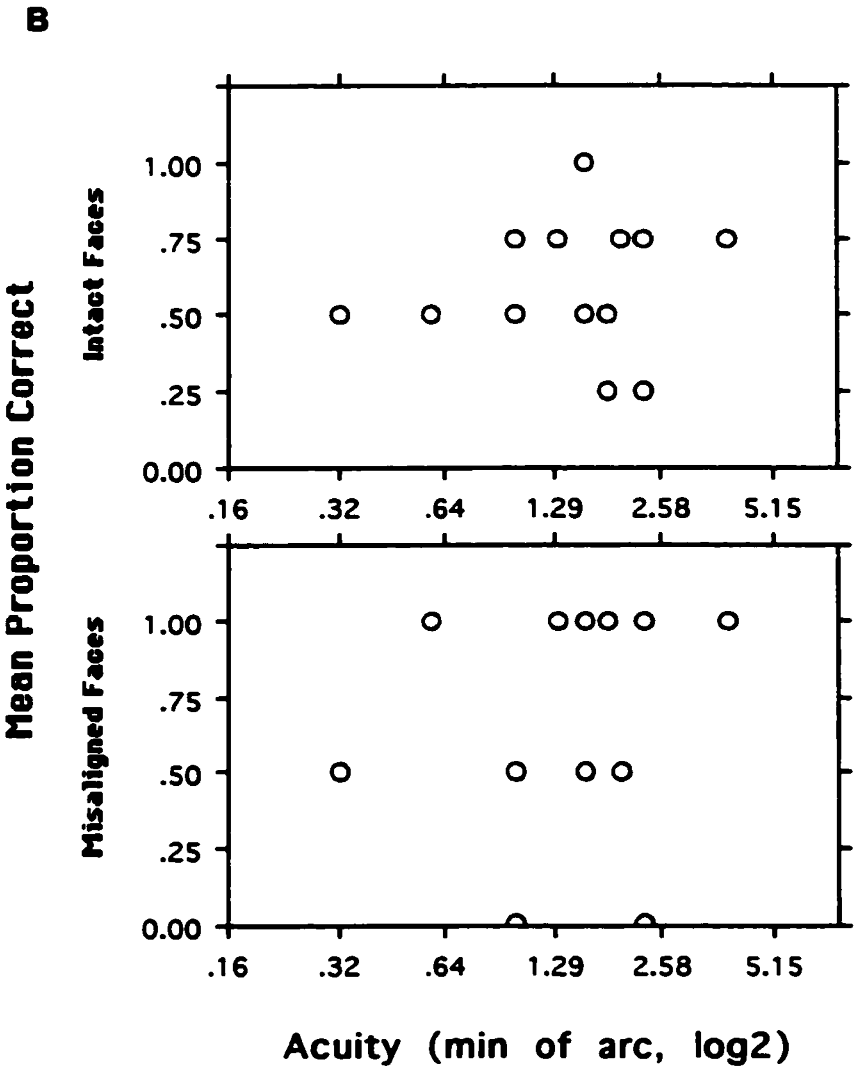
D


Mean Reaction Time
Same Faces
Change in Eye Shape (Local Change)
Change in Eye Size (Configural Change)
6000
5000
4000
3000
2000
1000
0
.16
.32
.64
1.29
2.58
5.15
Acuity (min of arc, log2)

Appendix 13

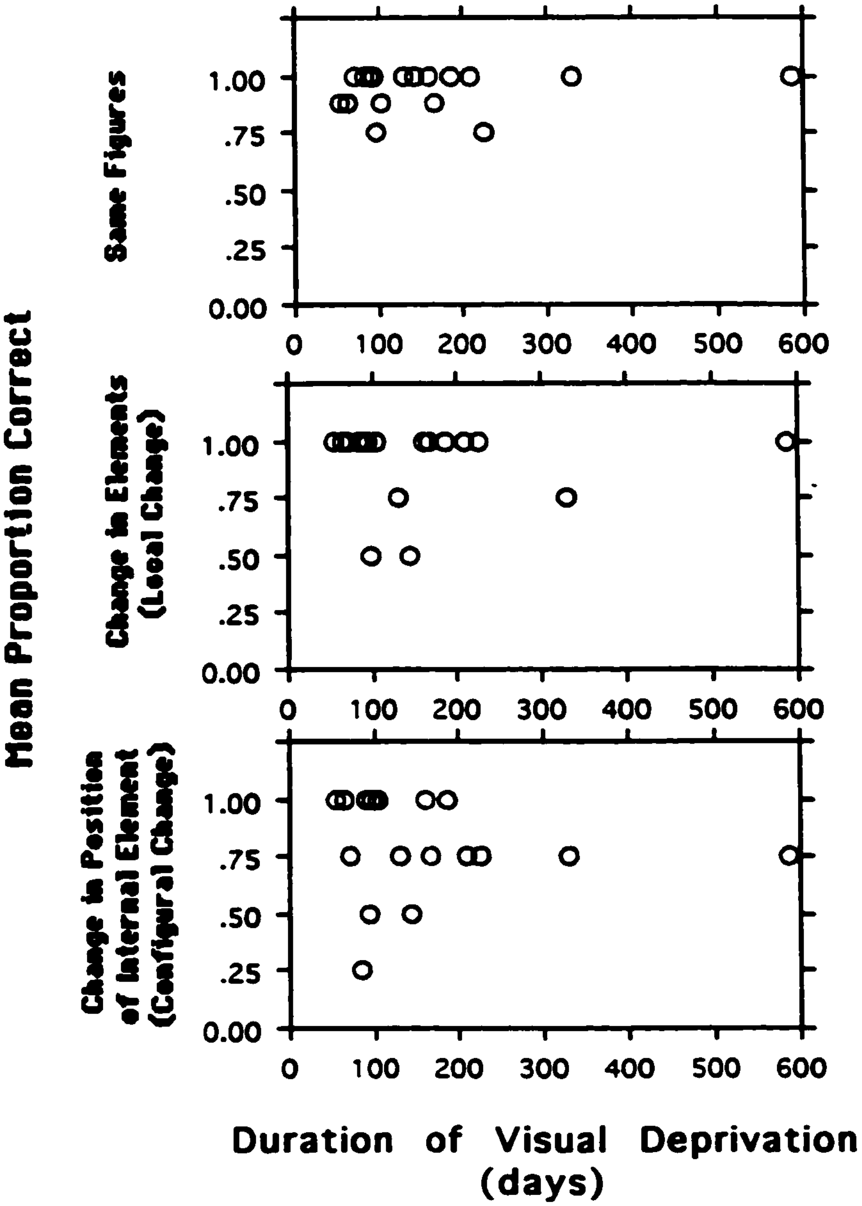
A

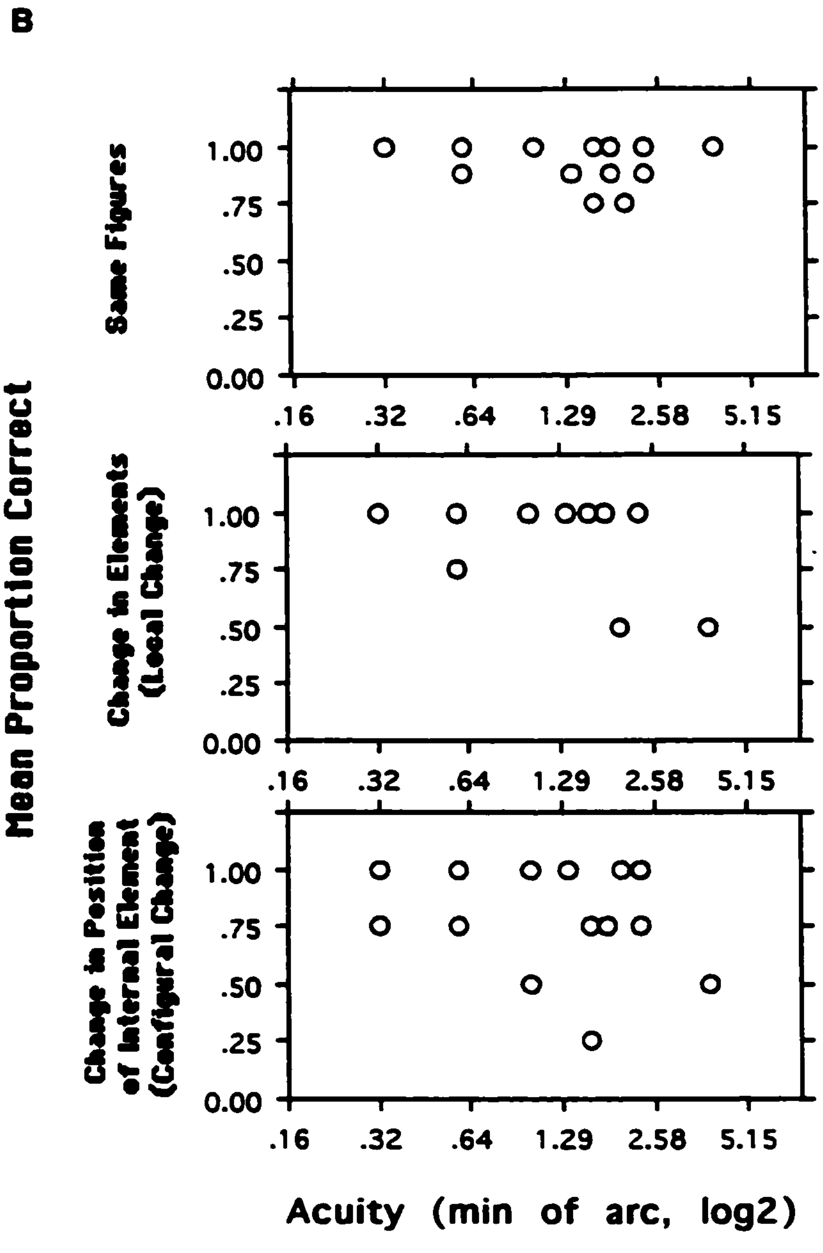

Mean Proportion Correct
Intact Faces
Misaligned Faces
1.00
.75
.50
.25
0.00
0
100
200
300
400
500
600
Duration of Visual Deprivation
(days)


B
Mean Proportion Correct
Intact Faces
Misaligned Faces
1.00
.75
.50
.25
0.00
.16
.32
.64
1.29
2.58
5.15
Acuity (min of arc, log2)

Appendix 14

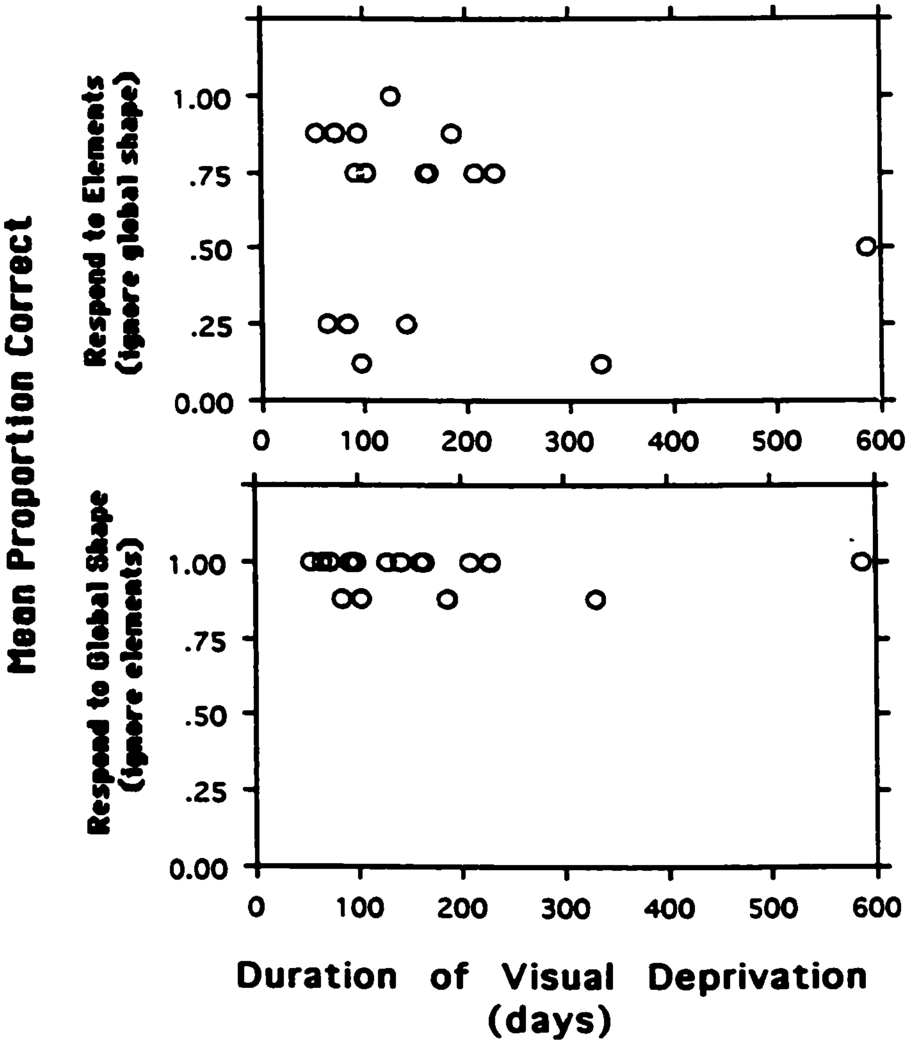
A

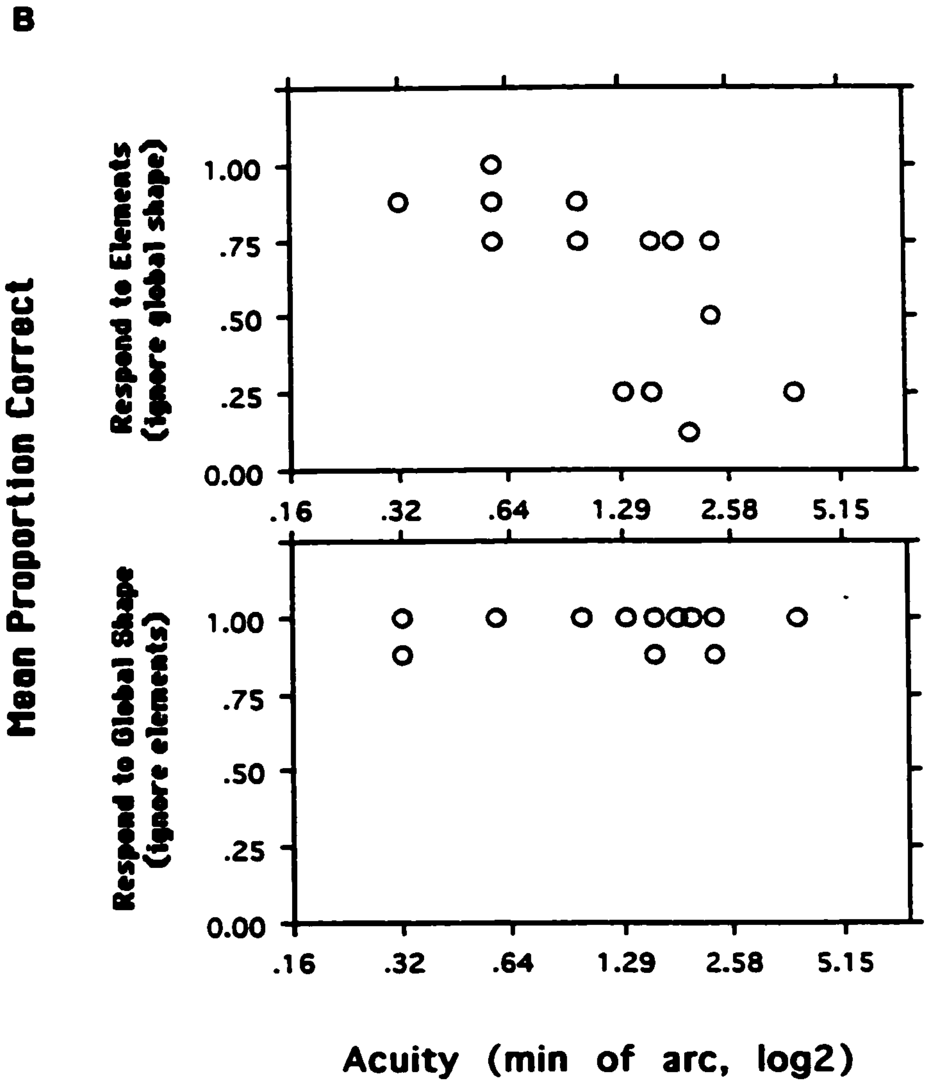

Mean Proportion Correct
Same Figures
Change in Elements (Local Change)
Change in Position of Internal Element (Configural Change)
1.00
.75
.50
.25
0.00
0
100
200
300
400
500
600
Duration of Visual Deprivation (days)


B
Mean Proportion Correct
Same Figures
Change in Elements (Local Change)
Change in Position of Internal Element (Configural Change)
1.00
.75
.50
.25
0.00
.16
.32
.64
1.29
2.58
5.15
Acuity (min of arc, log2)

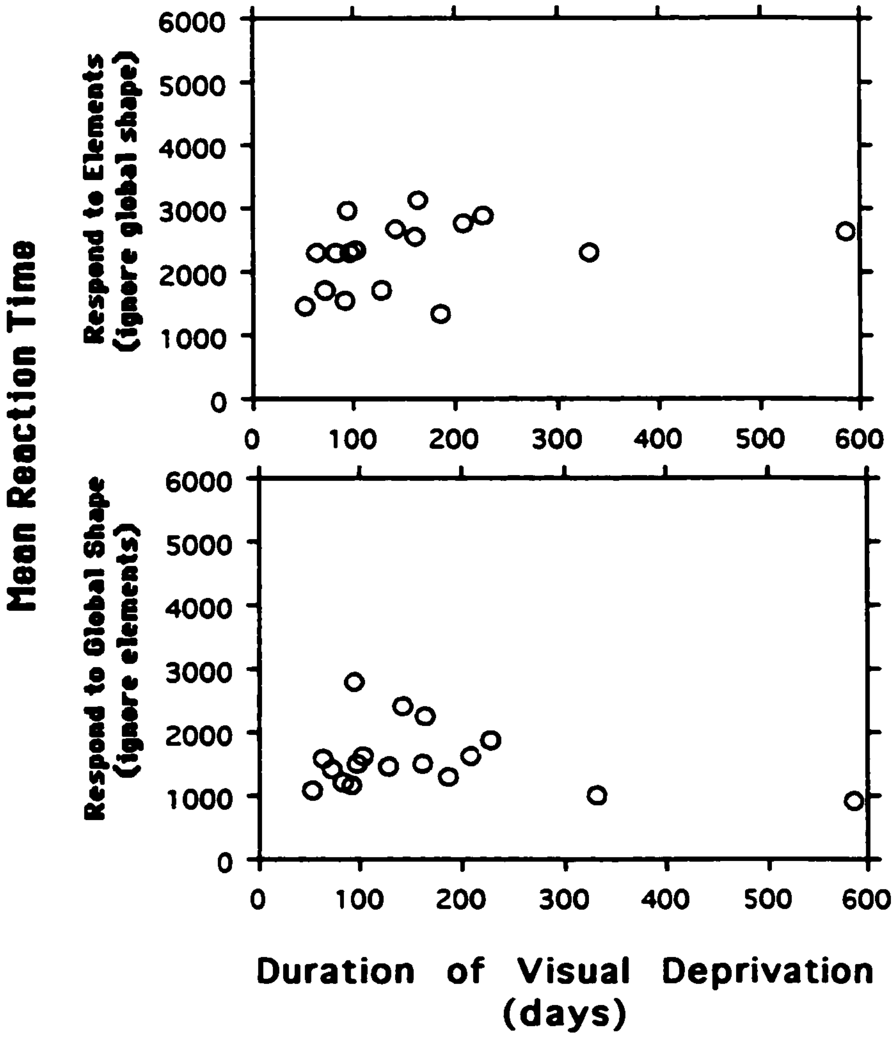
Appendix 15

A

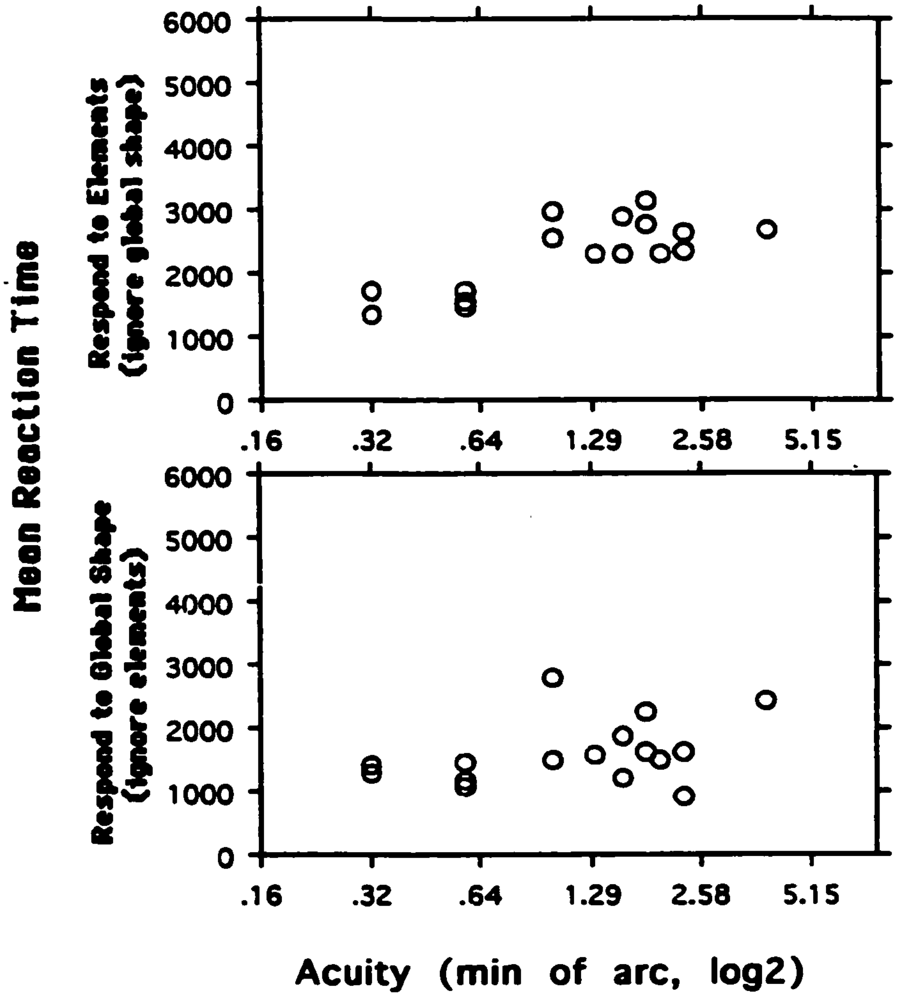

Mean Proportion Correct
Respond to Elements (ignore global shape)
Respond to Global Shape (ignore elements)
1.00
.75
.50
.25
0.00
0
100
200
300
400
500
600
Duration of Visual Deprivation (days)


B
Mean Proportion Correct
Respond to Elements (ignore global shape)
Respond to Global Shape (ignore elements)
1.00
.75
.50
.25
0.00
.16
.32
.64
1.29
2.58
5.15
Acuity (min of arc, log2)

C


Mean Reaction Time
Respond to Elements (ignore global shape)
Respond to Global Shape (ignore elements)
0
1000
2000
3000
4000
5000
6000
0
100
200
300
400
500
600
Duration of Visual Deprivation (days)

D


Mean Reaction Time
Respond to Elements (ignore global shape)
Respond to Global Shape (ignore elements)
6000
5000
4000
3000
2000
1000
0
.16
.32
.64
1.29
2.58
5.15
Acuity (min of arc, log2)