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XXIII CICLO

HOW THE ADULT SOCIAL BRAIN BECOMES THE WAY IT IS. THE ORIGIN AND THE DEVELOPMENTAL TIME COURSE OF FACE PROCESSING

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A mia madre, a mio padre e a mia sorella Erica,

che hanno permesso la realizzazione di questo traguardo

"William James once stated that the perceptual world
of the infant must be a "blooming, buzzing confusion".
What our research and other research on infants has
indicated is that the infant's world may be a bit more
blooming and a bit less buzzing than James has suspected".

L. B. Cohen, 1972

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Riassunto

Uno dei problemi fondamentali nello studio dello sviluppo cognitivo è comprendere come la cognizione emerga e quali siano i cambiamenti a cui essa va incontro nel corso dello sviluppo per raggiungere il livello maturo osservato negli adulti. Una grande sfida per tutti i ricercatori dello sviluppo riguarda il riuscire a determinare quali sono le abilità e le predisposizioni che il neonato possiede alla nascita, a comprendere i processi cognitivi che mette in atto per acquisire la conoscenza del mondo che lo circonda, e a studiare se e come tali predisposizioni si modificano in funzione dell'esperienza durante il corso dello sviluppo. Poichè è stato dimostrato che il volto è uno stimolo speciale per gli adulti, in quanto elaborato da aree neurali (Kanwisher, 2000) e da processi percettivi specifici e diversi da quelli utilizzati per l'elaborazione degli oggetti (Farah, Wilson, Drain, & Tanaka, 1998), lo studio dell'origine e dello sviluppo della capacità di elaborare tale stimolo risulta essere funzionale allo studio di un processo di specializzazione cognitiva.

In quest'ottica, la presente tesi di dottorato vuole essere un contributo allo studio della specializzazione funzionale del sistema umano per l'elaborazione del volto nei primi mesi di vita, con particolare riferimento alle modificazioni che il sistema subisce nella rappresentazione ed elaborazione di tale stimolo in funzione dell'esperienza. In particolare, i cambiamenti evolutivi a cui va incontro il sistema cognitivo per raggiungere il livello maturo osservato negli adulti sono stati esaminati confrontando in modo diretto le prestazioni di neonati, bambini di tre e sei mesi ed adulti attraverso l'utilizzo degli stessi paradigmi di ricerca (ricerca visiva, composite face paradigm). L'ipotesi su cui si basa questo lavoro è che la specializzazione cognitiva per il volto umano osservata negli adulti non sia presente alla nascita, ma sia il prodotto di un processo di sviluppo continuo e

dinamico in cui l'esperienza esperita nell'ambiente di vita specie-specifico gioca un ruolo fondamentale (Nelson, 2001, 2003; Johnson, 1993).

I primi due capitoli sono a carattere teorico: nel Capitolo 1 viene descritto l'approccio Neocostruttivista, considerato il quadro teorico di riferimento entro cui si inseriscono gli esperimenti presenti nella tesi, e viene spiegato il motivo per cui viene scelto il volto come stimolo paradigmatico per lo studio della specializzazione cognitiva. Nel Capitolo 2 viene invece discussa la specificità, neurale e funzionale, del sistema per l'elaborazione del volto negli adulti. Vengono riportati inoltre due modelli teorici fondamentali per la comprensione dell'abilità di elaborazione di tale stimolo negli adulti.

Nella seconda parte della tesi sono presentati i tre studi principali che la costituiscono la tesi e che hanno lo scopo di studiare le origini e il corso dello sviluppo della capacità di percepire e di riconoscere un volto umano (Capitoli 3, 4, e 5).

Nello Studio 1 (Capitolo 3), attraverso l'utilizzo della preferenza e dell'abituazione visiva, è stata indagata la natura della rappresentazione del volto alla nascita e nei primi mesi di vita. In linea con l'idea che la rappresentazione del volto si specializzi grazie all'esperienza visiva con tale stimolo nei primi tre mesi di vita (Turati, Valenza, Leo, & Simion, 2005), i risultati degli esperimenti dimostrano che alla nascita tale rappresentazione è di natura generale, mentre a 3 mesi essa diventa più specifica per questo particolare tipo di stimolo (Esperimenti 1, 2 e 3). Inoltre, gli Esperimenti 4, 5 e 6 dimostrano che la rappresentazione del volto alla nascita non è specie-specifica, in linea con l'ipotesi che il neonato entra a far parte del mondo con una rappresentazione del volto abbastanza generale da permettergli di percepire un volto umano e un volto di scimmia come appartenenti alla stessa "categoria volto". E' solo a 3 mesi, grazie all'esperienza visiva con tale stimolo, che tale rappresentazione diventa specifica per il volto umano (Nelson, 2001; Pascalis & Kelly, 2009).

Lo scopo dello Studio 2 (Capitolo 4) è stato quello di studiare se la preferenza per il volto osservata in contesti semplici (i.e., presentazione di soli due stimoli) potesse essere osservata anche in contesti complessi, quindi più ecologici. I movimenti oculari di bambini di tre e sei mesi e adulti sono stati registrati attraverso un sistema di eye-tracker durante un compito di ricerca visiva. È stato indagato se bambini di pochi mesi sono in grado di percepire ed identificare in modo efficiente un volto umano quando inserito in contesti complessi, ossia tra oggetti (i.e., stimoli distrattori eterogenei, Esperimenti 8, 9 e 10) e tra volti invertiti (i.e., stimoli distrattori omogenei, Esperimenti 11 e 12). I risultati hanno dimostrato come il volto umano è in grado di catturare e mantenere l'attenzione di adulti e bambini di sei mesi quando è inserito fra distrattori eterogenei, mentre tale stimolo cattura e mantiene l'attenzione dei bambini di tre mesi solo quando è inserito tra distrattori omogenei. Tali risultati sono in linea con gli studi che hanno dimostrato che il volto cattura l'attenzione dei bambini di pochi mesi di vita quando si trova in contesti complessi (Gliga, Elsabbagh, Andravizou, & Johnson, 2009).

Per percepire il volto target in contesti complessi, i bambini hanno dovuto elaborare il volto come una unità complessa, una Gestalt (Tanaka & Farah, 1993). Questo tipo di strategia di elaborazione del volto viene definita olistica e lo scopo dello Studio 3 (Capitolo 5) è stato quello di studiarne l'origine e lo sviluppo in neonati, bambini di tre mesi e adulti utilizzando lo stesso compito chiamato "composite face paradigm" (Young, Hellawell, & Hay, 1987) (Esperimenti 13, 14 e 15). I risultati dimostrano che, sebbene i primi segni della capacità di elaborare un volto come un'unità complessa si osservano in bambini di pochi mesi di vita, tuttavia è necessaria l'esperienza visiva per raffinare tale tipo di elaborazione del volto.

Complessivamente, i dati presentati in questa tesi sono in linea con l'idea che la specificità del sistema cognitivo per l'elaborazione del volto umano non sia presente alla nascita, ma sia invece il risultato di un processo di sviluppo, in cui giocano un ruolo fondamentale sia le predisposizioni innate del neonato, sia l'esperienza visiva esperita nel proprio ambiente di vita specie-specifico nei primi mesi di vita.

Abstract

One central issue in cognitive developmental science is to understand how cognition grows and change over time to reach an adult level of specialization. Determining the abilities with which infants come equipped into the world, their mechanisms for acquiring knowledge, and whether and how these abilities change as a function of development and experience is a challenging issue. Face processing is an interesting topic of research in that respect because faces form a special class of visual objects elaborated in adults by a specific anatomical and functional face system (e.g., Kanwisher, 2000; Farah, Wilson, Drain, & Tanaka, 1998). Since what determines this specialization and how this specialization emerges during development still remain unknown, the purpose of my PhD dissertation is to study cognitive specialization during early infancy through the investigation of the development of infants' abilities to process faces. In particular, my hypothesis is that the face processing specificity is not present at birth, but emerges gradually from the interaction between general constraints and attentional biases present in the first months of life and the critical visual input provided by the specie-specific environment (Nelson, 2001, 2003; Johnson, 1993).

With this consideration in mind, my thesis begins with two theoretical chapters: *Chapter 1* describes a neoconstructivistic approach to the emergence of cognition as the theoretical framework and discuss the specialty of the face stimulus for humans, whereas *Chapter 2* is about the specificity of the face processing system in adults and I review two theoretical models of face processing and the neural bases underlying this skill.

Subsequently, in the second part of the thesis I describe three studies aiming at investigating the origin and the developmental time course of both face detection and face

recognition (Chapters 3, 4 and 5). Importantly, to examine both the emergence and the developmental time course of the face processing abilities to become specialized, the same experimental paradigms are employed with newborns, 3- and 6-month-old infants and adults (e.g., composite face paradigm, a modified visual search paradigm). This allows a direct comparison between adults' and infants' performance.

In Study 1 *(Chapter 3)*, using both the visual preference and visual habituation techniques, a first series of experiments investigates the nature of face representation in newborns and in 3-month-old infants. According to recent evidence showing that infants' response to faces becomes more and more tuned to the face category over the first three-months of life (Turati, Valenza, Leo, & Simion, 2005), collected data demonstrate that 3-month-old infants, but not newborns, are sensitive to specific perceptual cues within a face, such as the correct position and orientation of the eyes (Experiments 1, 2 and 3). Furthermore, results obtained from Experiments 4, 5, 6 and 7 demonstrate that early facial representation is not human-specific, corroborating the hypothesis that newborns come into the world with a face representation that is sufficiently general as to bias newborns' visual attention toward multiple categories of faces (e.g., monkey faces vs. human faces), and that this face representation, due to the visual experience that infants do in the specie-specific environment, becomes more specific to human face during the first 3 months of life (Nelson, 2001; Pascalis & Kelly, 2009).

Due to the social relevance of the face stimulus and due to the ability of 3-month-old infants to form a specific representation of the human face, the aim of Study 2 *(Chapter 4)* is to investigate whether human face grab and maintain infants' attention in complex visual scenes. Specifically, using an eye-tracker system, adults' and 6- and 3-month-old infants' visual search behavior is compared in a modified visual search task of a target face among heterogeneous (e.g., various objects, Experiments 8, 9 and 10) and homogeneous distractors (e.g., inverted faces, Experiments 11, 12). Results demonstrate that a face among heterogeneous distractors captures and maintains adults' and 6-month-old infants' attention and that 3-month-old infants detect a target face only when embedded among inverted faces (e.g., homogeneous distractors), corroborating previous findings showing the face detection advantage in infants (Gliga, Elsabbagh, Andravizou, & Johnson, 2009).

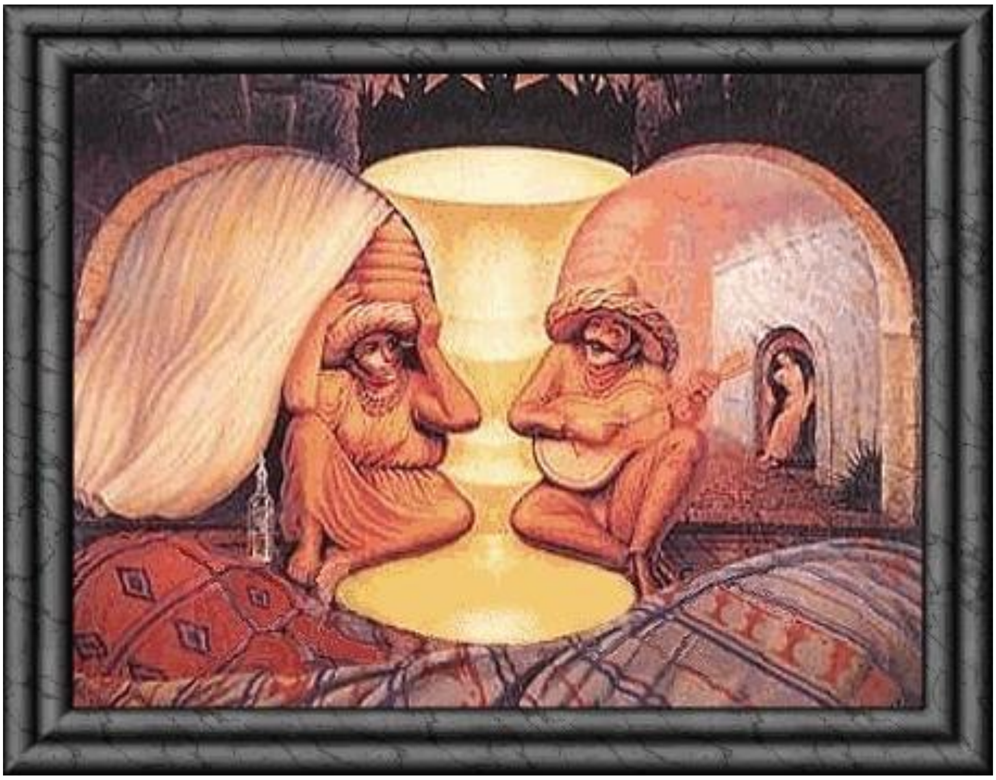
Importantly, to detect a target face among other distractors, infants have to process a face as a Gestalt, where the whole is more than the sum of its constituent parts (Tanaka & Farah, 1993). This kind of face processing, called "holistic", is investigated in newborns, 3-month-old-infants, and adults through a modified version of the composite face paradigm (Young, Hellawell, & Hay, 1987) and the recording of eye movements in Study 3 *(Chapter 5)*. The main outcome of the present study is that the tuning toward holistic information appears very early in life, although gradual experience-based developmental processes will progressively refine early holistic processing abilities (Experiments 13, 14 and 15).

Overall, these data demonstrate that face specificity is not prewired, but rather arises from general perceptual processes that, during development, become progressively tuned to the human face, as a result of extensive experience with this stimulus category in the first months of life.

CHAPTER 1

THE ARCHITECTURE OF THE MIND:

THE NEOCONSTRUCTIVISTIC APPROACH



1.1 The dichotomy between general and specific innate mechanisms as determinants of cognitive development

Arguments over the developmental origins of human knowledge are ancient, founded in the writings of Plato, Aristotle, Descartes, Hume and Kant. Indeed, developmental theories have been dominated by two different views both on the origin of knowledge and on the initial mechanisms that form the basis for cognitive development. On one view supports the hypothesis that knowledge emerges on the basis of domain general mechanisms of learning that are sufficient to explain how children learn about specific domain of knowledge such as language, number, space or faces. Although Piagetian, Behaviourist and more recently Connectionist theories fall within this view, Piaget's position, known as *epigenetic constructivism,* differs because cognitive development is considered as the outcome of a self organizing system that is structured and shaped by its interaction with the environment. The mind of the newborn is essentially unstructured and knowledge-free; it is equipped with just three domain-general processes (i.e., accomodation, assimilation and equilibration) which, in conjunction with a few innate reflexes (i.e., sucking, looking, grasping), are all that the child brings to the developmental process. The environment supplies the rest. The most important thing is that the child acts on the environment, initially just employing the few sensorimotor reflexes at its disposal, and the environment in its turns has an important role to play in the gradual emergence of structure in the mind. In other words, Piaget's constructivist theory holds that cognitive development is a continuous process of building knowledge on previous skills (e.g., perception, memory) and existing knowledge structures, from a foundation at birth consisting largely of reflexes and sensory impressions.

This constructivist view of development was challenged by the nativist view, according to which the early appearence of abilities hitherto unsuspected has supported the notion that knowledge begins early in life and constitutes parts of humans' innate endowment. Some authors maintain that human cognition is built on domain-specific system of knowledge and that the natural selection may have favored the evolution of mechanisms that leads to this knowledge (Kellman, 1993). From this point of view, the neonate is seen as having domain-specific predispositions allowing it to process specific types of inputs (Spelke, 1990; Baillargeon & Wang, 2002). More specifically, the human mind is thought to be a collection of special purpose mechanisms, each shaped, through adaptation to the environment during evolution, to perform a particular function. This nativistic view asserts that humans are born either with the innate capacity to develop information processing systems or cognitive or "cognitive modules" that allow them to make sense of the world, or that learning is guided by innately specified and content-specific principles that determine the entities on which subsequent learning takes place (Gelman, 1990; Spelke, 1991). In this perspective, deeply influenced by Chomskyan linguistics (1988) and by Fodor's modularity theory (1983), the infant comes into the world prepared to process different domains of knowledge. For example, the infant comes prepared to process faces or number. Accordingly, cognition would be specialized from the outset in processing content-specific inputs able to mediate complex cognitive functions (Spelke, 1991; Wynn, 1995). However, this approach seems to preclude the epigenetic constructivism principle to development because biological forms are not considered as a product of any dynamic interaction between the genes and the environment.

The dichotomy between general and specific innate mechanisms as determinans of cognitive development has been overcome by the neo-constructivistic approach to cognition that combines these two different explanations.

1.2 The Neoconstructivism

Karmiloff-Smith wrote: "I suggest that nativism (when redefined within a truly epigenetic perspective of genetic expression rather than genetic unfolding), on the one hand, and Piaget's constructivism, on the other, are complementary in fundamental ways, and that the ultimate theory of human cognition will encompass aspects of both (Karmiloff-Smith, 1994, p. 693)". Karmiloff-Smith (1994) argued that domain-specific predispositions give development a small but significant kickstart by focusing the young infant's attention on prioritary inputs. The crucial point is that the early period is followed by intricate interaction with environmental that shape the development. That is, dichotomy between general and specific innate mechanisms as determinants of cognitive development has been overcome by the neo-constructivistic approach to cognition (i.e., the term was generated by combining *neo*, taken from the Greek neos, meaning "new", and constructivism, taken from the Piaget's costructivist approach), that combines these two different explanations and states that nativism and epigenetic principle are not incompatible because it can be assumed the existence of some innate specified predispositions that would give the epigenetic process a head start in each domain of knowledge (see Simion & Leo, 2010).

Neoconstructivism views the cognitive development as a *continuous* process that emerges through the dynamic of probabilistic epigenesis and that progressively leads to an increasing functional specialization of neural circuits (Bates & Elman, 1993; Johnson, 1997; Karmiloff-Smith, 1992). The *probabilistic epigenesis* view of development (Gottlieb, 1992) emphasizes that gene activity, instead of following a strictly pre-specified schedule (i.e., predetermined epigenesis), is regulated by signals from the external and internal environment and that development is therefore subject to bidirectional interactions between gene activity, neural activity, behavior and the environment (Gottlieb, 2007). In this perspective, cognitive activity is seen as emerging gradually as a product of the interaction between innate constraints and the structure of the input provided by the *specie-typical environment* (de Schonen, 2002; Johnson, 1993; Nelson & Luciana, 2001). Therefore, in contrast to the classic nativist/modular thesis (Fodor, 1983; Spelke, 1991) that considers the infant brain as provided with build-in domain-specific representational contents, more recent models stress the role of a number of innately specified constraints or biases in the emergence of representations and thus in the origin of knowledge. The main hypothesis is that specific cognitive structures observed in adults may arise from primary, general innate constraints shaped by the nature of the experience the organism is exposed to in a given period of time (Karmiloff-Smith, 1992).

Within this theoretical framework, *innate constraints* are architectural, computational and temporal biases that shape information processing, limiting the types of input to be selected and constraining the computations on the input. More specifically, a behavior is seen as innate when its development is constrained concerning the neural architecture of the brain, to the types of computation applied, or to the timing of events in the developmental process (Elman, Bates, Johnson, Karmiloff-Smith, Parisi, & Plunkett, 1996). Consequently, the word "constraints" does not carry on any negative connotation, but rather, it possesses a positive connotation. Constraints are defined as biases in the information processing due to the properties of the brain architecture or of the perceptual systems in a given period of development. Benefits from these biases consist in selectively focusing the cognitive system toward certain aspects of the surrounding environment or facilitating processing of certain kinds of inputs, thus strengthening learning of some categories of stimuli rather than others, and, consequently, tuning the system to become specialized. In this vein, the constraints imposed by the development of the sensory systems may actually facilitate subsequent perceptual development by reducing the range of stimuli that infants has to deal with.

Importantly, there are *crucial time windows* (i.e., sensitive and/or critical periods, Greenough, Black, & Wallace, 1987; Greenough & Black, 1992; Nelson, 2001, 2003), during which experience manipulations profoundly affect cognitive development. Domain specific cognitive activity is, therefore, strictly linked to the exposure to certain experiences. For instance, the deprivation of early visual input due to bilateral congenital cataract in the first few months of life impairs face processing even after years from surgery, demonstrating that the visual experience during the first few months of life is necessary for the normal development of expert face processing (e.g., Le Grand, Mondloch, Maurer, & Brent, 2003).

Finally, as suggested before, experience shapes the development that occurs in a *specie-specific environmen*t. For instance, with regards to face processing, it has been demonstrated that infants of 6 months of age are better at discriminating monkey faces than are 9-month-old infants and adults (Pascalis, de Hann, & Nelson 2002). These results suggests that younger infants exhibit a more broadly tuned face-processing system that can discriminate among exemplars within multiple categories of faces (e.g., both human and monkey faces) and that this system becomes more specific (e.g., discrimination between human faces only), corroborating the idea that the face processing system is shaped by the faces encountered more often in the visual environment in the first months of life, that are human faces (de Schonen & Mathivet, 1989; Nelson, 2001; Scott, Pascalis, & Nelson, 2007). Another example of the role of experience in a specific environment comes from the domain of language. For example, speech perception is characterized by a loss of ability with age, such that 4-to 6-month-olds can discriminate phonetic differences that distinguish syllables in both their native and unfamiliar languages, whereas 10- to 12-

month-olds can only discriminate the phonetic variations used in their native language (Cheour, Ceponiene, Lehtokoski, Luuk, Allik, Alho, et al.,1998; Kuhl, Williams, Lacerda, Stevens, & Lindblom, 1992).

To summarize, in contrast to the classic nativist/modular thesis, the neoconstructivism framework suggests that the specific cognitive systems are the product of a "process of modularization"; that is to say, the modular architecture is the result of a gradual development rather than the starting point. Consequently, brain specialization, domain specificity and cognitive modules are considered to emerge epigenetically and developmentally through the interaction with postnatal development, rather than being assumed as genetically pre-specified. Evolution has pre-specified many innate biological constraints on development that are domain general mechanisms becoming "domain specific" with the process of development. During this process the same general mechanisms used repeatedly to process a certain class of stimuli become specific. Some apparent constraints contribute to the development of new structures and new modes of functioning, which will be advantageous at later stages of development (Karmiloff-Smith, 1992) and provide starting points that channel the subsequent perceptual and cognitive development (e.g., Turkewitz & Kenny, 1982).

The neuropsychological equivalent of the neoconstructivism is the *neuro-constructivism*, which emphasizes the interrelation between brain development and cognitive development (Karmiloff-Smith, 1992; Sirois, Spratling, Thomas, Westermann, Mareschal, & Johnson, 2008; Quartz & Sejnowski, 1997). From a neocostructivistic point of view, the development is a progressive increase in the complexity of representations, with the consequence that new competences develop based on earlier and simpler ones. In the same vein, the neuroconstructivistic approach considers this increase in representational complexity as realized in the brain by a progressive specialization of cortical structures.

Specifically, neuroconstructivism offers a theoretical framework in which cognitive development is closely linked to the development of the underlying cortical structures in the brain. By characterizing the constraints that operate on the development of neural structures that support mental representations, cognitive development is explained as a trajectory emerging from the interplay of these constraints.

Brain development is viewed as an increasing restriction of the fate of component elements, such as neurons and neural circuits. In other words, as development proceeds, neurons and cortical circuits become increasingly specialized, dedicated to particular functions and less capable of change. The cerebral cortex does not appear to contain intrinsic pre-specified representations to support functions such as face recognition or linguistic processing. Rather, the appropriate representations emerge through the constraints of the complex cortical and subcortical networks and through the interaction between the infant and the statistical regularities latent in the environment. Endogenous constraints select the aspect of the environment to which orienting attention and, interacting, with the structure of the input typical of the infant's environment, guide and shape the gradual emerging of specialized processing (Werker & Vouloumanos, 2001). In this perspective, experience appears to play a prominent role in recruiting the cortical areas potentially suited to be activated by certain kind of stimuli. The activation of these cortical networks leads as a consequence to a process of a progressive neural specialization (Nelson, 2001).

To conclude, the neocostructivistic framework provides an integrated view of development and adult processing because the adult state is viewed as merely a state along the developmental trajectory. From this perspective, the investigation of adult processing benefits from being analyzed through a developmental lens to reveal which constraints have shaped development to reach the adult state. Adult cognitive processing is often characterized as consisting in a set of qualitatively different, specialized, domain-specific modules. The neoconstructivist perspective (and the neuroconstructivism as well) instead focuses on how regions of functional specialization are formed given the outlined constraints, providing explanations of adult processing that are less focused on qualitatively different encapsulated modules. Moreover, progress in research in the neuroconstructivist framework will be made by a better understanding of the constraints operating on neural development, by improved methods of linking brain and behavior in developing children (see Aslin & Fiser, 2005), and by computational modelling which has the potential to offer explanations of the interactions between brain and cognitive development (Mareschal, Sirois, Westermann, & Johnson, 2007; Westermann, Mareschal, Johnson, Sirois, Spratling, & Thomas, 2007).

It is within this theoretical framework that many researchers investigate the origin and the developmental time course of the "social brain".

1.3 The social brain

One of the most prominent, and to an extent unique, characteristics of the human brain is the ability to process stimuli in a social context (Adolphs, 1999; Brothers, 1996). Detecting and discriminating humans from objects is critical for adaptive behavior. Many vertebrates orient toward or look longer at social agents. Newly hatched chicks attend to patterns similar to the head region of their caregivers (Morton & Johnson, 1991) and detect social agents on the basis of the way they move (Regolin, Tommasi, & Vallortigara, 2000). Similarly, monkeys manifest a preference for faces as compared to objects (Sugita, 2008). These findings support the idea of the existence of hard wired mechanisms to detect social stimuli which might be present in animals including humans (Johnson, 2007).

Human adults have areas of the brain specialized for processing and integrating sensory information about the identity, behavior, and intentions of other humans, corroborating the idea that a network of specific cortical circuits preferentially processes social information. Indeed, a variety of cortical areas have been implicated in the 'social brain' including the superior temporal sulcus (STS), the fusiform 'face area' (FFA) and orbitofrontal cortex (Farah, Rabinowitz, Quinn, & Liu, 2000; Kanwisher, 2000; Allison, Puce, & McCarthy, 2000).

One of the major debates in cognitive neuroscience concerns the origins of the 'social brain' in humans, and theoretical arguments abound about the extent to which this is acquired through experience. The ontogeny of the social brain network is one aspect of human postnatal functional brain development, and it is therefore useful to consider work within this field within the context of three general perspectives on developing brain function. Johnson (2001, 2005) reviewed three perspectives on how the neuroanatomical development of the brain could be related to the changes in motor, perceptual, and cognitive abilities observed during infancy and childhood: a maturational perspective, a skill-learning viewpoint, and interactive specialization.

The maturational view assumes that, through evolutionary pressure, specific parts of the brain and areas of the cortex have become dedicated to process social information. Some of the specific circuits to process social stimuli would be present and functioning at birth, in contrast others circuits would become available through maturation later during development. The sequence of the maturational timetable would not be affected by experience. Evidence concerning the differential neuroanatomical development of cortical regions is used to determine an age when a particular region is likely to become functional. Success in a new behavioral task at one specific age is then attributed to the maturation of a newly functional brain region.

The skill-learning hypothesis maintains that social stimuli are not different from other stimuli. Some circuits become specialized for social stimuli simply because adults become experts in processing them. The specialization would arise not because of the social nature of stimuli (i.e. domain specificity), but because of the expert-level discrimination for processing complex visual patterns, independently of the category to which the stimuli belong (i.e. process specificity). It is hypothesize that the regions active in infants during the onset of new perceptual or behavioral abilities are the same as those involved in skill acquisition in adults (Johnson, Grossman, & Farroni, 2008).

The interactive specialization view emphasises the importance of the initial biases to "bootstrap" later developing systems, and the notion of partial functioning of neural pathways which, interacting with the environment, shapes the subsequent functional and structural development. This alternative point of view assumes that postnatal functional brain development, at least within the cerebral cortex, involves a process of organizing interregional interactions (Johnson, 2002), by which cortical regions go from initially having very broadly tuned functions to having increasingly finely tuned (more specialized) functions (Johnson, 2001). Starting from a constructivist viewpoint, this third hypothesis maintains that the structural and functional changes in regions of the cortex co-develop as a function of the interaction with the environment (Johnson, 2000) and that the timing of events plays a critical role in developmental trajectories. The specialization of the cognitive system cannot be ascribed to the pre-specification of a particular region of the cortex, but to a particular sequence of interactions between pre- and post-natal environment and cortical circuits, resulting in successive reorganizations of the cortical circuits themselves (de Schonen, 2002). The specific properties of a brain region are partly determined by its pattern of connectivity to other regions and to their pattern of activity. Cognitive specialization is, therefore, an activity-dependent and an experience-dependent process, strictly linked to the exposure to certain experiences occurring over a particular period of time, called critical or sensitive period (Greenough & Black, 1992). The onset of new behavioral competencies during infancy and childhood will therefore be associated with changes in activity (adjustments in tuning functions) over several regions and not just by the onset of activity in one or more additional region(s). According to this view, brain regions do not develop in isolation but are heavily constrained by their connections and interactions with other regions, a phenomenon recently termed *embrainment* (Mareschal, Johnson, Sirois, Spratling, Thomas, & Westermann, 2007). The interactive specialization approach suggests that when a new computation or skill is acquired, there is a reorganization of interactions between different brain structures and regions. This reorganization process could change previously existing mappings between cortical regions and their functions. Thus, the same behavior could potentially be supported by different neural substrates at different ages during development.

To summarize, during prenatal development, spontaneous activity in sensory systems appears to play an important role in contributing to the differentiation of cortical regions. In early postnatal life, infants contribute further to the specialization of their brain by preferentially orienting and attending to certain types of stimuli, such as faces. Later, social experience and interaction with caregivers may contribute to the specialization of developing parts of the cerebral cortex. Much of later postnatal brain development, therefore, can be viewed as an active process to which infant contribute. In this vein, studying the postnatal emergence of cortical specialization for different cognitive functions offers the possibility of new perspectives not only on the study of perceptual and cognitive development in healthy human infants, but also for social development and atypical developmental pathways. Indeed, *developmental disorders,* such as autism, can be understood through altered constraints that push the developmental trajectory off its normal track to reach a different endstate (Karmiloff-Smith, 1998; Thomas & Karmiloff-Smith, 2003). Thus, atypical development can, like typical development, be characterized as an adaptation to multiple interacting constraints, with the only exception that the constraints are different. These atypical constraints then lead to different outcomes through the same processes of representation construction.

In line with this interactive specialization developmental point of view, the present thesis will examine the emergence of the specialized cognitive system devoted to processing social stimuli and how innate mechanisms and perceptual experience contribute to the development of the social brain. To this end, we will focus on the evidence on infants' abilities since birth of processing social stimuli on the basis of the presence of a face (i.e. face detection). Evidence will be presented to demonstrate the innate predispositions of the human system to detect social stimuli at birth and how the pre-wired perceptual constraints and attentional biases interact with experience to guide and shape the emerging of a specialized system to process social stimuli.

1.3.1 The case of face processing as an example of the progressive specialization of the cognitive system

To address the issue about how a cognitive system becomes a specialized system in adulthood, a peculiar class of visual stimuli, namely faces, will be considered. Indeed, the functional and neural specialization present in the adults' system for processing faces (e.g., Farah et al., 2000; Kanwisher, McDermott, & Chun, 1997; Kanwisher, 2000), renders faces an ideal class of stimuli to investigate the time course and the factors affecting such specialization. Indeed, interest in face recognition has played prominently in various scientific disciplines for much of this century, and even parts of the last (Darwin, 1859).

Cognitive psychologists have been interested in this phenomenon because there is evidence that faces are somehow perceived differently than other patterned objects, and thus, may represent a 'special' class of stimuli. In the same vein, cognitive neuroscientists are interested in face recognition because there is evidence that this ability is subserved by discrete neural circuits, and thus, represents a specialized brain function.

Faces play an important role in social interaction. It is commonly accepted that the ability of fast and accurate face analysis plays a crucial role for people. Indeed, faces are the unique source of information concerning human beings. Merely looking at somebody's face enables us to determine sex, age, race and attractiveness, and what is even more important, tentatively estimate mood, intelligence and honesty, and friendly and hostile attitudes in its owner.

The crucial issue pertains to the specificity of face perception, that is, whether the face is an extraordinary stimulus (Kanwisher et al., 1997; Farah et al., 1998) or if the brain processes faces in the same manner as any other category of objects, like animals or buildings (Diamond & Carey, 1986; Chao, Haxby, & Martin, 1999). Another issue concerns the underlying mechanism of this extraordinary human competence. Some authors argue that the ability to process faces as special stimuli is due to the presence of inborn predispositions (Johnson & Morton 1991; Morton & Johnson 1991; Farah et al., 1998, 2000; Johnson, 2005, McKone, Kanwisher, & Duchaine, 2007). Other authors emphasize the role of learning processes, claiming that we become experts in face recognition just by experience (experience-dependent; e.g., Gauthier & Logothetis, 2000; Gauthier & Tarr, 1997).

Thus, developmental behavioral and neuropsychological work can potentially contribute to this debate by providing evidence about the developmental trajectory of face-processing abilities in the human brain. Since development cannot be explained in terms of innate, building in representational contents, it becomes relevant for developmental researchers to investigate what types of general perceptual constrains and attentional biases are present in the first months of life and how they contribute to the specialization of the cognitive system (Simion & Leo, 2010).

CHAPTER 2

FACE PROCESSING IN ADULTS

Introduction

Human faces are the most important stimuli in our visual world. The human face represents a unique, highly salient and biologically significant visual stimulus that reveals a great deal of cognitive and social information to a perceiver. There is no doubt that a person can be identified by voice, body shape, gait and so on, but a face is the most distinctive and widely used key to a person's identity. Indeed, a face provides many information regarding not only identity, but also direction of attention (Langton, 2000), intentions (Baron-Cohen, 1995) and emotions (Ekman & Friesen, 1982). Adults are experts in processing faces and can recognize thousands of individual faces.

Although different behavioral and neuropsychological evidences showed that faces are special (e.g., Yin, 1969; Kanwisher, 2000), there is no completely agreement yet as how the term "special" should be defined. Several lines of neuropsychological research have suggested that faces are special, by means that the human face is an extraordinary visual stimulus processed by dedicated brain areas (e.g., FFA, Kanwisher, 2000; Kanwisher & Yovel, 2006). Moreover, different behavioral evidence showed that face recognition is different from object recognition (e.g., Farah et al., 1998). For instance, the face inversion effect, discussed in more detail later, provided indication that face recognition is different from other kinds of object recognition (e.g., Yin, 1969). However, some authors emphasize the role of learning processes, claiming that face is not a special stimulus per se, but that human adults become experts in face processing thanks to the visual experience with this stimulus (Diamond & Carey, 1986; Gauthier & Tarr, 1997; Gauthier & Logothetis, 2000). For instance, it has been demonstrated that activity in the fusiform face area (FFA) could be enhanced by stimuli other than faces by increasing expertise with them (e.g., birds, Tarr

& Gauthier, 2000; Gauthier, Tarr, Anderson, Skudlarsky, & Gore, 1999). Furthermore, dog experts showed an inversion effect comparable to the face inversion effect, demonstrating the role of the visual experience in shaping visual processing (Diamond & Carey, 1986).

Considering this open question pertains to the specificity of neural and perceptual processes involved in face perception and to the role of the visual experience, the focus of the present Chapter will be to describe the specialized adult face processing system, presenting both a cognitive (Bruce & Young, 1986) and a neural model (Haxby, Hoffmann, & Gobbini, 2000) employed to interpret face processing in adults.

2.1 Are faces a special class of visual stimuli for adults?

A first evidence of a specialized neural system for face perception came from studies of non-human primates, whose brains are most similar to ours. Research indicated that regions of the superior temporal sulcus (STS) and the inferior temporal gyrus contain neurons which exhibit activity when a monkey is shown a picture of human or monkey face (Gross, Roche-Miranda, & Bender, 1972; Hasselmo, Ross, & Baylis, 1989; Perrett & Mistlin, 1990; Desimone, 1991), providing the first evidence for face selective neurons. Importantly, it has been demonstrated that neurons in the STS analyzed mainly the changeable aspects of the face, like emotional expression (Hasselmo et al., 1989), eye gaze, head position (Perrett, Smith, Potter, Mistlin, Head, Milner, & Jeeves, 1985), whereas neurons in the inferior temporal gyrus seem to process the invariant features of faces (Hasselmo et al., 1989; Perret & Mistlin, 1990). Furthermore, neurons responsive to faces have also been observed in the amygdala (Rolls, 1984; Nahm, Perrett, Amaral, & Albright, 1991). Overall, this evidence demonstrated that the primate brain has specialized groups of neurons that selectively respond to faces.

But what about humans? The main issue concerns the fact that it is not clear to what extent the face-specific brain regions in monkeys are functionally similar to those in humans (Gauthier & Logothetis 2000; Haxby et al., 2000, Kanwisher & Moscovitch, 2000). With the development of the brain imaging techniques[1], the brain regions involved in face processing could be studied non-invasively in the intact human brain (Sergent, Ohta, & MacDonald, 1992; Kanwisher et al., 1997; Haxby et al., 2000; Haxby, Hoffman, & Gobbini, 2002). The perception of faces has been found to involve a distributed network of brain areas, including regions in the medial temporal lobe and prefrontal cortex (Haxby et al., 2002), as well as in the fusiform gyrus (Puce, Allison, Gore, & McCarthy, 1995). There is a specific region that has received particular attention: the "*fusiform face area*" (FFA, Kanwisher et al., 1997) in the lateral fusiform gyrus. Its activation is high (especially in the right hemisphere, Sergent et al., 1992) when participants are looking at faces; in contrast activation decreases remarkably when participants are looking at non-face stimuli such as houses or landscapes (Haxby, Ungerleider, Clark, Schouten, Hoffmann, & Martin, 1999; Ishai, Ungerleider, Martin, Schouten, & Haxby, 1999; Epstein & Kanwisher, 1998). Considering this neural evidence, it has been suggested that the FFA is a specific cortical area in the human brain specialized for face perception (Kanwisher, 2000).

Perhaps, the most important evidence about the existence of a dedicated face processing system in the human brain was suggested first by the observation of *prosopagnosic patients*, who had a selectively impaired ability to recognize familiar face, but a relatively unimpaired ability to recognize other objects (e.g., de Renzi, 1986; McNeil & Warrington, 1993). Prosopagnosia is due to from damage in the ventral occipitotemporal and temporal

[1] Brain imaging techniques: fMRI (functional magnetic resonance imaging) is a form of neuroimaging that uses magnetic resonance to measure hemodynamic responses in relation to neural activity; PET (positron emission tomography) is a unique technique which allows the measurement of tissue function in vivo using compound labelled with short-lived positron emitting radionuclides. This technique has been used extensively in neuroscience for functional mapping of the brain.

cortex. An example of prosopagnosia can be found in patient L.H. (Farah, 1996), who was very impaired in recognizing familiar faces, although his general object perception was intact. Conversely, Moscovitch and colleagues (1997) have reported a case of patient C. K., who had intact impaired object processing but intact face processing abilities (e.g., he was suffering from associative object agnosia), providing additional evidence of the double dissociation between face and objects recognition (Moscovitch, Winicour, & Behrmann, 1997). Evidence in favor of this view comes also from a single case study (Farah et al., 2000). The patient suffered from prosopagnosia acquired as a result from damage to ventral temporo-occipital cortex at 1 day of age. When tested at 16 years of age, he showed impairments with faces and a more moderate deficit with objects. The authors concluded that "the distinction between face and object processing, and the anatomical localization of face processing, are explicitly specified in the genome" (Farah et al., 2000). Overall, the evidences described here seem to support the idea that faces are a special class of visual stimuli because of the existence of dedicated brain areas involved selectively in face processing. However, a different view is that cortical specialization for faces emerges during a prolonged developmental process involving accumulated experience with faces (Gauthier & Nelson, 2001; Gauthier, Tarr, Moylan, Skundlarski, Gore, & Anderson, 2000). Recent neuroimaging studies indicated that expertise with non-face stimuli, such as cars and birds, recruits the same ventral temporal regions of the adult brain that are selective for face processing (Gauthier, Skudlarski, Gore, & Anderson, 2000; Gauthier et al., 1999). Gauthier and colleagues (Gauthier & Tarr, 1997) argued that face-responsive regions are specialized for visual experience, and not for faces per se. According to the *expertise hypothesis*, they proposed that these regions respond to any objects that the subjects perceived as distinct individuals (i.e., subordinate level of categorization), rather than as generic exemplars of a category (i.e., categorical level). Indeed, in an fMRI study, it has been found that individuals who are experts at bird and car recognition showed increased FFA activity for objects in their domain of expertise, compared with non-experts. Moreover, in the best car experts, car activity has been found to be equivalent or superior to that for faces (Gauthier et al., 1999).

Such specialization can also be obtained for novel objects (Gauthier & Tarr, 1997). Adult participants were trained to become experts at discriminating members of a novel class of stimuli called 'Greebles' (Figure 1). These stimuli are visual patterns that share the structure and are recognised by name. The authors found activation of the FFA in participants when discriminating greebles after becoming experts with those visual stimuli. In this vein, face processing abilities would be the result of general processes devoted to the highly expert identification of within-category exemplars from any object class (e.g., Gauthier & Logothetis, 2000; Tarr & Gauthier, 2000).

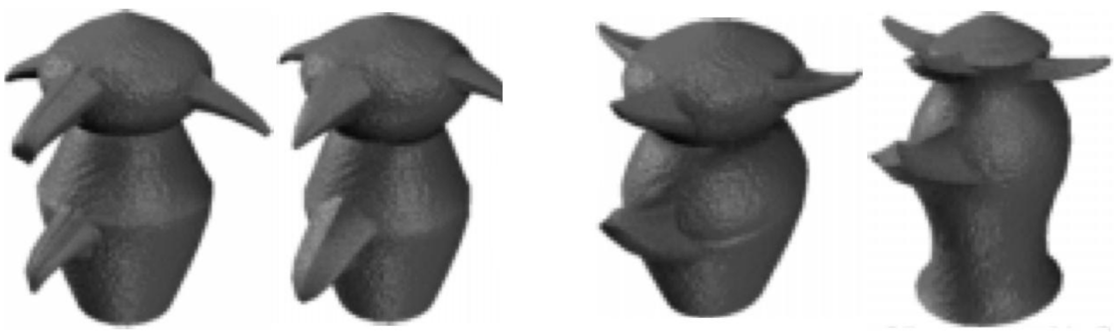


Figure 1: Exemplars of the visual stimuli called "Greebles" (from Gauthier, Williams, Tarr, & Tanaka, 1998).

To conclude, alternatively to the idea of the existence of a module for face processing (Kanwisher et al., 2000), specialization for faces in adults could simply be the result of our experience with these objects (i.e., we recognize faces at a more specific level than most objects and we acquire a lot of experience for such visual stimuli).

2.2 Face processing strategies in adults

At a functional level, behavioral studies showed that in adults face processing involves cognitive processes different from those involved in the recognition of other objects (e.g. Farah et al., 1998). Indeed in literature, a convincing demonstration that faces are a special class of visual stimuli and that their processing is the result of a dedicated face-processing system is the so called *"face inversion effect"*, and refers to the phenomenon by which upside-down faces are disproportionately more difficult to recognize than other inverted objects (Yin, 1969). The inversion effect has been considered as the hallmark of face-specific recognition and is often used as a marker of expertise in face processing. Interestingly, this effect is thought to interfere with perceptual face processing strategies, which are referred as *configural information*.

It is generally accepted that the exceptionally proficient face recognition abilities seen in adults are mainly derived from the rapid and efficient use of specific perceptual processing strategies which involve the encoding of configural information that emerges from the spatial relations among facial features, which is contrasted with the processing of the shape of individual features (e.g., featural processing). It has been proposed that the use of configural processing strategies for faces derives from the high degree of expertise with this stimulus category that humans naturally develop (Diamond & Carey, 1986). The *expertise hypothesis* is supported by findings from behavioral studies conducted with both natural experts, who had become extremely skilled in the recognition of particular classes of real-world objects, such as birds and cars (Diamond & Carey, 1986), and laboratory-trained experts of artificial objects (i.e. greebles; Gauthier & Tarr, 1997). In these studies, experts show a wide range of face-specific behavioral effects when tested within their domain of expertise, and some authors interpret this evidence as an indication that experts use configural processing to recognize objects of expertise in the same way as they do with faces (e.g. Bukach, Gauthier, & Tarr, 2006)

Diamond and Carey (1986) proposed a model that subdivides configural information into first-order and second-order relational information. First-order relational information refers to qualitative spatial relations among facial features, that is the basic arrangement of face features with two eyes above a nose, which is above a mouth. Second-order relational information refers to fine spatial relations between features (for example, the distance between the eyes). According to this model, Maurer, Le Grand, & Mondloch (2002) suggested that configural face processing includes sensitivity to first-order relations, holistic processing, and sensitivity to second-order relations.

Detecting face-like *first-order relations*, that specifies the stimulus as a face, is facilitated by the fact that all faces share the same basic configuration. Adults have a remarkable ability to detect faces based on first-order relations even without normal facial features, at least when the stimuli are upright (Maurer et al., 2002). For example, adults detect a stimulus as a face when the features are formed from an arrangement of fruit and vegetable shapes (e.g., Moscovitch et al., 1997, Figure 2) or when presented with a two-tone Mooney stimulus in which the features are formed of only patches of intense light and shadow and require closure (e.g., Kanwisher, Tong, & Nakayama, 1998, Figure 3).

Figure 2*:* An Archimbaldo painting (The Vegetable Gardener, upright and inverted).

Figure 3*:* Mooney face stimuli (Maurer & de Schonen; Leo & Simion, 2009a)

To detect the first-order relations of a face, adults tend to integrate facial features into a whole and then process the stimulus as a Gestalt, rendering the processing of individual features less accessible. More specifically, the expression holistic processing refers to encoding of the overall structure of the face, in which face parts and their relations are not explicitly represented, but glued together in an undifferentiated whole (Tanaka & Farah, 1993).

Evidence for the holistic type of processing comes from different paradigms. One of the most influential study was designed by Tanaka and Farah (1993), who operationalised the concept of holistic processing by developing a task in which participants were presented with a series of faces and were tested on their recognition of features such as eyes, mouth, or nose. The test consisted of showing the feature in isolation and showing it within the context of the whole face, hence the name 'Part-Whole Paradigm'. Faces could be presented in the canonical orientation or upside-down. Better performance is tipically observed for the whole compared to the part condition (Tanaka & Farah, 1993; Tanaka, Kay, Grinnell, Stansfield, & Szechter, 1998) (Figure 4). Indeed, participants were more accurate in the recognition of the features presented in the whole condition than in isolation, but only when faces are presented upright. On the contrary, when features where presented inverted, the performance on whole condition decreased, whereas accuracy on the part condition was not influenced by inversion manipulation. Thus an inversion effect was only observed in the whole-face condition (Tanaka & Farah, 1993).

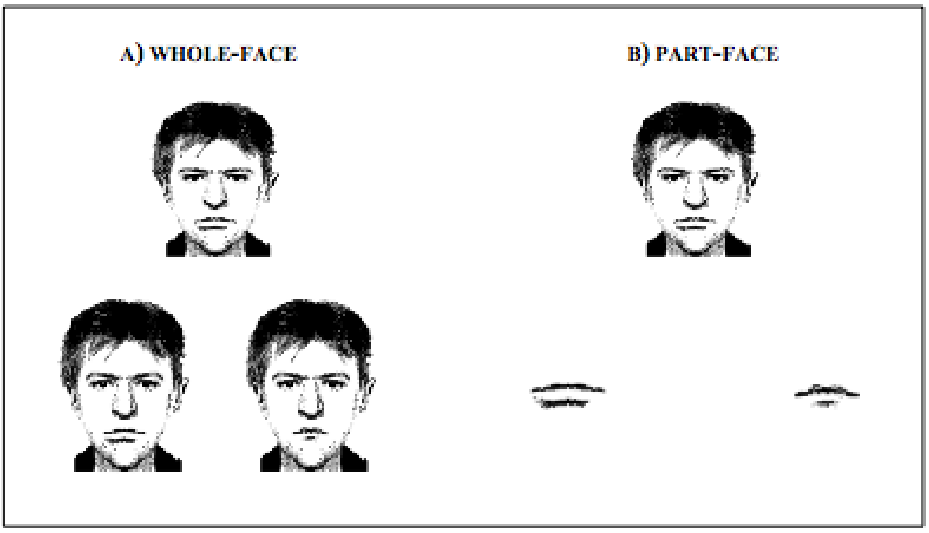


Figure 4: Stimuli employed in a part-whole paradigm. Upper stimulus is a target: the participant must select which of the lower two photos matches with the target. Adapted from Tanaka and Farah (1993).

However, the most convincing demonstration of this *holistic face processing* is the "composite face effect", which refers to the observation that recognition of the top half of a face is more difficult when the top half is aligned with the bottom half of a different face, creating the impression of a novel face, as compared to when the two halves are misaligned through a lateral shift (Hole, 1994; Young et al., 1987) (Figure 5). Subjects are slower and less accurate in recognizing the top half of one face presented in a composite with the bottom half of another face when the composite is upright and fused than when the composite is inverted or the two halves are offset laterally (e.g., manipulations that disrupt holistic processing). Furthermore, this face illusion was observed both for familiar and famous face and for unfamiliar faces. The difference between the subjects' performance in the aligned and misaligned condition is taken as a measure of the interference produced by holistic processing of the novel composite face on the recognition of its constituent parts (see Chapter 5).

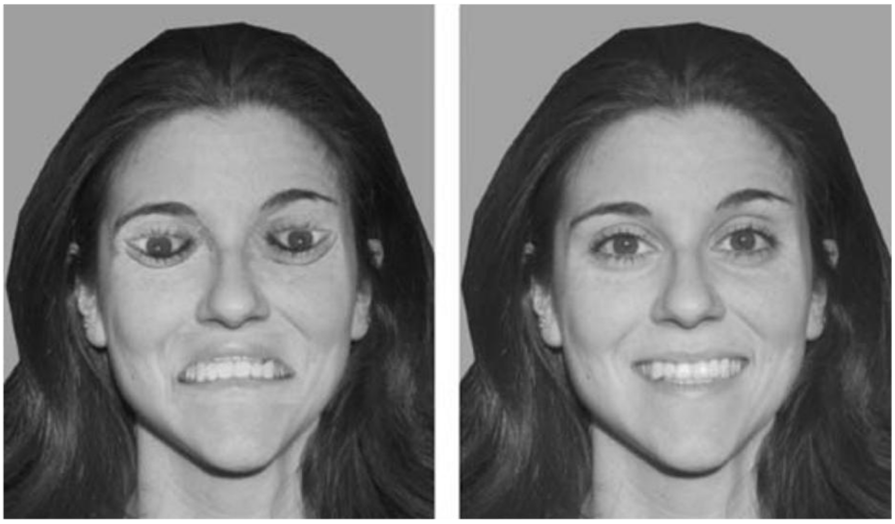
Figure 5: Aligned and Misaligned face halves used in the composite paradigm. Two face pairs from the misaligned condition are in the top row, and two face pairs from the aligned condition are in the bottom row. In each face pair, the top halves are either identical (left panel) or different (right panel). For all face pairs, the bottom halves are different (from Mondloch, Pathman, Maurer, Le Grand, & de Schonen, 2007).

Because all faces share the same first-order relations, recognition of individual faces requires the encoding of information about subtle variations in the shape or spacing of the features. *Sensitivity to second-order relations* is defined such as the differences among individuals in the spacing of facial features (Maurer et al., 2002). Evidence for separability of second-order information processing from featural processing cames from studies that employed a set of faces that differ from one another only in the spacing of individual features or only in the local information by changing the shape, color, or luminance of the features (Freire, Lee, & Symons, 2000; Leder, Candrian, Huber, & Bruce, 2001; Leder & Bruce, 2001; Leder & Bruce, 1998) (Figure 6). Results demonstrated that when viewed upright, adults readily distinguish among the faces within each set. On the contrary, inverting these faces impairs the ability to distinguish faces that differ in second-order relations, but has little effect on the ability to distinguish faces that differ in featural information, demonstrating that inversion affects second-order information perception more than featural processing.

Figure 6*:* Example of a set of faces employed to study the separability between featural information from second-order relational information. The original face is depicted on the left on each panel; the spacing set (top panel); the featural set (middle panel), and external contour set (bottom panel) (from Mondloch, Le Grand, & Maurer, 2002).

Another evidence that highlighted the existence of separate mechanisms involved in second-order relational versus featural processing of faces is to blur the stimuli to remove fine-detailed information about facial features. Adults are able to recognize the identity of blurred faces with reasonable accuracy, but are severely impaired if the faces are simultaneously blurred and inverted, because blurring removes featural information and inversion disrupts sensitivity to second-order relations (Costen, Ellis, & Craw, 1994; Collishaw & Hole, 2000).

Maybe the most famous demonstration of the importance of second-order information for face recognition comes from the so called "Thatcher Illusion" (Thompson, 1980). Thatcherization is created by rotating by 180° the eyes and the mouth within an image of a smile face with the effect that the resultant face appears grotesque, but only if the face is presented in its canonical orientation. Indeed, adults fail to quickly discriminate a thatcherized face from an unaltered face when the image is rotated 180° because this bizarre expression disappears. Thatcherizing a facial pattern changes second-order relation information without altering both featural and first-order information that are still detected (e.g., the stimulus is seen as a normal face) (Figure 7).



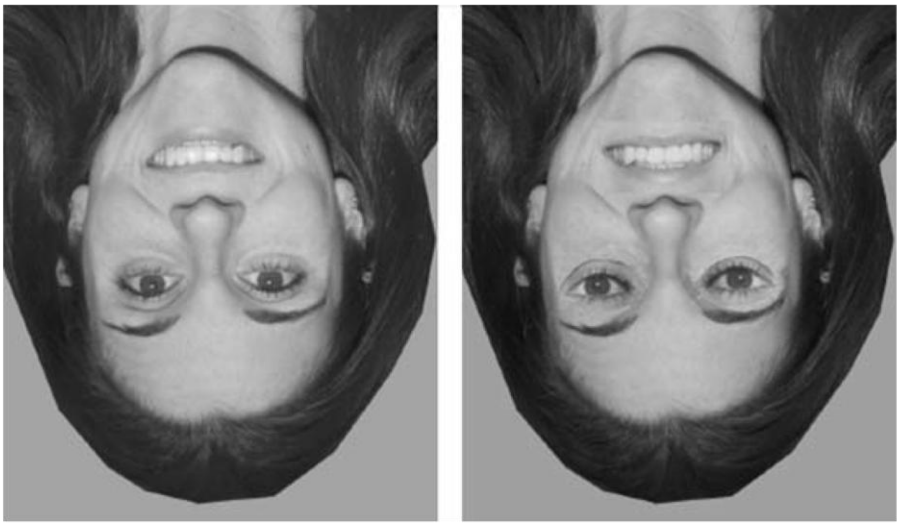


Figure 7: Examples of Thatcherized face stimuli (from Leo & Simion, 2009b).

Importantly, as suggested at the beginning of the paragraph, inversion interferes with all three types of configural processing, since it increases difficulty in detecting the first-order relations of a face and mitigates both the composite face effect and the part–whole recognition effect that mark holistic processing of upright faces. Finally, it also seriously impairs the accuracy of adults in discriminating among faces that differ only in second-order relations (Maurer et al., 2002).

In conclusion, it has been demonstrated that there are at least three different types of configural processing of faces: sensitivity to the first-order relations, holistic processing, and sensitivity to second-order relations. These three types can be distinguished by behavioral tasks and it seems logical that the three types operate in a hierarchical order: detection of the face based on first-order relations as a necessary first step before holistic processing and detection of second-order relations among the features. However, none of the existing data rules out the possibility that the three types of configural processing operate largely in parallel (Maurer et al., 2002).

2.3 A cognitive model for face processing

To examine the nature of the operations that occur to process faces and whether such operations are exclusively involved in face processing, it is important to refer to specific tasks, as different tasks make different demands. Tasks like face detection, face discrimination and face recognition are known to require different processes. Therefore, certain tasks may require face-specific processes, whereas other tasks may be performed on the basis of processes that are not specific to faces. *Face detection* involves a decision whether a given stimulus is a face, and implies the capacity to detect that all faces share the same first order relational features with two eyes above a nose, which in turn is above a mouth. *Face discrimination* involves a comparison between two simultaneously presented faces and a decision as to their sameness or difference. Finally, *face recognition* involves a judgment of previous occurrence and, thus, whether a face has been seen earlier.

The distinction between these processes has been originally proposed by one of the most influential models of adults' face processing. More than 20 years ago, Bruce and Young (1986) created a functional model of face processing that posited separate and independent functional routes that process information about human face. Although other cognitive models of face processing have been described after Bruce and Young work (e.g., Burton, Bruce, & Johnston, 1990; Ellis, Burton, Young, & Flude, 1997; Hancock, Bruce, & Burton, 2000), this framework remained the dominant account of face perception.

The model is shown as a box diagram in Figure 8. Each box represents any processing cognitive module, which plays a distinct functional role, and whose can be isolated or independently manipulated through specific experiments. An early stage of face processing involves the *structural encoding* of faces, in which data about the face structure are faster and automatically encoded. The representation of a face at this level still depends on both the viewing condition (i.e., angle of profile, lighting) and facial configuration (i.e., eye gaze, expression and mouth position). The face representation produced by structural encoding is then processed by separate systems that perceive personal identity, expression and speech related mouth movements. According to the authors, at this early stage, view-centred descriptions provide information for the *analysis of facial speech* (e.g., the facial speech code related to lips and tongue movements during speech) and for the *analysis of expression* (e.g., the expression code encodes information about facial expression), whereas the expression-independent descriptions provide information for the *face recognition units* (FRUs).

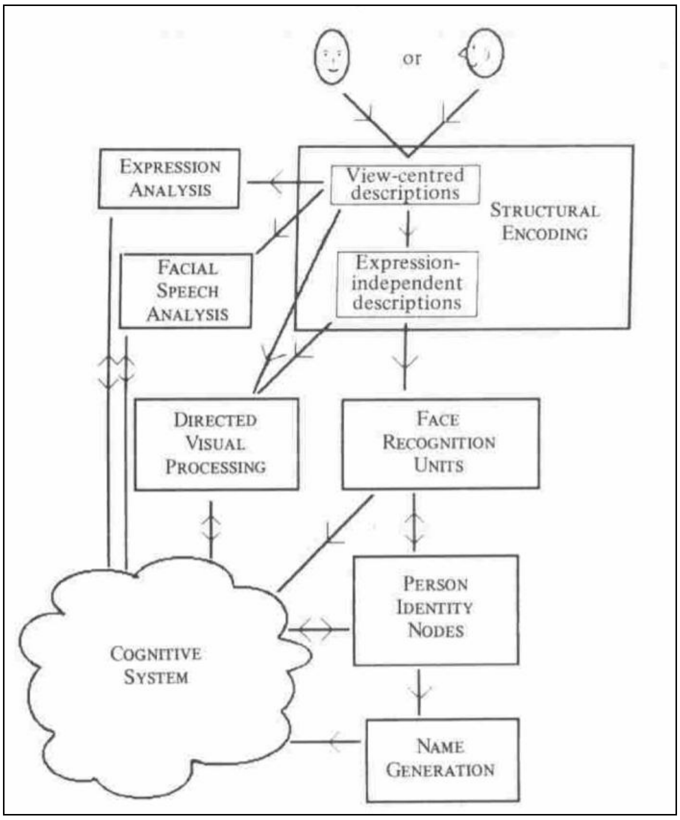


Figure 8: The functional cognitive model of face processing in adults proposed by Bruce & Young (1986) (from Bruce & Young, 1986).

Each face recognition unit contains stored structural descriptions, which allows views of one known face to be discriminated from views of other faces, whether known or unknown. The basic idea is that there is a separate face recognition unit for every familiar face, and that a unit will become active when any view of the appropriate face is seen. Importantly, the face recognition units respond only to face and do not respond to a person's voice or name. The activation of a face recognition unit in turn leads to the activation of the appropriate *person identity code* (PIN). It is the stage at which person recognition, as opposed to face recognition, is achieved. The person identity code allows access to semantic information about the identity of each known individual and encodes additional information related to the seen face, such as information about the owner's occupation, friends, his / her living place and so on, helping to establish the identity of the person to whom the face belongs. Unlike FRUs, PIN may be accessed by many routes since the same PIN will be made active not only by a person's face, but for example also by a person's voice. It appears clear that face recognition can break down whereas person recognition by other visual cues remains intact, since prosopagnosics become adept at using other visual cues (such as the voice). The last stage, called the *name generation*, stores information related to the name of the recognized person and can occur only by the PINs, according to this model. As one can see from the Figure, the main system is called *cognitive system,* that is responsible for the generation of the visually derived semantic codes, using information from the analysis of expression, facial-speech, structural encoding, directed visual processing, the face recognition units, person identification nodes and finally the name generation. Importantly, in their model of cognitive system for face perception, Bruce and Young (1986) proposed an organization that is hierarchical and branching, in which all the systems processed different face information independent from each other.

In summary, this functional model proposes that face processing is a sequential process, which involves several stages and is independent of and parallel to the other processes designed to deal with different kinds of facial information.

2.4. A neural model for face processing

Currently, Bruce and Young's model is often used as a first step to more contemporary theoretical considerations (Palermo & Rhodes 2007; Vuilleumier & Pourtois, 2007). One example is the model proposed by Haxby and colleagues (Haxby et al., 2000; Gobbini & Haxby, 2007). These researchers argued that face perception is mediated by a distributed neural system in humans that is formed by multiple, bilateral regions. They attempted to show how cognitively distinct aspects of face perception are mediated by distinct neural representations. The logic behind is that to recognize a face, the brain has to process information related to the changeable face aspects such as facial expression eye gaze direction or head position separately from features which are invariant allowing identification of the face's owner (Figure 9).

As described before in this chapter, evidence of a specialized neural system for face perception came from studies of non-human primates. Single unit recording studies in macaques have identified neurons in the superior temporal sulcus (STS) that are involved more in the perception of facial movement and static images of changeable aspects of face, and neurons in the inferior temporal cortex that appears to be involved more in perceiving facial identity (Perrett et al., 1985; Hasselmo et al., 1989; Desimone, 1991). Overall, the findings from single-neuron recording studies in the monkey suggested a dissociation between the roles of face-selective cells in the STS and inferior temporal cortex.

Turning to the work with humans, thanks to the development of functional brain imaging (i.e., fMRI), it has been possible to observed a similar dissociation for the processing of various aspects of a face: the fusiform gyrus (e.g., FFA) is responsible for the analysis of invariant elements related to the identity (Hoffman & Haxby 2000; Haxby et al., 2002, Gobbini & Haxby, 2007), whereas the region of superior temporal sulcus is responsible for analysis of the changeable aspects of faces.

Considering these evidences, Haxby and colleagues (2000) proposed a model for the organization of the system that emphasizes this distinction, with the representation of invariant aspects of a face that underlies the recognition of individuals, whereas the representation of changeable aspects of face that underlies the perception of information that facilitates social communication, such as eye gaze, expression, lip movement. According to this model, these processes are controlled by "*the core system*" and by an "*extended system"*. The core system comprises three functionally distinct regions of extrastriate cortex in both hemispheres: the inferior occipital region that contributes to early stage of face perception provides input both to the lateral fusiform gyrus (including the fusiform face area or FFA) for the processing of invariant characteristics of faces and to the superior temporal sulcus (STS) for the processing of changeable aspects. The authors emphasized that the full analysis of information regarding a face requires strict cooperation of the core system with the *extended system*, which comprises brain structures responsible for other cognitive functions. The intraparietal sulcus and presumably the frontal eye field process gaze direction and head position, in order to guide spatial attention; the superior temporal gyrus is involved in the processing of speech-related lip movements for the extraction of phonemic information; the anterior temporal lobe is involved in retrieving the name and other information associated with the face; and finally the amygdala and the insula are thought to mediate perception of the emotional content of facial expressions. In other words, the extended system acts together with the core system to facilitate the recognition of different facial cues.

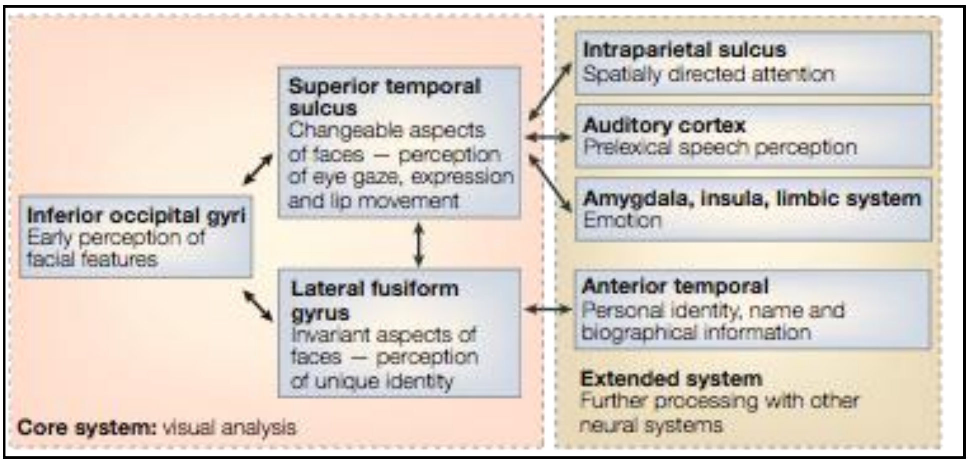


Figure 9: The human neural system for face perception proposed by Haxby and colleagues (2000) (from Calder & Young, 2005).

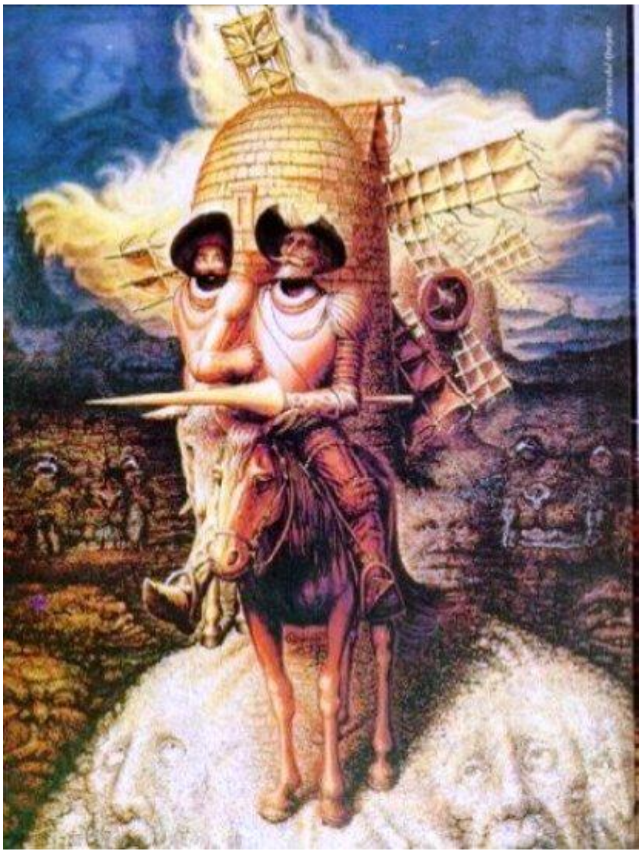
Although this model shares some elements with Bruce and Young (1986) cognitive model, such as the fact that different aspects of the face are process by different and independent codes or neural regions, however the main different point is that in the neural model of Haxby and colleagues (2000) is emphasizes the fact that the two separated systems, the core system and the extended system, work together and in parallel. In other words, at the heart of this model is the proposal that many face perception functions are accomplished by the coordinated participation of multiple regions and, importantly, these regions can also participate in other functions by interacting with other systems.

Conclusion

Evidence from behavioral, brain lesion and neuroimaging studies suggests that in adult face processing involves distinct, domain-specific perceptual processing (Maurer et al., 2002) carried out by dedicate brain areas (e.g., Farah et al., 2000; Kanwisher, 2000). The functional and neural specialization presented in the adult face processing system renders faces an ideal class of stimuli to investigate the time course and the factors affecting such specialization. Some authors claim the existence of a specialized system for face processing already at birth (*experience-independent*; e.g., Farah et al., 2000), whereas others raise the possibility that such specialization is a product of experience (*experience-dependent*; e.g., Gauthier & Logothetis, 2000). So, data from infants, and newborns especially, become relevant for resolving this debate because they do not have the years of experience with faces necessary to acquire expertise. The aim of the following chapters will be to support the idea that the face specificity is not prewired, but rather arises from general perceptual processes that, during development, become progressively tuned to the human face, as a result of extensive experience with this stimulus category.

CHAPTER 3

THE NATURE OF FACE REPRESENTATION IN THE FIRST MONTHS OF LIFE



Introduction

As described in Chapter 2, evidence from behavioral, brain lesions and neuroimaging studies suggested that in adults face processing involves distinct, domain specific perceptual processing (Maurer et al., 2002) carried out by dedicated brain areas (Farah et al., 2000; Kanwisher et al., 1997; Kanwisher, 2000). However, what determines this specialization and how this specialization emerges during development still remain largely unknown. Recent findings support the hypothesis that the presence at birth of general perceptual biases on visual processing seems sufficient to cause the human face to be a frequent focus on newborns' visual attention, allowing, through experience, the gradual development of a face processing system (Simion, Macchi Cassia, Turati, & Valenza, 2001; Turati, et al., 2005; Nelson 2001, 2003). In this vein, it has been suggested that humans might be born with some representation of the human face (Johnson & Morton, 1991; Johnson, 2005; Valenza, Simion, Macchi Cassia, & Umiltà, 1996; Macchi Cassia, Turati, & Simion, 2004), but a still open question concerns whether this face representation is innate and a product of an evolutionary pressure or whether it is only a product of a rapid learning process derived from experience with faces during the first hours of life.

Considering this literature, the aim of the present Chapter is to examine cognitive specialization during early infancy through the investigation of the development of face representation. In the first section of the Chapter will be described the theoretical models interpreting face preference at birth and in the first few months of life. Evidence will be reviewed supporting the contention that newborns' face preference is due to a set of non-specific constraints that stem from the general characteristics of the human visuo-perceptual system, rather than to a representational bias for faces. In the second section, experiments will be reported that shown that infants' response to faces becomes more and more tuned to the face category over the first three-months of life, revealing a gradual progressive specialization of the face processing system, as the perceptual narrowing hypothesis claims (Nelson, 2001, 2003).

3.1 The emergence of cognitive specialization for face processing

Three major approaches to the development of the face processing system have been distinguished (de Haan & Halit, 2001).

A first view argues that the development of face specialization is an *experience-independent process* (Farah et al., 2000). Due to the social relevance of face for humans, natural selection led, through phylogenesis, to the evolution of innate face-specific devices that would be available before any postnatal experience and explicitly specified in the genome (Farah et al., 1998, 2000). Evidence in favor of this view comes from a single case study that described an infant, who, at 1 day of age, sustained brain damage that resulted in a profound impairment in face processing (Farah et al., 2000). This module has been thought to be an *experience-independent* mechanism dedicated to face processing and selective response of newborns to face stimuli is considered a the direct precursor of the adult cortical face processing system.

A second approach characterizes the development of face processing as an *experience-dependent process,* hypothesizing that extensive and prolonged experience with faces would gradually render humans exceptionally proficient in recognizing individual exemplars belonging to this special class of visual stimuli. From this point of view, that highlight the role played by experience in the ontogenetic development of face processing, general learning processes are thought to be sufficient to explain thel emergence of a cortical system for the processing of faces (Diamond & Carey, 1986; Gauthier & Logothetis, 2000; Tarr & Gauthier, 2000). Importantly, within this experience-dependent approach, the general learning processes can occur at any time during development and might involve any class of visual stimuli.

Recently however, many studies on the development of face processing system share the idea that the emergence of the ability to process faces is the result of the interaction between innately specified predispositions and the extensive experience everyone has with faces (de Schonen 2002; Johnson, 1993; Le Grand et al., 2003; Nelson, 2001, 2003). This third approach describes the development of face processing system as an *experience-expectant process*, claiming that the functional and neuroanatomical specialization for faces processing revealed in human adults would emerge gradually from the interaction between innate constraints and the structure of input provided by the specie-typical environment, with innate constraints having the function of potentiating early learning (Johnson, 1993). The cortical tissue has gained, through evolutionary pressures, the potential to become specialized for face processing. However, this specialization would emerge on condition that the critical type of input is provided within crucial time windows (Nelson, 2001, 2003). According to a probabilistic epigenesis perspective (see Chapter 1), the interactions between genes, structural brain changes, and psychological functions are bidirectional and contribute to cognitive development (Greenough & Black, 1992). In particular, the partial functioning of neural pathways would shape subsequent development of neural structures and circuits that are the basis for further functional development (see Simion, Turati, Valenza, & Leo, 2006). This process would be a progressive tuning of certain cerebral tissues, from a large range of visual information to the specific type of information that faces convey (Johnson, 2000; Nelson, 2001, 2003).

One way of disentangling the issue of the origin and the development of cognitive specialization for faces might be to study the developmental time course of a phenomenon present few hours after birth, such as the newborns' face preference.

3.2 Models of face preference at birth

A great number of behavioral studies established that humans are born with a predisposition or bias to attend to faces. Indeed, despite their lack of experience, newborns prefer both schematic and real faces over almost any other category of visual stimuli (Goren, Sarty, & Wu, 1975; Johnson, Dziuarawiec, Ellis, & Morton, 1991; Valenza et al., 1996; Macchi Cassia et al., 2004; Johnson, 2005). Although the existence of the face preference few hours after birth may not provide conclusive evidence for an innate face processing system, it seems suggestive of a specialized cognitive system operating from very early in life. There is little dispute over the existence of a newborns' face preference, however the debate concerns what mechanisms underlay this preference at birth.

Indeed, some researchers hypothesized that faces, already at birth, represent a special class of visual stimuli because humans are born with a specific and innate mechanism selectively tuned to the face geometry (Johnson & Morton, 1991; Johnson, 2005). It has been proposed that a subcortical visuomotor system, named *Conspec*, is present at birth, which allows newborns to detect a face in the visual environment (Morton & Johnson, 1991; Johnson & Morton, 1991). This subcortical system is thought to possess a very simple representation of a face, that is three high-contrast blobs arranged in a triangular formation within a bounded contour. This representation would be suitable only for directing the newborn gaze towards face-like patterns, but is insufficient for more elaborate face discrimination. Interestingly, the finding that newborns only display a face preference when stimuli are presented in the temporal visual field (which is related to subcortical pathways), but not when they are presented in the nasal visual field (related to cortical pathways) is consistent with the subcortical location hypothesis (Simion, Valenza, Umiltà, & Dalla Barba, 1998). A two-process model was hypothesized in which at birth infants posses a subcortical orienting mechanism, Conspec, that guides the preference for faces since its primary function is to ascertain that facial input is maximized during the first two months of life (de Schonen & Mathivet, 1989), before a second cortical face-learning mechanism, Conlern, comes up. That is, at approximately 2 months of age, infant preference is controlled by another mechanism responsible for learning about faces. By ensuring that infants have visual experience with faces, the subcortical mechanism would favor the gradual emergence of the specialized cortical circuits that underlay face processing in adults. In other words, Conlern functions at the cortical level as a non-specific mechanism that facilitates learning about the characteristics of the face one Conspec has served to orient the newborn to conspecifics faces. As suggested by the authors, there is no linkage between the two mechanisms, rather they may interact indirectly through the environment. That is, "Conlearn [...] is a non-specialized learning mechanism. Effectively it learns about the characteristics of faces because the infant pays a lot of attention to them. The role of Conspec is to direct this attention." (p.175).

Recently, Johnson (2005) has updated his model arguing the existence of a low-spatial frequency (LSF) face configuration detector, provided by evolutionary pressure active throughout the life span. Indeed, recent evidence from behavioral (Tomalski, Csibra, & Johnson, 2009), electroencephalograph and magnetoencephalograph techniques (Bailey, Braeutigam, Jousmaki, & Switheneby, 2005) demonstrated subcortical processing in adults, suggesting that a rapid LSF face detector cannot be dismissed. Considering this evidence, it is likely that Conspec does not vanish at 2 months of age but is rather a rudimentary LSF face detector that endures throughout life to perform this important function. In this model, face detection would be supported by a "quick and dirty" subcortical route sensitive to a raised surface with darker areas corresponding to the locations of eyes. This subcortical pathway might be important to trigger the network of cortical regions that makes up the adult social brain. In this vein, specialization of the face cortical circuits might emerge due to a combination of factors including subcortical mechanisms that function to guide infants' visual attention to faces during the first weeks of life, biasing the input to the developing cortical system, increasing experience with faces, and increasing demands to process faces as infants develop. Importantly, it has been proposed that impairments to the subcortical route result in specific types of atypical development, such as autism. Specifically, if the subcortical face-processing route is important for the development of the adult social brain network, then disruption of this pathway by congenital factors could have important negative consequences for the social brain network as a whole (Johnson, 2005).

An alternative and complementary model hypothesizes that both Conspec and Conlern mechanisms are present at birth and that the visual cortex also heavily contributes from birth to develop a face recognition system (Acerra, Burnod, & de Schonen, 2002). This *computational model* predicts that feedbacks between the subcortical and cortical system are likely, arguably making them an integrated system. In line with anatomical data on human newborn brains that showing that V1 neurons (i.e., primary visual cortex) are able to receive and convey information to other neurons (LeRoy Conel, 1939), the authors suggest that those neurons are involved in face preference at birth, together with other occipital cortical areas and subcortical structures, such as the superior colliculus. In this vein, face processing at birth is underlying by low-level (V1) processing and by subcortical structures (face-preference model), whereas the subsequent face processing mode (face-learning model) is the result of the combined development of low- and higher-level (V1 and Fusiform gyrus) adaptive processing (Acerra et al., 2002). Newborns' face preference is thought to be due to the cumulative and combined effect of tuning properties of visual neurons in V1 for low spatial frequencies and the limitations of the immature visual system at birth, that give a perceptual advantage to faces compared to most other visual stimuli (Figure 10).

Figure 10: As a newborn baby see a human face (Olivetti research Laboratory Database; Samaria & Harter, 1994; Acerra et al., 2002)

Although the computational model assumes that the mechanisms underlying face preference at birth are general and not face-specific like Conspec, Acerra and colleagues and Johnson and Morton's model share the idea that orienting responses towards faces present at birth allow newborns to select and acquire visual information on some aspects of face during the gradual maturation of the right fusiform gyrus, which is found to be active around 2 months of age (Tzourio-Mazoyer, de Schonen, Crivello, Reutter, Aujard, &

Mazoyer, 2002). The maturation of the FFA and of other cortical and subcortical structures occurs during this early period.

Importantly, the computational model is consistent with the *Linear System Model* (LSM) proposed by Banks and Salapatek (1981), suggesting that newborns prefer to look at what they see better, due to the limitations of their visual system. It is possible that face preference develops because certain neurological constraints (e.g., immature cortex), predispose newbrons to find particular characteristics of visual stimuli attractive and such characteristics, such as high contrast areas or curves, are found in faces as well as in other stimuli (Easterbrook, Kisilevsky, Hains, & Muir, 1999). Any two-dimensional, achromatic pattern can be described on the basis of the spatial frequencies, amplitude (contrast), orientation and phase of its constituent sine wave gratings. For any patter, two functions may be derived: the amplitude spectrum, comprising the amplitude and orientation of the component spatial frequencies, and the phase spectrum, comprising the phase and orientation of the components. The LSM holds that the attractiveness of a pattern is determined solely by the amount of effective energy of that pattern. The amplitude spectrum of the pattern is filtered through the Contrast Sensitivity Function (CSF) of the subject, which indicates the inverse of the contrast that is necessary for the subject to detect sine waves of different spatial frequencies and the amplitude and the phase spectra of the stimulus, obtained by the decomposition of the stimulus in sine waves of different spatial frequencies according to the Fourier trasform (Acerra et al., 2002, p.99). Each age has an appropriate CSF, so in newborns CSF removes all information at frequencies greater than 2 cycles per degree (c/d). In a choice situation, newborn's visual preference are for those stimuli that provide spatial frequency and contrast information that fits the visual window (i.e., the CSF) better that the pattern with which it is paired (Figure 11).

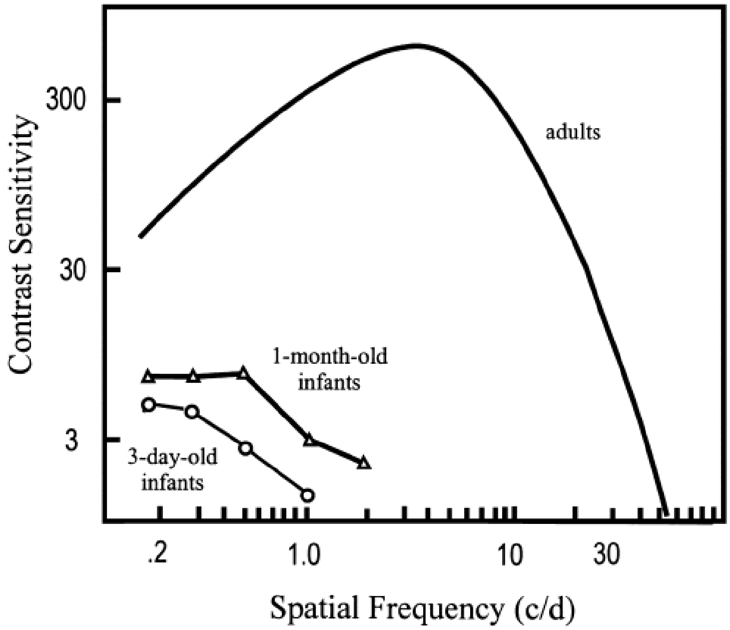


Figure 11: Contrast Sensitivity Functions for adults and 1-month-old infants and the CSF for 3-day-old infants (from Banks & Ginsburg, 1985; Acerra et al., 2002).

The sensory hypothesis claims that newborn's preferences for visual patterns are determined solely by their visibility. In this vein, faces are not different from other visual stimuli. In other words, this model accounting for newborns' visual preferences in terms of the match between the characteristics of the newborns visual system and the psychophysical properties of the stimuli as described by both the low level properties (i.e. contrasts and spatial frequencies content described by the amplitude spectrum) and higher level variables (i.e., the structural properties of a stimulus described by the phase spectrum) according to the Fourier's transforms. This sensory hypothesis suggests that the newborns' preference for a visual stimulus is determined by the amplitude spectra of the pattern filtered by the CSF of the newborns and when two stimuli with identical amplitude spectrum, the infant's visual preference is determined by their phase spectrum (Kleiner, 1987).

Consistent with the LSM model, an *alternative account* explains face preference at birth as due to the match between perceptual and structural properties present in a face and the constraints of the newborns' sensory system (Simion et al., 2001; Simion, Macchi Cassia, Turati, & Valenza, 2003). This alternative hypothesis suggests that the presence at birth of non-face-specific attentional biases is sufficient to produce the emergence of the functional and neural specialization for faces observed later during development. The adult face processing system appears thus capable of bootstrapping from minimal information, not requiring highly specific predispositions. Considering the alternative view, face preference at birth would be the result of the cumulative effect of a set of non-specific constraints that stem from the general characteristics of the immature visual system and a collection of general structural properties that attracts newborns' attention. This claim derives mainly from the demonstration that, besides facedness, newborns manifest spontaneous preference for other structural properties of visual stimuli. For example, when horizontal gratings were paired with vertical gratings, newborns preferred the horizontal ones (i.e., Slater, Earle, Morison, & Rose, 1985; Farroni, Valenza, Simion, & Umiltà, 2000). Because the patterns were equated for quantity of energy (Low Spatial Frequencies), one can assume that orientation, which is a structural property of the stimulus, was the crucial factor in determining the preference for horizontal gratings. Therefore, facedness might be preferred because of the addictive effect of a collection of structural and perceptual properties. Indeed, faces are symmetrical along the vertical axis, present more patterning in the upper compared to the lower half and have rounded rather straight edges. The possibility exists that some, if not each of these properties, plays a role in promoting the newborns' attentional response toward face-like stimuli and veridical face images.

Many studies showed that at least two non-specific structural properties not only are preferred at birth when embedded in non-face geometric configurations (Macchi

Cassia, Simion, Milani, & Umiltà, 2002; Simion, Valenza, Macchi Cassia, Turati, & Umiltà, 2002; Macchi Cassia, Valenza, Simion, & Leo, 2008), but also play a major role in determining newborns' preference for faces (Macchi Cassia et al., 2004; Turati, Simion, Milani, & Umiltà, 2002). Indeed, newborns' visual preferences have been related to a larger sensitivity to visual patterns presenting a greater number of high-contrast elements in the upper compared to the lower part of the stimulus, rather than to facedness per se (i.e., up-down asymmetry, Simion et al., 2001, 2002; for a review, Simion, Di Giorgio, Leo, & Bardi, in press). For instance, it has been demonstrated that newborns orient their gaze more frequently to, and look longer at, geometrical stimuli with more elements in the upper part when contrasted with the upside-down version of them (Simion et al., 2002) (Figure 12).

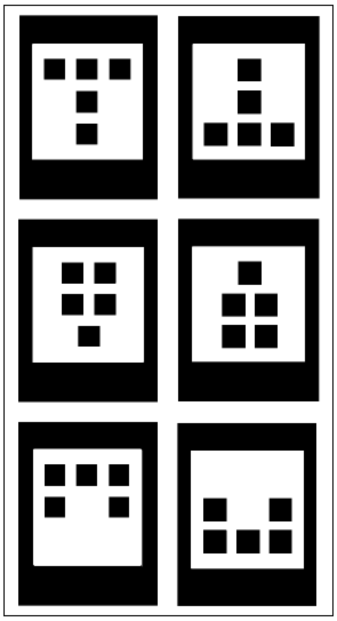


Figure 12*:* Stimuli used to investigate the up-down asymmetry with geometrical stimuli (from Macchi Cassia et al., 2002).

The same results were replicated with face-like stimuli (Turati et al., 2002) and with real faces (Macchi Cassia et al., 2004) in which the geometry of the face was disrupted. Indeed, Turati and colleagues (2002) demonstrated that an upright stimulus with two blobs randomly located in the upper part, and only one blob in the lower, was always preferred over the upside-down stimulus, thus showing that the correct face disposition of the inner elements is not necessary to induce a preference (Figure 13).

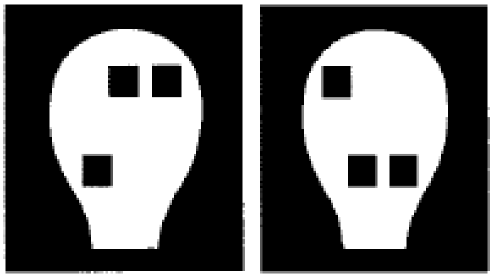


Figure 13: An upright stimulus with two squares randomly located in the upper part and one located in the bottom part is preferred over the upside-down stimulus (from Turati et al., 2002).

Furthermore, when face-like and non-face-like pattern are equated for the number of elements in the upper part of the configuration newborns' face preference disappears (Turati et al., 2002) (Figure 14).

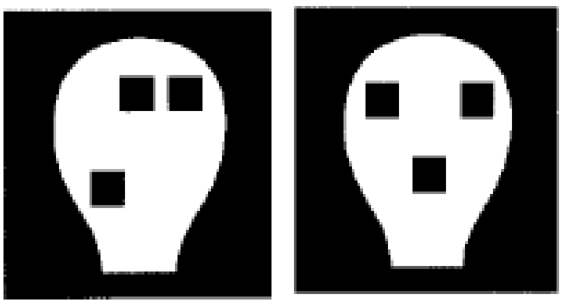


Figure 14: Newborns' preference disappears when the two facelike are equated for the number of elements in the upper part (from Turati et al., 2002).

Even more interesting is the result showing a visual preference for a non-face-like arrangement of elements located in the upper portion of the stimulus over a face-like arrangement positioned in the lower portion of the pattern (Turati et al., 2002) (Figure 15).

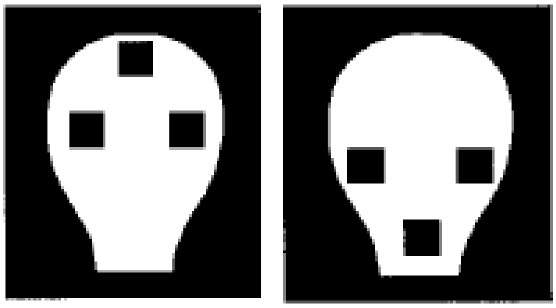


Figure 15: Newborns prefer a non-facelike pattern with more elements in the upper part (from Turati et al., 2002).

These results strongly suggested that when facedness and up-down asymmetry were directly contrasted, the upper position of the elements within the contour (i.e., up-down asymmetry), rather than the spatial relations among the blobs (i.e., facedness), proved to be the crucial factor in determining newborns' preference. The same conclusion was supported by similar results obtained using real faces and manipulating the position of the inner features within the face (Macchi Cassia et al., 2004). Newborns preferred a scrambled face with more features in the upper part (Figure 16); moreover they and did not manifest any visual preference between a real face and a scrambled face equated for the number of features appearing in the upper halves (Figure 17). Finally, when a veridical face was contrasted with a scrambled face with more elements in the upper part, newborns manifested a preference for the scrambled face (Simion et al., 2006).

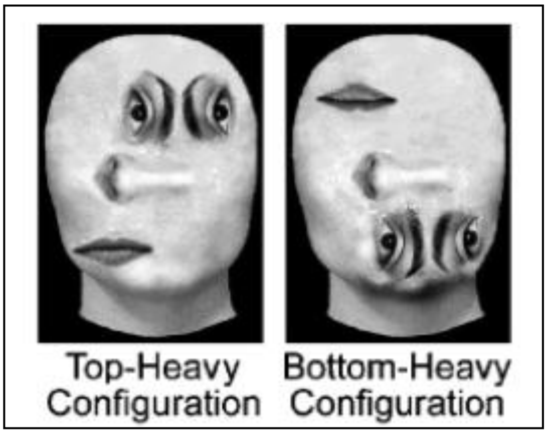


Figure 16*:* Real face images employed to demonstrate the up-down asymmetry (from Macchi Cassia et al., 2004).

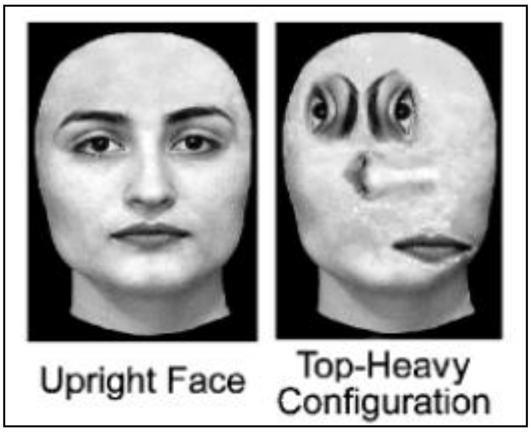


Figure 17*:* Newborns did not manifest a preference when the two faces are equated for the number of elements in the upper half (from Macchi Cassia et al., 2004).

These findings suggest that it may be unnecessary to assume the existence at birth of a subcortical "face detector" sensitive to face geometry. Rather, newborns' face preference likely results from a general attentional proclivity toward top-heavy stimuli, which may in turn derive from endogenous constraints of the newborns' visual system. Specifically, Simion et al. (2002) suggested that a possible explanation might derive from the existence of an upper versus lower visual field difference in visual sensitivity, similar to that already observed in adults (e.g., Heywood & Churcher, 1980; Rizzolatti, Riggio, Dascola, & Umiltà, 1987). Newborns may find top-heavy patterns more easily detectable than other stimuli because of the existence at birth of an upper-visual-field advantage in visual sensitivity. This advantage is supposed to be due to a major role in visual exploration of the upper visual field played by the superior colliculus (Sprague, Berlucchi, & Rizzolatti, 1973), which is supposed to affect consistently newborns' visual behavior (Atkinson, Hood, Wattam-Bell, & Braddick, 1992).

The second non-specific property that can explain face preference at birth is the presence of a *congruent* or corresponding relationship between the shape and orientation of the contour and the spatial disposition of the included features. Faces can be described as a congruent configuration, since they display a greater number of features (the eyes) in the wider, upper portion of the face outline and only one feature (the mouth) in the narrower part. The hypothesis that congruent visual configurations may be preferred at birth over non-congruent patterns appears reasonable in light of two lines of evidence. First, newborns are highly sensitive to configural–holistic properties emerging from the interrelations between the component parts of the stimuli. For instance, they can perceive the invariance of the spatial relationship between single features, which vary in their absolute position within an array (Antell, Caron, & Myers, 1985). Also, newborns are able to group separate sets of elements according to Gestalt principles (Farroni et al., 2000, Figure 18), and they find configural and global cues in hierarchical patterns more easily detectable than featural and local information (Macchi Cassia et al., 2002). Second, based on Gestalt theories of visual perception (Palmer, 1991), in comparison to non-congruent configurations, congruent configurations provide a better fit for the criteria of figural simplicity and regularity that render visual patterns more easily and economically processed and represented by the human perceptual system.

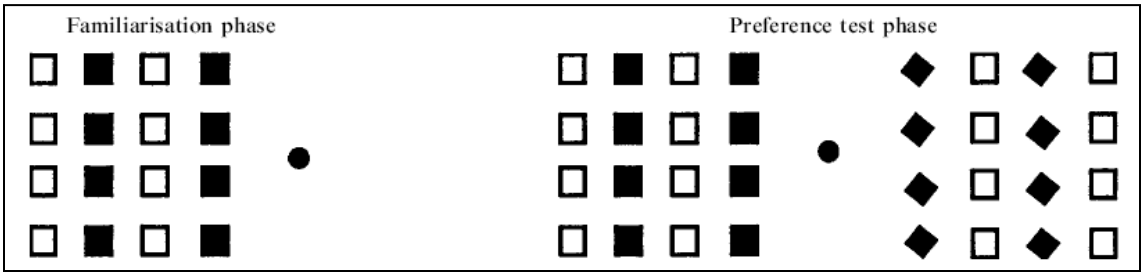


Figure 18: Stimuli employed to demonstrate newborns' ability to group separate sets of elements according to Gestalt principles (from Farroni et al., 2000).

Because newborns have been shown to perceive and organize visual arrays according to Gestalt principles, such as lightness similarity (Farroni et al., 2000) and common motion (Valenza & Bulf, 2007), it seems reasonable to hypothesize that newborns may be sensitive to other stimulus dimensions that contribute to figural goodness, such as symmetry, repetition, and regularity. Each of these dimensions is maximally present in congruent visual configurations. Evidence revealed that when congruent and non-congruent non-face configurations were compared (using both triangles and trapezoids), a reliable tendency to prefer the congruent pattern was observed in newborns. A top-heavy congruent stimulus was preferred over a top-heavy non-congruent stimulus, thus indicating that the congruency and top-heavy properties have an additive effect on newborns' preferences (Macchi Cassia et al., 2008) (Figure 19).

Overall, the results described here support the idea that face preference is a preference for some general perceptual and structural properties that faces share with other visual stimuli.

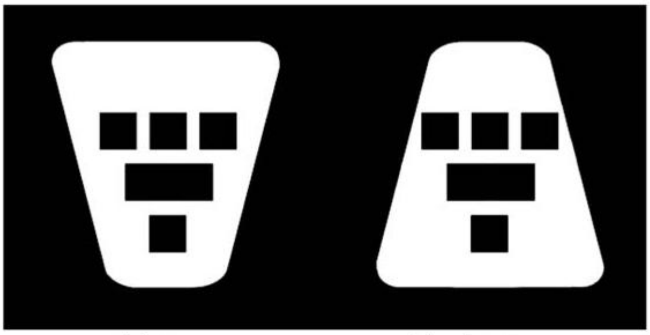


Figure 19: Stimuli employed to demonstrate that a top-heavy congruent stimulus was preferred over a top-heavy non-congruent stimulus (Macchi Cassia et al., 2008).

3.3 The nature of face representation at birth and in the first few months of age

As well as the debate concerning the mechanisms underlying face preference at birth, another long-standing issue concerns the nature of the face representation at birth. There is agreement about the idea that humans might be born with some representation of the human face (Johnson & Morton, 1991; Valenza et al., 1996; Macchi Cassia et al., 2004), but a still open question concerns whether this face representation is innate and a product of an evolutionary pressure or whether it is only a product of a rapid learning process from experience with faces during the first hours of life.

Several empirical findings support the *nativist hypothesis*, suggesting that newborn babies may begin life with a specific representation of the human face (Slater & Kirby, 1998; Slater, von der Schulenburg, Brown, Badenoch, Butterworth, Parsons, & Samuels, 1998; Meltzoff & Moore, 1977; Slater & Quinn, 2001). From this perspective, an early appearing representation bias that is specific to faces may be more elaborate than a preference for three dark dots in a triangle corresponding to eyes and mouth (e.g., Config). Indeed, newborns imitated a variety of facial gestures that they see, giving aid to the hypothesis that the innate face representation might be very detailed from the beginning (Meltzoff & Moore, 1977). The authors maintained that this could not be possible without a specific and innate representation of their own face. Recently, Quinn and Slater (2003) suggested that the face-processing system could be innately provided by evolutionary pressure and that newborns' initial face representation could be formed through proprioception in utero, since proprioceptive feedback provided by facial movements could contribute to the formation of a face specific representation at birth. In this vein, the face representation formed in utero would be responsible of orienting of attention toward matching configurations (i.e., other kinds of faces). However, Pascalis and Kelly (2009) suggested that if the exact mechanisms supporting early face preference remain unclear, it could include both fast learning based on early interactions in the post partum period as well as an innate system selected by evolution. Considering the limited amount of experience newborns have with a limited number of face, it could be suggested that face representation will be crude in the first days of life. With experience, the human specificity of the representation will increase.

An alternative interpretation of face preference at birth is in term of prototype and cognitive averaging process ("*learning account*", Langlois & Roggman, 1990; Rubenstein, Kalakanis, & Langlois, 1999). Learning about faces and the formation of a representation of faces might be extremely rapid in the first days of life and according to a single study, newborns might be able to form a face representation in less than 1 minute after birth (Walton & Bower, 1993). The results of a preference for attractive over non-attractive faces have been interpreted as in favour of the learning account hypothesis, since attractive faces might match more closely the prototype that newborns have formed during their brief experience in the first hours after birth (Slater & Kirby, 1998; Slater, Bremner, Johnson, Sherwood, Hayes, & Brown, 2000; Slater, Quinn, Hayes, & Brown, 2000). However this interpretation has been questioned by recent results showing that the preference for attractive face is not human-specific. These findings corroborate the idea that the initial settings of our perceptual system push infants to look at some entities because of the presence of a family of preferred perceptual features (Quinn, Kelly, Lee, Pascalis, & Slater, 2008).

In line with this interpretation face preference at birth may be a product of a general perceptual and information processing mechanism that subsequently becomes "tuned" to human faces as a direct consequence of the extensive experience with this stimulus category provided by the species-typical environment within the first days of life (Scott et al., 2007). This "*perceptual narrowing*" hypothesis (Lewkowicz & Ghazanfar, 2006; Nelson, 2001, 2003) suggests that at birth, the nature of face representation is broadly general and that subsequently becomes finely tuned as a function of the progressive increase in the selectivity and localization of the cortical circuits involved in face processing, due to the facial input received (Johnson, 2000). This concept of a face representation is well understood within the framework of the multidimensional face space model proposed by Valentine (1991). This norm-based coding model suggests that faces are encoded as vectors according to their deviation from a prototypical average of the face space. As proposed by Nelson (2001), this face prototype is broadly tuned at birth and the dimensions that this prototype encodes may differ both qualitatively and quantitatively in infants compared with adults. Pascalis and colleagues (2005) suggested that "a good way to think about the development or formation of a face prototype is based on the experience or kinds of faces one meets. For example, if this prototype is thought of as a continuum of all incoming faces, then the more a face deviates from the prototype (other-race and other-species faces), the less this face is easily discriminated, compared with faces that are more similar to the prototype. Importantly, the development of the face prototype is likely influenced by a number of factors, including exposure time (number of faces seen), dynamic and emotionally salient information provided within the face and changes in the categorization of individuation of people. Combined, these experiences gradually lead to the face prototype becoming more specific (Pascalis et al., 2005, p. 5298)". The development of face prototype is greatly influenced by the experience with certain kinds of faces present in the environment, as well as the exposure time to those faces (Pascalis, Scott, Kelly, Shannon, Nicholson, Coleman, & Nelson, 2005).

Early in life, infants possess a remarkable ability to discriminate among and between a large corpus of different faces, such as faces from an unfamiliar species or an unfamiliar race. With experience, the infant's face-representation system becomes more precise and increasingly restricted to faces with which infants are most familiar. This, in turn, results in the development of expertise, in which the ability to discriminate between faces that one has not been exposed to (or has had less exposure to) is not as good as discrimination between faces which one has experienced. An intriguing demonstration of perceptual narrowing and of the importance of early visual experience has recently been observed in animals by Sugita (2008). In this study, infant Japanese macaques were separated from their mothers at birth and reared by human caregiver for 6-24 months. During this period, the monkeys had no interaction with other monkeys or with humans. Indeed, the monkeys were prevented from seeing any faces: human caregivers wore masks whenever interacting with the monkeys. When tested using a preferential looking paradigm during the deprivation period, all monkeys showed a preference for both monkey and human faces over objects. But when human and monkeys faces were presented simultaneously, monkeys did not exhibit a preference for either category of face. After the deprivation period, the infant monkeys were exposed for the first time to either human faces or monkey faces. Interestingly, when monkeys were tested a month after the deprivation period, their preferences had altered. Indeed, they exhibit a preference for facial features to which they were exposed. Monkeys that were exposed to human faces showed a preference for human faces. In contrast, monkeys that were exposed to monkey faces manifested a preference for monkey faces. These results seems to be consistent with the hypothesis of the existence of a broadly tuned face representation at birth as well as an apparent sensitive period during which a broad but flexible face prototype develops into a concrete one for efficient detection of familiar face thanks to the visual experience (see Di Giorgio, Leo, Pascalis, & Simion, *submitted*). Specifically, according to Nelson's hypothesis, the face processing system should become specific to human faces around or soon after three months, as a function of the faces seen in the visual environment (de Schonen and Mathivet, 1989; Nelson, 2001). An example of how the social environment influences the tuning of face processing during the first months of life is the so called "other-gender effect". It has been demonstrated that 3-month-old infants prefer to look at female faces when paired with male faces and this preference was interpreted as a gender bias of the face prototype toward the primer caregiver (Quinn, Yar, Kuhn, Slater, & Pascalis, 2002). Another example is the well known "other-race effect" (ORE), in which adults find it easier to differentiate faces from their own ethnic group (Meissner & Brigham, 2001). It has been demonstrated that selectivity based on ethnic facial differences emerges at the same age, with 3-month-old infants preferring to look at faces from their own group, as opposed to faces from other ethnic groups (Bar-Haim, Talee, Lamy, & Hodes, 2006; Kelly, Slater, Lee, Gibson, Smith, Ge, & Pascalis, 2005). The lack of preference for either own-or other-race faces in newborns indicates that the infant's face representation may be "ethnically unspecified" at birth, but is subsequently shaped according to the ethnicity of faces viewed within the visual environment (Kelly et al., 2005). A final example of the importance of early experience is the "other-species effect": 6-month-old infants are able to discriminate between both human and monkey faces, but the ability to discriminate monkey faces has diminished by 9 months of age (Pascalis et al., 2002).

The neuropsychological equivalent of this process of perceptual narrowing would be an increase in the selectivity and localization of the cortical circuits involved in face processing (Johnson, 2000). Over time, these circuits would pass from being activated by a broader range of stimuli to responding to only certain kinds of stimuli, thus leading to a more localized and specialized neural response. Note that this recently proposed model of face processing development differs from that previously proposed by Johnson and Morton (1991) in that it assumes that general, rather than specific initial input, is sufficient to set the stage for the development of the face processing system into its adult-like, specialized form. Indeed, some recent neuropsychological studies that measured event-related-potential (ERP; Halit, de Haan, & Johnson, 2003) or performed positron emission tomography (PET) scans (Tzourio-Mazoyer et al., 2002) suggested that, by 2-to 3-months of age, there are the first signs of cortical specialization for faces.

Considering the evidence of face processing specialization within the first months of life, several behavioral studies were carried out to verify whether the same general biases that induce face preference at birth, such as the top-down asymmetry and the congruency, still operate and explain face preference three months later. For instance, it has been demonstrated that upright natural faces are still preferred and this result confirms the presence of the "inversion effect" at three months of age (Turati et al., 2005). This preference for the upright face was present not only when the face was contrasted with an inverted face, which has fewer elements than the face in the upper part, but also when it was contrasted with a scrambled face equated for the number of elements in the upper half (Turati et al., 2005; Macchi Cassia, Kuefner, Westerlund, & Nelson, 2006). Crucially, when an image of an upright face was presented together with a top-heavy scrambled face with a greater number of elements in the upper part of the configuration, 3-month-olds still manifest a preference for the face (Simion et al., 2006). Altogether, these results showed that 3-month-old infants always prefer the real face, demonstrating that at this age the up-down asymmetry in the distribution of the inner features can no longer be considered as a crucial factor able to induce infants' preference for a face. Such pattern of evidence differs from that observed at birth, where faces are no longer preferred if they are paired with configurations equated with up-down asymmetry (Macchi Cassia et al., 2004; Turati et al., 2002).

To summarize, from the results described here, at birth face preference seems to depend on the existence of general biases that orient newborns' attention toward certain structural properties that faces share with other complex visual stimuli (Simion et al., 2001, 2002; Turati et al., 2002). In contrast at 3 months of age the face preference appears to be the product of more specific mechanisms that respond more selectively to those perceptual characteristics that distinguish faces from other stimulus categories. These data suggest the existence of different mechanisms that underlie face preference at birth and in 3-month-old infants. This is line with an experience-expectant perspective (Nelson, 2003) that highlight the importance of both general constraints of the human visuo-perceptual system and exposure to certain experiences shortly after birth to drive the system to become functionally specialized to process faces in the first months of life.

Considering this literature, Study 1 explores in more detail the nature of face representation at birth and its development in the first 3 months, investigating on one hand which of the properties embedded in a face attract newborns' and 3-month-old infants' attention (e.g., the position of the eyes and their orientation in the natural arrangement in the face; Experiments 1-3), and, on the other hand, investigating whether early facial representation is human-specific (Experiments 4-7).

3.4 Study 1

Despite the vast amount of literature that investigated face preference at birth, a matter of dispute concerns which of the properties embedded in a face attract newborns' attention, such as the position of the eyes and their orientation in the natural arrangement in the face.

It has been demonstrated that the *eyes* play an important role to attract newborns' attention compared to others internal elements located in a face (e.g., Batki, Baron-Cohen, Wheelwright, Connellan, & Ahluwalia, 2000). Indeed, developmental studies demonstrated the relevance of the eyes perception in newborns in eliciting a face preference. For example, newborns preferred real face with eyes open rather than the same face with eyes closed (Batki et al., 2000), and they preferred a face that engages them in eye contact (Farroni, Csibra, Simion, & Johnson, 2002). Further a recent study with newborns demonstrated that when the eyes are occluded, face preference disappears, whereas when hindered features are not salient (i.e., mouth or nose) face preference is preserved (Gava, Valenza, Turati, & de Schonen, 2008). Furthermore, studies of infants' scanning suggest that four-month-old infants spend more time exploring internal features, when they are habituated with an upright face (Gallay, Baudouin, Durand, Lemoine, & Lécuyer , 2006) and that, around 3-

months of age, among all of the facial features, the eyes appear to be of particular importance in face perception (Hainline, 1978) independently from their location in the face (Maurer, 1985).

With this in mind, Experiments 1, 2 and 3 were aimed at investigating which of perceptual cues (i.e., position and orientation of eyes within a face) make face so attractive at birth and at 3 months of age. Two variables have been manipulated: the position (Experiment 1) and the orientation of the eyes (Experiments 2 and 3) within a face.

Experiment 1

The aim of experiment 1 was to test whether at birth the position of the eyes within a face is relevant to induce a face preference.

Method

Participants

Participants were 12 (4 females) healthy, full term newborns (mean age 43.5 hours), recruited at the maternity ward of the Pediatric Clinic of the University of Padova. All of them were middle-class infants and Caucasian. Four additional newborns were tested, but were not included in the final sample because one showed a strong position preference (i.e., he looked to one direction more than 80% of the time) and three did not complete testing due to fussiness. All of them met the screening criteria of normal delivery, a birth weight between 2445 and 4280 g, and an Apgar score between 9 and 10 at 5 minutes. Newborns were tested only if they were awake and in an alert state (Prechtl & O'Brien, 1982), after parents gave their informed consent. The ethic committee of the Hospital of Padova, where all the testing was conducted, granted permission.

Stimuli

Three pairs of stimuli were presented, each composed of an upright canonical face and the same inverted face with the eyes correctly oriented but located in the lower part (Figure 20). Black-and-white photographs of women's faces were used. Photographs were modified with Adobe Photoshop 7.1. More specifically, hair was removed from each photograph and, on the upside-down face, only the inner portion of the face was rotated 180° whereas the orientation of the eyes was keep constant, although positioned in the lower part. The stimuli were about 18 cm high X 11.5 cm wide (about 34° X 26° of visual angle).

Figure 20: Stimuli employed in Experiment 1 to investigate the role of the position of the eyes within a face to induce newborns' preference.

Apparatus

The newborn baby sat on the experimenter's lap, 30 cm from a 30-inch computer screen (2560 x 1600). Infants' eyes were aligned with a red flickering LED at the center of the screen, which was used to attract the infant's gaze at the start of each trial and to check that the infant's sight was level with the horizontal midline of the screen during the testing session. Both stimuli were projected bilaterally on a black screen at a distance of approximately 8 cm (15°) from a central fixation point. A video camera, mounted above the central screen, recorded the infant's eyes movements. To prevent interference from irrelevant distracters, plain white curtains were drawn on both sides of the chair where the experimenter sat with the baby in her lap.

Procedure

The experiment was carried out using a preferential looking procedure, previously used with newborns (Simion et al., 2002). Every trial began with the center flashing light. When the infant fixated the light, one of the experimenters, who watched the infant's eyes by means of a video monitor system, started the sequence of the trial by pressing a key on the computer keyboard. This automatically turned off the central LED and activated the slide projector, which presented the stimuli on the screen. The stimuli remained on as long as the infant fixated on one of them (infant control procedure). When the infant shifted the gaze from the display for more than 10 s, the observer turned off the stimuli and the center light automatically turned on. All the infants were submitted to two trials in which the two stimuli were shown bilaterally, one on the left and one on the right of the central LED. Left/Right position of the stimuli was counterbalanced between the trials. The session ended when the baby did not look at either stimulus for more than 10 s. Videotapes of infant's eye movements throughout the trial were subsequently analyzed frame by frame by two coders (an experimenter and a student); both coders were unaware of the kind of stimulus presented. The coders recorded, separately for each stimulus and each position, the total fixation time, that is, the sum of all fixations, and the number of orienting responses. The mean estimated reliability between on-line and off-line coding was r (10) =

.87, $p <. 001$, N = 12 (Pearson correlation) for either dependent variable (total fixation time and number of orientations).

Results and Discussion

To determine whether newborns showed a spontaneous visual preference toward one of the stimuli presented, two separate *t*-test for dependent samples were performed to compare total fixation time and the number of orienting response. Newborns looked longer at the canonical face (*M* = 51443 ms, *SD* = 16332) compared to the same inverted face whit the eyes correctly oriented but located in the lower part (*M* = 34922 ms, *SD* = 14866), t (11) = 2.7, $p < .02$. Effect size analyses revealed that newborns' preference for upright canonical face corresponded to a medium-large effect size in Cohen's standard (Cohen, 1988) (Cohen's d = .70). Additional analyses were conducted on preferences scores (percentages) for the natural face. Each infant's looking time at canonical face was divided by the total looking time on both test stimuli and converted into a percentage score. Therefore, only scores significantly above 50% indicated a preference for the upright canonical face compared to the face with the eyes located in the lower part. Preference score for the canonical face were significantly above the chance level of 50 per cent (*M* = 59.7%, *SD* = 18.1, one sample t (11) = 2.9, $p < .02$ (Cohen's d = .72). As regard to the number of orientations, this dependent variable did not reach the significant level. Results demonstrated that newborn infants preferred the canonical upright face, where all the inner elements are correctly positioned and oriented. However, this results could be due to the newborns' preference toward configurations with more elements in the upper part (i.e., top-down asymmetry). To verify this issue, Experiment 2 presented newborns with two faces with the same number of inner elements in the upper part (i.e., the eyes) and that differed only for the orientation of the eyes.

Experiment 2

Method

Participants

The final sample was formed by 12 (7 females) healthy, full term newborns (mean age 46.3 hours), recruited at the maternity ward of the Pediatric Clinic of the University of Padova. All of them were middle-class infants and Caucasian. Two additional newborns were tested, but were not included in the final sample because they showed a strong position preference (i.e., he looked to one direction more than 80% of the time). All of them met the screening criteria of normal delivery, a birth weight between 2650 and 3780 g, and an Apgar score between 8 and 10 at 5 minutes. Newborns were tested only if they were awake and in an alert state, after parents gave their informed consent.

Stimuli

Three pairs of stimuli were presented, each composed of an upright canonical face and the same face with the eyes correctly located in the upper part of the face but misoriented (Figure 21). Black-and-white photographs of women's faces were used. Photographs were modified with Adobe Photoshop 7.1.

Figure 21: Stimuli employed in Experiments 2 and 3 to investigate the role of the orientation of the eyes within a face in inducing newborns' and 3-month-old infants' preference.

Apparatus and Procedure

The apparatus and the procedure were the same of those described in Experiment 1.

Results and Discussion

To verify whether the correct orientation of the eyes was a perceptual cue sufficient to elicit newborns' preference for the canonical face, two separate *t*-test for dependent samples were performed to compare total fixation time and the number of orienting response. Newborns did not look longer at the canonical face (*M* = 31882 ms, *SD* = 15301) compared to the same face whit the misoriented eyes (*M* = 33962 ms, *SD*= 13522), *t* (11) = .29, *n.s.* A preference score was also computed as in Experiment 1, revealing that the mean preference score for the canonical face was 47.7% (*SD* = 16.3) and did not differ significantly from the chance level of 50%, *t* (11) = .12, *n.s.* Finally, also the number of orientations did not reach the significant level.

Thus, the present result indicated that newborns were not sensitive to the orientation of the eyes within a face, corroborating the idea that face representation at birth is broad and not sensitive to specific cues within a face. However, in line with the literature that demonstrated the effect of the visual experience for the formation of a specific face representation in the first few months of life, it seemed relevant to investigate whether 3-month-old infants were sensitive to the correct orientation of the eyes within a face (Experiment 3).

Experiment 3

Method

Participants

Participants were 12 3-month-old healthy and full-term infants (7 females, mean age = 98 days). They were middle-class infants and all of them were Caucasian. Five additional infants were tested but not included in the final sample because they showed a strong position preference (i.e., they looked to one direction more than 90% of the time). Infants were tested only if awake and in an alert state after parents gave their informed consent.

Stimuli

The same stimuli used in Experiment 2 were employed in Experiment 3.

Apparatus

The experiment was run using an apparatus that allows the automatic recording of eye movements direction because of an infrared camera (i.e., an eye-tracker system). Infants were placed in an infant seat at a distance of about 60 cm from the computer screen where the stimuli were presented. A system for the automatic registration of eye movements made by Applied Science Laboratories (ASL) was employed and consisted of an infrared camera located at the bottom of the computer screen. Using a remote control and a live image of the participant's left eye, an experimenter, blind to the purpose of the study, guided the camera to keep the participant's eye constantly in focus. The eye-tracking system automatically detected the position of the pupil and the corneal reflection of the infrared light-emitting diodes (LEDs) in the eye. Because these signals changed as a function of the observer's gaze direction, the apparatus determined, with a frequency of 50 Hz, the x-y coordinates corresponding to the participant's fixation points during stimulus presentation. Two crosses of different colors corresponding to the signals coming from the participant's pupil and corneal reflection were superimposed on the images of the stimuli presented, giving a second experimenter a direct indication of the quality of the signal collected during the experiment. Stimulus presentation and data collection were performed using E-Prime 1.1.

Procedure

Each infant was tested on a single occasion in a quiet and dark room, seated approximately 60 cm from a 19-inch (1024 x 768 pixels) computer screen. The experiment started with a calibration phase immediately followed by the habituation phase and the test phase. During calibration, a smiley face cartoon was presented in the center of the screen. When the infant started to look at it, the smiley moved to the top left corner of the screen and remained in this position until the infant fixated it. Then, it moved to the bottom right corner and remained in this position. These three positions were used to compute the pupil-corneal reflection from three points on the screen, allowing the system to derive gaze direction during test phases. Calibration accuracy was checked and repeated if necessary.

A visual preference procedure adapted to 3-month-old infants was used. Applying the ASL algorithm, a fixation was defined as a period of a least 100 ms during which the fixation point did not change by more than 1 degree of visual angle. The experimental session began with the presentation, in the middle of the screen, of a central fixation point particularly attractive for the infant (i.e., a colored moving smiley). This central fixation point was used to attract infants' attention toward the computer screen where the stimuli were shown, and to check that the infants' gaze was aligned with the horizontal midline of the screen during the entire experimental session. As soon as the infant looked at the central fixation point, the first pair of stimuli automatically appeared on the computer screen and the central fixation was removed. Each stimulus pair was presented for 8 s. Afterwards, the central fixation point reappeared in the middle of the screen and the trial loop started again. Each of the five pairs of stimuli was presented four times, in a pseudorandom sequence, for a total of 20 trials. The left vs. right position of the stimuli within each pair was counterbalanced. A software program processed the raw data coming from the eye-tracker system, calculating infants' total fixation time toward the upright canonical face and the same face with the eyes misoriented.

Results and Discussion

Two separate series of statistical analyses were performed. The first series of analyses were concerned with the overall looking time on the stimuli. In this way, the eye-tracker potentials were used to avoid human coders, and data obtained paralleled those classically registered in a visual preference paradigm. So results obtained with 3-month-old infants in Experiment 3 were comparable with those obtained with newborns in Experiment 2. It is important to note that, at present the eye-tracker system is inappropriate for use with newborns because of the poor differentiation of the pupil at birth, that renders almost impossible for the infrared camera to detect the position of the pupil and the corneal reflection of the infrared light-emitting diodes in the newborns' eye. A second series of analyses were run to examine which perceptual cues within the canonical face and the face with the misoriented eyes attracted infants' gaze, an opportunity allowed by the eye-tracker.

Overall total looking time

To test whether 3-month-old infants exhibited a visual preference toward one of the stimuli presented, *t*-test for dependent samples were performed to compare total fixation time. Statistical analyses revealed that 3 months infants looked longer the canonical face (M = 19512 ms, SD = 11082) compared to the face with the misoriented eyes (M = 15600 ms, SD = 8688), t (11) = 3.06, $p < .02$ (d = 1.1). Moreover, the mean preference score for the canonical face was above the chance level (M = 55.8%, SD = 4.8), t (11) = 4.27, $p < .02$ (d = 1.2). These findings clearly demonstrated that the 3-month-olds' gaze seems to be attracted by the interrelation between the arrangement of the inner features and by the position and orientation of the single facial features (i.e., eyes correctly oriented and located in the upper part of a face).

Distribution of looking time

To understand which perceptual cues of each stimulus attracted infants' gaze, a series of statistical analyses were performed on percentage of looking toward four selected areas (i.e., areas of interest, AOI) corresponding to the upper and the lower parts of each stimulus within the pair. One-sample t tests were applied to verify whether such percentages of looking differed from a chance level of 25%. The following distribution of looking was observed. The 3-month-old infants looked at the upper half of the canonical face for 14243.2 ms, corresponding to 41% of total fixation time (M = 40.8%, SD = 13.9), *t* (11) = 3.7, *p* < .05 (d = .39), and at the lower part for 5266.8 ms of the face corresponding to 15% (*M* = 15.3%, *SD* = 11.3), *t* (11) = 2.9, *p* < .05 (d = .63). The upper half of the face with misoriented eyes was fixed for 11587 ms corresponding to 33% of total fixation time (*M* = 33.1%, *SD* = 11), *t* (11) = 2.5, *p* < .05 (d = .25), and the lower part for 4014.3 ms corresponding to 11% of total fixation time (*M* = 10.7%, *SD* = 8.3), *t* (11) = 5.7, *p* < .01 (d = 1.3). Taken together, these findings indicated that, contrary to newborns' performances, 3-month-old infants showed a preference for the canonical human face, showing that at this age infants are sensitive to the face-specific perceptual characteristics.

Conclusion from Experiments 1-3

The main aim of those experiments was to explore which perceptual cues, such as the location and the orientation of the eyes within a face, are relevant in inducing a face preference in newborns and whether these perceptual cues were able to elicit the same preference in 3-month-old infants. Taken together, the present results corroborated other findings (Turati et al., 2005; Macchi Cassia et al., 2004) showing that, although newborns preferred the canonical face when contrasted when the same upside-down face (Experiment 1), their face preference is determined by the activity of general perceptual constraints rather than a content-determined bias toward the face geometry, since newborns did not respond selectively (i.e., they did not look longer to) to a specific perceptual characteristic of human face, that is the correct orientation of the eyes (Experiment 2). Contrary to the data obtained with newborns, results from Experiment 3 suggested that face preference in 3-month-old infants is the result of perceptual cues specific to faces. Indeed, a major role in inducing face preference at 3 months seems to be played by the eyes, but only when they are located and oriented in their natural arrangement within the face.

To summarize, whereas at birth face preference seems to depend on the existence of general biases that allow newborns to orient their attention toward certain structural properties that faces share with other visual stimuli (Simion et al., 2001; Turati et al., 2002), at 3 months of age face preference appears to be the product of more specific mechanisms that respond more selectively to perceptual face-specific characteristics. Moreover, the data obtained here provided direct support for the perceptual narrowing hypothesis (Nelson, 2001, 2003), showing that the nature of face representation at birth is general and global, whereas it becomes more specific to faces in the first three months of life.

In the same vein, the goal of Experiments from 4 to 7 will be to determine with more precision the nature of face representation at birth, investigating whether only few hours of experience with human faces are sufficient to produce a face representation and whether the nature of this representation is specific enough to allow newborns to make a distinction between faces belonging to different species but which share the same configuration of the face (human vs. monkey) or whether newborns possess a general face representation so that to consider human and monkey faces as belonging to the same general "face category" (Di Giorgio et al., *submitted*).

Experiment 4

Recently the nature of infants' early representation was investigated by Heron-Delaney, Wirth, & Pascalis (*in press*). The findings demonstrated that 3.5- and 6-month-old infants attend more to pictures of human beings than other non-human primates (a gorilla or monkey). The same preference was observed when infants were presented with the whole body or the face only. In contrast, a preference for human faces was also observed in newborns only in the condition when the body was not present. The authors interpreted the results as a demonstration that newborns have learned something about human faces during the first few days of life. However, since the stimuli used in that study were not equated as for low level perceptual properties, the face preference might be due to the difference in the visibility of the two stimuli such as a difference in contrast. Moreover, in those pictures the non human primate faces stand out as their fur was dramatically different from the human's skin so that the perceptual cue that newborns might have used is the fur and not the difference in the global configuration of the two faces. The aim of Experiment 4 was to investigate whether newborns show a spontaneous preference between a human and a monkey face. Importantly, in order to prevent that differences in perceptual characteristics of the stimuli, such as the presence of the fur or the different external contour that may affect newborns' discrimination and preference performance, both the human and monkey faces were equated for low-level variables (i.e., low spatial frequencies and high contrast areas). Importantly, the only perceptual characteristic that differentiate the two stimuli is the presence, only in the human face, of the correct contrast polarity within the eyes (i.e., the black pupil surrounded by the white sclera, Kobayashi & Kohshima, 1997).

Method

Participants

Eighteen normal, healthy, full-term Caucasian newborns were selected from the Pediatric Clinic of the University of Padova. Six babies were removed from the study for the following reasoning: three babies changed their state during the testing (the newborn become too tired or started to cry) and three babies had a strong position bias (looking more than 80% of the time in one direction). So the final sample consisted of 12 newborns (6 males). All infants met the screening criteria of normal delivery, a birth weight between 2570 and 3980 g, and a 5-min Apgar score above 8. Their ages at the time of testing ranged from 24 to 72 hr. Newborns were tested only if they were awake and in an alert state and after parents gave their informed consent.

Stimuli

Grey scale digitized full-frontal images of two human and two monkey faces were prepared using Adobe Photoshop 7.0 (Figure 22). Two pairs of stimuli comprising a human and a monkey face were presented. Monkey faces were manipulated taking off the hair on the cheeks, to equate monkey and human faces for all the low-level variables (i.e., low-spatial frequency, contrast, luminance). The stimuli were about 18.5 cm high X 13.5 cm wide (about 34° X 26° of visual angle).

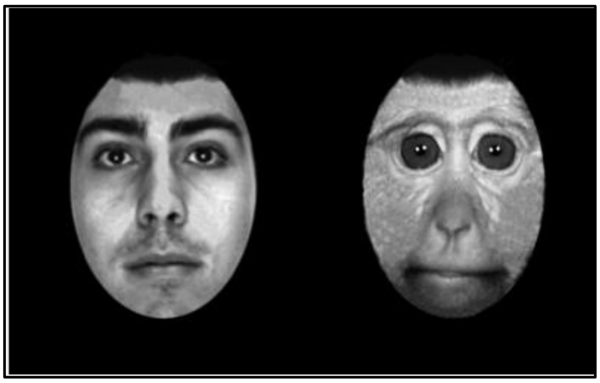


Figure 21: Examples of a human face and a monkey face employed in Experiment 4 and 5 (from Di Giorgio et al., submitted).

Apparatus and Procedure

The apparatus and the procedure employed in this experiment were the same of those described in Experiments 1 and 2. The experiment was carried out using a preferential looking procedure. As for previous experiments, the coders recorded, separately for each stimulus and each position, the total fixation time and the number of orienting responses. The mean estimated reliability between on-line and off-line coding was r (10) = .79, p <. 05, N = 12 (Pearson correlation) for either dependent variable.

Results and discussion

To determine whether newborns showed a spontaneous visual preference for one of the two stimuli presented, two separate *t*-test for dependent samples were performed to compare total fixation time and the number of orienting response. Newborns did not manifest a visual preference response. Indeed, they did not look longer at the human face (M = 33194 ms, SD = 13958) rather than to the monkey face (M = 32529 ms, SD = 15119), t (11) = .09, *n.s.* As in the previous experiments additional analyses on preferences scores (percentages) for the human face were conducted. Preference was not above the chance level of 50 per cent (M = 50%, SD = 18.1, one sample t (11) = .12, *n.s.*, two-tailed). Furthermore, newborns did not orient more frequently to the human face (M = 13.2, SD = 5.5) than to the monkey face (M= 14, SD= 5.3), t (11) = .38, *n.s.* Finally, examination of the data for individual infants revealed that only 5 out of 12 newborns looked longer at the human face (binomial test, n.s.) and that 7 out of 12 newborns oriented more frequently to the human face (binomial test, n.s.). Finally, the correlation between the age of newborns (hours) and the preference score was not significant (r = .06, n.s.).

Heron-Delaney et al. (*in press*) have found a preference for human faces over monkey faces during the first week of life, in an experimental condition where hair/fur was present. In contrast, present result demonstrated that newborns did not show any spontaneous visual preference when the two faces were equated for low-level variables, even if the eyes of the two faces differ because of the contrast between sclera and iris. A possible interpretation for the lack of any visual preference might be that the face representation during the first week of life is not precise enough to be labelled human specific but rather includes other primates' faces. However, one possible reason why newborns did not manifest any visual preference could be that, due to their visual limitations, they were not able to discriminate between the two stimuli. Experiment 5 was aimed to verify this hypothesis if newborns were able to discriminate between the stimuli presented.

Experiment 5

Experiment 5 tested whether newborn babies were capable of discriminating, after exposure, a human face from a monkey face, equated for all level-variables. Considering the hypothesis of the existence of a general face representation at birth (Nelson, 2001), it was predict that newborns should be able to process both faces and therefore to discriminate between them.

Method

Participants

The final sample consisted of 14 healthy and full-term newborn Caucasian babies (5 males) from the Pediatric Clinic of the University of Padova. Three newborns who changed their state during the testing were excluded from the final sample. All infants met the screening criteria of normal delivery, a birth weight between 3100 and 3980 g, and a 5-min Apgar score between 8 and 10. Their ages at the time of testing ranged from 24 to 72 hr. All were tested only if they were awake and in an alert state. Informed consent was obtained from their parents.

Stimuli

The same grey scale full-frontal images of the human and monkey faces used in previous experiment were employed in Experiment 5.

Apparatus

The apparatus was the same of that described in Experiments 1, 2 and 4.

Procedure

The experiment was carried out using an infant-control habituation procedure (Horowitz, Paden, Bhana & Self, 1972). The infant was judged to have habituated when, from the fourth fixation on, the sum of any three consecutive fixations was 50% or less than the total of the first three fixations (Slater et al., 1985). Half of the newborns were habituated to the human face, the other half of the sample was habituated to the monkey face). During the habituation phase, the same stimulus was presented side by side. The stimuli were projected bilaterally and remained on the screen until the habituation criterion was reached. Bilateral rather than central presentation was chosen for two reasons. First, when newborns look at a centrally presented stimulus, it is difficult for an observer to decide if they are actually looking at the stimulus or if they simply do not move their eyes from the central position. Second, at birth photoreceptors in the central fovea are very immature, thus resulting in a poor vision in the central area of visual field (Abramov, Gordon, Hendrickson, Hainline, Dobson, & LaBossiere, 1982; Atkinson & Braddick, 1989).

The habituation phase was followed by a preference test in which a preference could be expressed between the familiar face and a novel one. The two test stimuli were shown in both left and right positions, the positions being reversed from the first to the second presentation. During the preference test phase, the experimenter recorded the duration of infant's fixations on each stimulus by pressing two different push buttons depending on whether the infant looked at the right or the left position. Presentation lasted until each stimulus had been fixated at least once and a total of 20 s of looking had been accumulated.

Results and Discussion

All newborns reached the habituation criterion. A one-way ANOVA was run comparing total fixation times to reach the habituation criterion for the two groups of subjects habituated respectively to the human face and the monkey face. The comparison was not significant, $F(1, 12) = .006$, *n.s.*

To test whether newborns were able to recognize and discriminate the novel stimulus from the familiar one, a novelty preference score (percentage) was computed. Each infant's looking time at the novel stimulus during the two test presentations was divided by the total looking time to both test stimuli over the two presentations, and subsequently converted into a percentage score. Hence, only scores significantly above 50% indicated a preference for the novel stimulus. The mean novelty preference score was 66.9% ($SD = 8.8$) and differed significantly from the chance level of 50%, $t(13) = 20.9$, $p <.01$) ($d = 1.3$). When habituated to a monkey face newborns manifest a novelty preference for the human face (69%). In the same vein when habituated to a human face they manifest a preference for the monkey face (58%).

This outcome demonstrates that newborns are able to discriminate a human face from a monkey face, even though the two faces were equated for all low-level variables. This finding demonstrates that newborn babies are able to perceive and encode the subtle differences between a human face and a monkey face, even if they include both the exemplars in the same category. To further support this conclusion is needed to demonstrate that both human and monkey faces determine the same inversion effects.

Experiment 6

The purpose of Experiment 6 was to investigate whether an empirical phenomenon thought to indicate face-specific processing, the inversion effect (Yin, 1969; Slater et al., 2000; Turati et al., 2006), might also extended to processing of monkey faces at birth. If newborns perceive monkey faces as belonging to the “face category”, as well as human faces, they should prefer the upright monkey face rather than the inverted one.

Method

Participants

The participants were 12 full-term healthy Caucasian newborns (8 males) recruited at the maternity ward of the Pediatric Clinic of the University of Padova. A further newborn was excluded from the final sample because he changes his state during the testing was. All infants met the screening criteria of normal delivery, a birth weight between 2620 and 3700 g, and a 5-min Apgar score between 8 and 10. Their ages at the time of testing ranged from 24 to 72 hr. The criteria for selection of the babies were identical to those used in the previous experiments.

Stimuli

The same grey scale full-frontal images of the monkey faces used in Experiment 4 and 5 were employed (Figure 22). An upright monkey face was contrasted to the same inverted monkey face.

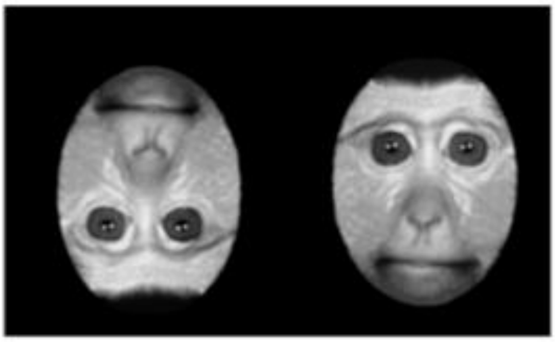


Figure 22: Upright and inverted monkey faces employed in Experiment 6 (from Di Giorgio et al., submitted).

Apparatus and Procedure

A visual preference was employed and the apparatus was the same of the previous experiments.

Results and Discussion

To verify newborns preference toward the stimuli, *t*-test for dependent samples were performed, one for each dependent variable. Newborns looked longer toward the upright monkey face (M = 38650 ms, SD = 15980) when compared to the same inverted monkey face (M = 25518 ms, SD = 7259), t (11) = 2.5, p <. 05 (d = .70). Preference scores for the upright monkey face were above the chance level of 50 per cent (M = 59%, SD = 12), t (11) = 2.5, p <.05 (Cohen's d = .70). Examination of the data for individual infants found that 8 out of 12 newborns looked longer at the upright monkey face (binomial test, n.s.). Furthermore, t test performed on the number of orientation revealed that newborns did not orient more frequently to the upright monkey face (M = 12, SD = 2.7) rather than to the inverted monkey face (M = 10, SD = 2.1), t (11) = 1.8, *n.s.* Examination of the data for individual infants found that 8 out of 12 newborns oriented more to the upright monkey face (binomial test, n.s.). Finally, as in Experiment 2, the correlation between the age of newborns (hours) and the preference score was not significant (r = .02, n.s.).

The result of Experiment 6 shows that, as well as for human face, the inversion manipulation affects newborns' visual preference of monkey faces. This outcome demonstrates that newborns perceive monkey faces and human faces as belonging to the same "face category". Alternative interpretations of the preference for the human-monkey upright face can refer to either the presence of a greater number of elements in the upper part or to the presence of first-order configural information (Simion et al., 2002). Indeed, recent results with Mooney-face patterns, in which the face is formed only from white lit surfaces and black unlit shadows, equated for the number of elements in the upper part support the role of first order configural information since newborns prefer to look at holistic patterns that are closer to upright faces (Leo & Simion, 2009).

Conclusions from Experiments from 4-6

There is prominent evidence in support of the proposal that at birth the face representation is broad and unspecified and that the face processing system is shaped by the faces seen in the visual environment in the first months of life (de Schonen & Mathivet, 1989; Nelson, 2001; Sugita, 2008). Newborns did not manifest a spontaneous visual preference for faces from own- or other-ethnic groups (Kelly et al., 2005) and they did not respond differentially to the gender of faces presented (Quinn, Uttley, Lee, Gibson, Smith, Slater, & Pascalis, 2008), however no study had yet investigate whether face representation is specie-specific in newborns. The experiments presented here were aimed to disentangle this question by contrasting human face and monkey face equated for low level perceptual properties. Results from Experiment 4 demonstrates that newborns did not manifest any visual preference for a human face over a face that is human like (primate) corroborating the idea that face representation is not human-specific at birth. This results corroborate previous findings obtained with animal studies (Sugita, 2008) that reveals clear evidence of a basic, coarsely tuned face-recognition system in primate present at birth. The lack of any preference for one of the two faces cannot be substantiate by a lack of discrimination between them because results of Experiment 5 showed that newborns are able to discriminate between a human face and a monkey face.

Importantly, the only perceptual characteristic that differentiate the two stimuli is the presence, only in the human face, of the correct contrast polarity within the eyes (i.e., the black pupil surrounded by the white sclera). The human species seem to be the only primate species with a white sclera and a dark iris (Kobayashi & Kohshima, 1997). Although the presence of this perceptual characteristic might explain newborns' discrimination in Experiment 5, it fails to explain the null preference for the same stimuli in Experiment 4. A possibility to explain why newborns discriminated the two faces but failed to prefer a human face over a monkey face comes from Experiment 6, which showed that at birth the inversion effect affects the perception of monkey faces, just as affects the perception of human faces (Macchi Cassia et al., 2004), suggesting the idea that at birth both human and monkey faces are processed in the same way and are members of the same category. It is possible that at birth the face category includes not only the basic category of human faces, which in turn includes the subordinate categories of Caucasian and Asian faces (Kelly et al., 2005), but includes also faces of non-human primates. Notwithstanding, one could interpret the preference for the upright monkey face compared to the upside-down one with the formation of the prototype in the few hours after birth, since faces are encountered in the upright orientation much more frequently than in others. However, the correlation between the age of the newborns tested and the preference score in Experiments 4 and 6 was not significant, suggesting that there was no time enough for newborns to build a face representation neither human specific nor orientation specific. As suggested before, alternative interpretations of the preference for the upright monkey face compared to the inverted one can refer to either the presence of a greater number of elements in the upper part or to the presence of first-order configural information (Simion et al., 2002; Leo & Simion, 2009).

A question that the present study leaves open concerns the role of the eyes. It has been suggested that the eyes are important in determining the neonate's orientation toward faces. The results of the present study seem to show that the human eye is no more attractive than a primate eye and open new questions about their role. As for the role of the eyes in inducing face preference at birth, a recent study demonstrated that the low-level variables embedded in the eyes, such as the low-spatial frequencies (LSF), are crucial in eliciting a face-like preference at birth (Di Giorgio, Leo, & Simion, *submitted*).

To summarize, the obtained data demonstrated that newborns are able to discriminate a human face from a monkey faces, but, due in part to the immature visual system at birth (Abramov et al., 1982), fail to show a preference for a face of conspecifics when compared with a monkey face because they perceived both stimuli as faces in general. The overall pattern of outcomes is consistent with the hypothesis that newborns come into the world with a face representation that is sufficiently general as to bias newborns' visual attention toward multiple categories of faces (e.g., monkey faces vs human faces).

Based on this outcome, it becomes interesting to investigate whether this face representation, due to the visual experience that infants do in the specie-specific environment, becomes more specific to human face during the development (Nelson, 2001; Pascalis et al., 2002; Pascalis & Kelly, 2009), as suggested by studies demonstrating that 3 months of experience are sufficient to induce a gender (i.e., female vs male, Quinn et al., 2002) and an own-race preference (Kelly et al., 2005). So, the aim of Experiment 7 was to verify whether 3-month-old infants show a visual preference for a human face over a monkey face.

Experiment 7

Method

Participants

Participants were 12 3-month-old healthy and full-term infants (6 females, mean age = 97.6 days). They were middle-class infants and all of them were Caucasian. Five additional infants were tested but not included in the final sample because they showed a strong position preference (i.e., they looked to one direction more than 90% of the time). Infants were tested only if awake and in an alert state after parents gave their informed consent.

Stimuli

Stimuli employed in Experiment 4 were used here.

Apparatus and Procedure

The experiment was run using the eye-tracker system during and infants were tested in a visual preference paradigm. The procedure was the same of that used in Experiment 3.

Results and Discussion

As in Experiment 3, the results are presented in two sections: the overall looking time and the distribution of looking time.

Overall looking time

To test whether 3-month-old infants exhibited a visual preference toward one of the stimuli presented, *t* test for dependent samples were performed to compare total fixation time. Statistical analyses revealed that 3 months infants looked longer at the human face (M = 36737 ms, SD = 15895) compared to the monkey face (M = 20363 ms, SD = 8238), t (11) = 2.7, $p < .05$ (d = 1.3). Moreover, the mean preference score for the human face was above the chance level (M = 62.5%, SD = 18.4), t (11) = 2.3, $p < .05$ (d = .67). As for the number of orientations, infants looked more frequently the human face (M = 108.5, SD = 41.9) than to the monkey face (M = 66.7, SD = 38.7), t (11)= 2.9, $p < .05$ (d = 1.1). These findings clearly demonstrated that the 3-month-olds' attention seems to be attracted more by the human face than by the monkey face.

Distribution of looking time

To understand which perceptual cues of each stimulus attracted infants' gaze, a series of statistical analyses were performed on percentage of looking toward four selected areas (i.e., areas of interest, AOI) corresponding to the upper and the lower parts of each stimulus within the pair. One-sample *t* tests were applied to verify whether such percentages of looking differed from a chance level of 25%. The following distribution of looking was observed. The 3-month-old infants looked at the upper half of the human face for 25110 ms corresponding to 43% of total fixation time (M = 42.6%, SD = 24.6), t (11) = 2.5 $p < .001$ (d = .73) and at the lower part for 11626 ms corresponding to 20% of total fixation time (M = 19.8%, SD = 22.9), t (11) =.78, n.s. The upper half of the monkey face was fixed for 15479 ms corresponding to 29% of total fixation time (M = 29%, SD = 20.3), t (11) = .69, n.s., and the lower part of the monkey face for 4884 ms corresponding to 8% of total fixation time (M = 8.3%, SD = 8.9), t (11) = 6.4, $p < .001$ (d = 1.1) (Figure

23). Importantly, infants looked longer the upper half of the human face (*M* = 25110 ms, *SD* = 17553), compared to the upper part of the monkey face (*M* = 15479 ms, *SD* = 8781.2), t (11) = 2.8, $p < .05$ (d = .9).

Taken together, these findings indicated that, contrary to newborns' performances, 3-month-old infants showed a preference for the human face when contrasted with a monkey face. Data also revealed that this preference is due mainly to a higher percentage of looking toward the area of the human face that corresponds to eyes, which attracted nearly half of the total looking time toward the stimuli (42.6%), corroborating previous studies that suggested that around 3-months of age, among all of facial features, the eyes appear to be of particular importance in inducing face preference.

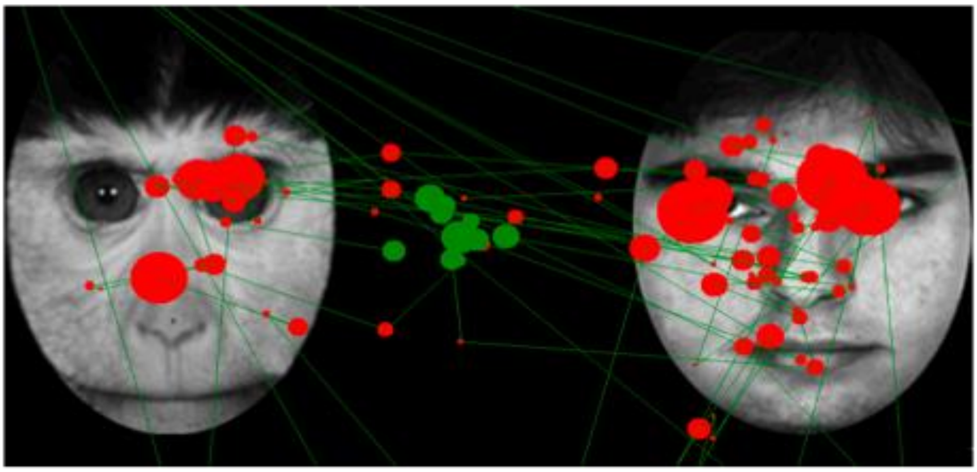


Figure 23: Example of eye movements of a 3-month-old infant during the visual preference task.

Conclusion

The goal of the Study 1 was to provide direct evidence in favor of the perceptual narrowing hypothesis (Nelson, 2001, 2003) concerning the presence of a broad face representation at birth and its developmental time course in the first months of life. Taken together, the data obtained corroborated previous findings (Turati et al., 2005; Kelly et al., 2005; Quinn et al., 2008, 2003) showing that at birth face representation was broad and that at three months of age face representation becomes more specific to human face category. Evidence described herein suggests that face specificity is not prewired, but rather arises from general perceptual processes that, during development, become progressively tuned to the human face, as a result of extensive experience with this stimulus category.

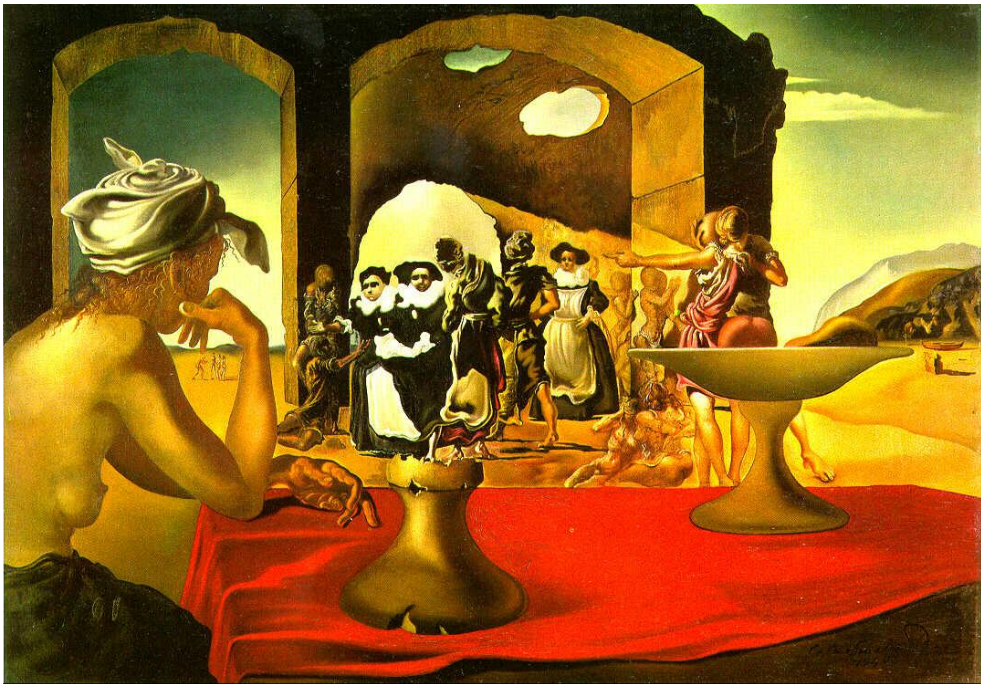
Overall, the data presented in this chapter are in line with an experience-expectant perspective, that emphasizes the relevance of both general constraints of the human visuo-perceptual system and exposure to certain experiences shortly after birth to drive the system to become functionally specialized to process faces in the first month of life. Importantly, the perceptual narrowing approach highlight the role of the visual experience as a determinant factor for the specialization of the face processing system. However, at present, little is known about the specific experiences that lead to expert face processing or how early perceptual experience contributes to the specialization of the neural structures underlying face processing. These issues should be the focus of future research, employing both behavioral and neuropsychological tasks (e.g., ERP and NIRS[2]).

[2] Event related potentials (ERPs): a set of voltage changes contained within a period of electroencephalogram (EEG) that are time-locked to an event, for example, presentation of an object. This is a noninvasive technique with excellent temporal resolution. Near infrared spectroscopy (NIRS): a neuroimaging technique that uses infrared resonance to measure changes in blood and tissue oxygenation in a noninvasive way.

CHAPTER 4

FACE DETECTION IN

COMPLEX VISUAL DISPLAYS



Introduction

As described in Chapter 3, the majority of developmental studies that investigated face detection and recognition employed habituation-and novelty- and familiarity-preference paradigms, in which the total fixation time towards a stimulus is the main measure. In these studies, however, only a single stimulus is presented, so attentional selection is not required as there is no competition with other stimuli. Consequently, although these studies have considerably expanded our knowledge of infants' perceptual processing, they have shed little light on the development of mechanisms responsible for selecting a target amidst competing stimuli.

Indeed, human visual world is rich of many stimuli that represent possible input for visual and cognitive processing and for guiding behavior. Because our visual system has a limited capacity, selection must occur to prioritize important stimuli for their subsequent processing, while ignoring less important ones. Despite the large amount of evidence on infants' face detection and recognition (de Haan, 2001), only a few studies have investigated whether infants are capable to detect a face within complex visual scenes.

Due to the social relevance of the face stimuli early in life and due to the emergence of a specific face representation at 3 months (Chapter 3), the aim of Study 2 will be to investigate whether infants can detect a target face in a more ecological situations, that is when a face is embedded among both heterogeneous and homogeneous objects.

4.1 Face detection in complex displays in adults

For adaptive reasons and because of their ubiquity, faces are probably the most biologically and socially significant visual stimuli for humans. For this reason, a great debate in adult literature concerns whether faces, due to their social and biological relevance for humans, could capture and maintain attention when competing for attentional resources with other objects in the visual field. The power of faces to capture and maintain attention has been widely demonstrated in adults using different paradigms (Ro, Russell, & Lavie, 2001; Lewis & Edmonds, 2005; Fletcher-Watson, Findlay, Leekam, & Benson, 2008; Bindemann, Burton, Hooge, Jenkins, & de Haan, 2005).

For instance, Ro and colleagues (2001) found that faces had a detection advantage over other objects: changes to upright faces are detected more rapidly and accurately than changes to objects or to the background in a *flicker paradigm* (Ro et al., 2001; Palermo & Rhodes, 2003; Humphreys, Hodsoll, & Campbell, 2005) (Figure 24). In this paradigm, an original image A repeatedly alternates with a modified image A', with brief blank fields placed between successive images. Differences between the original and modified images can be of any size and type. The observer freely views the flickering display and hits a key when the change is perceived. To prevent guessing, we ask the observer to report the type of change and describe the part of the scene that was changing (Rensink, 2002; Rensink, O'Regan, & Clark, 1997). In other words, the logic behind this change detection phenomenon is that subjects are sometimes remarkably poor at detecting changes between two images of real-life scenes when the images are separated by a large transient, so that they appear to flicker. This phenomenon is termed *change blindness* (for reviews, see Simons, Chabris, Schnur, & Levin, 2002). Although someone argues that this advantage in face detection might be due to the "odd-one-out" effect, that is the phenomenon by which participants categorize stimuli as either "face" or "non-face" (Palermo & Rhodes, 2003), other studies suggest that such a strategy for categorization cannot fully explain the advantage in face detection.

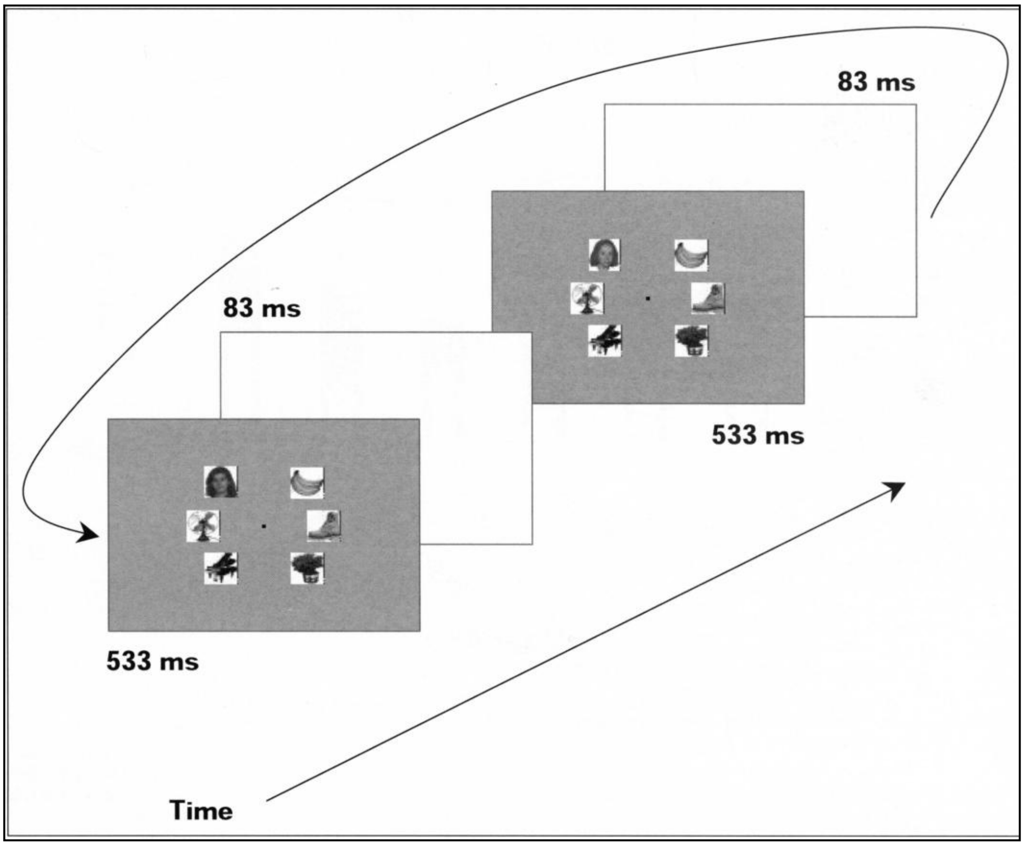


Figure 24: Example of the events for a trial in Ro et al.' study (2001). Following an inter-trial interval of fixation for 2,000 ms, the first frame of object items appeared for 533 ms. A transient (blank white screen) was then presented for 83 ms, followed by the presentation of the second frame of objects for another 533 ms. Another transient was then presented, and this sequence repeated until the subject responded, or 20 s had elapsed. Six objects, one from each of six different categories (faces, food, clothes, musical instruments, appliances, and plants), were presented in each display, and the center of each object was placed 5° from fixation. Across trials, six instances from each category were used (from Ro et al., 2001).

An example of this comes from the study of Humphreys and colleagues (Humphreys et al., 2005), in which participants were presented with images featuring four females and found that changes in faces were detected faster than changes in bodies, which in turn were detected faster than changes in the background. This study demonstrated that the face detection advantage in the change blindness paradigm is based on the attentional bias toward the face, independent of the rapid categorization of the face as opposed to other object categories.

Moreover, evidences showed that attention may be preferentially directed to face in natural scenes (Lewis & Edmonds, 2005; Fletcher-Watson et al., 2008) and that faces not only grab attention but also have an advantage in retaining adults' attention over other stimulus categories (i.e., go/no-go classification task, Bindemann et al., 2005) and, finally, that faces gave rise o inhibition of return alongside a concurrent non-face objects.

As well as the other paradigms, the visual search task has been increasingly employed to study face perception in complex arrays (Hansen & Hansen, 1988; Lewis & Edmonds, 2005; Langton, Law, Burton, & Schweinberger, 2008; Suzuki & Cavanagh, 1995; Calvo & Nummenmaa, 2008; Tong & Nakayama, 1999). In a typical visual-search task, participants are asked to detect a target stimulus among distractors (Treisman & Gelade, 1980). The time to find the target is measured as a function of the number of distractors present in the array. The logic behind these studies is the following: if the target stimulus draws attention automatically, then the number of distractors in the array will have a minimal or null effect on search time (Treisman & Gelade, 1980). The search is defined "efficient" (e.g., parallel search) when the number of distractors does not influence the search time, whereas the search is "inefficient" when the number of distractors present in the array affects the search time for the target (e.g., serial search). Several studies, using a visual search paradigm, failed to demonstrate that a schematic face or a more realistic face popped out among scrambled and inverted faces as distractors.

Nothdurft (1993), using an upright drawing of a face with hair as target and the same drawings but inverted as distractors, failed to find pop out. However, when the facial features were removed from the drawings and only the hair remained, the face target popped out. The pop out phenomenon in this case was interpreted as due to a perceptual characteristic of the stimulus employed and not due to the significance of the face as a visual stimulus.

Brown, Huey, and Findlay (1997) used black-and-white photographs with the hair removed and set in ovoid templates in a special visual search paradigm, in which the target and distractors are presented in the periphery, around a fixation point. The subjects were asked to move their eyes to the target as quick as possible. Targets were upright or inverted faces with distractors being in the opposite orientation. This study again failed to establish pop out for faces. Importantly, the authors found a practice effect specific for upright, but not for inverted faces. Subjects trained on upright face targets improved markedly in latency and accuracy for upright faces only, while those trained on inverted faces improved only slightly for both upright and inverted faces equally. The authors conclude that upright faces have a special status in tasks that require configural learning.

Kuehn and Jolicoeur (1994) investigated whether perceptual features of the stimuli presented such as orientation, quality and similarity affect visual search for faces. Results demonstrated that faces do not pop out when embedded among distractors containing facial features, but that search for a face became easier and faster when the distractors looked less like faces. Indeed, when the distractor did not contain any facial features, but was a globe in the shape of a face, the upright face did pop out.

Other researchers have used schematic or real faces to investigate whether some kinds of emotional expression could be detect faster than others (Purcell & Stewart, 1986; Ohman, Lundqvist, Esteves, 2001; Calvo & Nummenmaa, 2008; Figure 25). For example, Hansen and Hansen (1988) demonstrated that a face with an angry expression pops out from an array of happy faces. However, Purcell, Stewart, and Skov (1996) argued that this pop out effect was the result of an artifact of extraneous dark areas in the angry faces, which the subjects became aware of and used to detect the target. In sum, none of the above studies have conclusively found a pop out effect for visual search of faces on a background of inverted faces or other face like distractors.

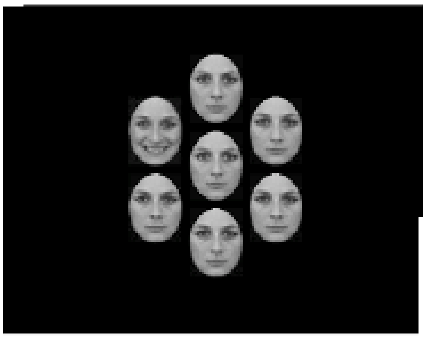


Figure 25: Examples of real face images employed to investigate whether a happy face is detected faster when embedded among neutral faces (from Calvo & Nummenmaa, 2008)

However, when researchers have used other objects as distracters as opposed to inverted faces, the results are more promising (Hershler & Hochstein, 2005). For instance, some recent evidence supports the conclusion that as a target in visual display, a face stimulus can capture attention among non-face distractors (Rousselet, Macè, & Fabre-Thorpe, 2003; Langton et al., 2008). For instance, it has been demonstrated that a face popped out (i.e., was find efficiently) from cars and houses, so that the search time remains constant regardless the number of distractors. In contrast, a car did not pop-out from faces and houses (Hershler & Hochstein, 2005). Moreover, due to their social relevance, it has been demonstrated that faces cannot be ignored when presented as search non-targets (Suzuki & Cavanagh, 1995) and when a face represents an irrelevant distractor interfered with search for the target object, whereas an irrelevant object as distractor did not interfere with search for the target face (Langton et al., 2008).

For instance, Langton and colleagues (2008) reported three experiments that investigate whether faces are capable of capturing attention when in competition with other non-face objects. The study demonstrated that participants took longer to decide that an array of objects contained a butterfly target when a face appeared as one of the distracting items than when the face did not appear in the array (Figure 26).

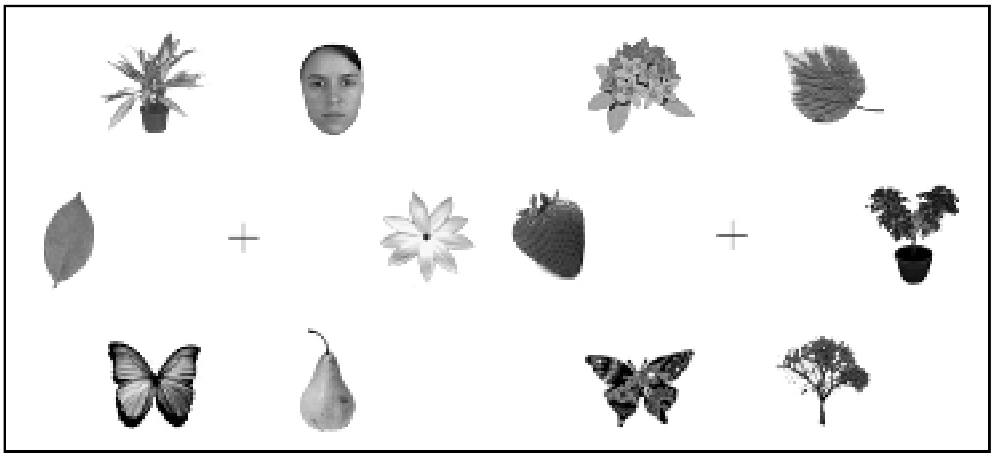


Figure 26: Examples of face-present (left panel) and face-absent (right panel) stimulus arrays used in the experiments. The butterfly items acted as targets in Experiments. Participants either searched for faces or butterflies (from Langton et al., 2008).

This irrelevant face effect was eliminated when the items in the arrays were inverted ruling out an explanation based on some low-level image-based properties of the faces. More interesting, irrelevant faces interfered with search for butterflies but, when the roles of faces and butterflies were reversed, irrelevant butterflies no longer interfered with search for faces. This suggests that the irrelevant face effect is unlikely to have been caused by the relative novelty of the faces or arises because butterflies and faces were the only animate items in the arrays. The author concluded that the experiments offer evidence of a stimulus-driven capture of attention by faces.

Overall, the research findings presented here seems to support the idea that faces have the power to attract and maintain adults' attention over other object categories. In other words, these studies demonstrate the special perceptual processing of the human face.

From a developmental point of view, infants' face detection have been extensively investigated in displays containing one or two faces, leaving open the question as whether the same face preference obtained in infants of few months would be obtained also when a face is embedded among competing visual stimuli. There is no doubt that we are a social species that depends highly on face-mediate social interaction between conspecifics and thus we should benefit from mechanisms which allow us to orient and to maintain attention toward faces from the first months of life (Gliga & Csibra, 2007; Johnson, 2005).

4.2 Visual search strategies in infancy

Developmental studies investigated both infants' ability to detect and recognize faces and infants' capacity to efficiently detect a discrepant target object in complex visual display. As regard to face processing, it has been demonstrated that from birth, human newborns are biased to pay attention towards faces over other visual stimuli in the environment. For instance, it has been widely demonstrated that they not only attend to and prefer faces over other visual stimuli (Johnson et al., 1991; Valenza et al., 1996; Macchi Cassia et al., 2004), but they recognize the face of their mother (Bushnell, Sai, & Mullin, 1989; but see Pascalis & de Schonen, 1994) and they recognize a face that changes in viewpoint (Turati, Bulf, & Simion, 2008).

As regard to the ability to efficiently detect a target stimulus in complex visual displays, studies that used the mobile conjugate reinforcement procedure (Adler, Gerhardstein, & Rovee-Collier, 1998; Adler, Inslicht, Rovee-Collier, & Gerhardstein, 1998; Rovee-Collier, Bhatt, & Chazin, 1996; Rovee-Collier, Hankins, & Bhatt, 1992), the classical visual habituation or preference paradigms (Colombo, Ryther, Frick, & Gifford, 1995), or more recent eye-tracker technique (Adler & Orprecio, 2006; Bulf, Valenza, & Simion, 2009), provided evidence that young infants are able to exhibit "pop-out", where their attention is captured by a stimulus (or patch of stimuli) that is surrounded by dissimilar stimuli.

For instance, the visual habituation procedure was used to demonstrate that some perceptual features, such as line-crossing and orientation, are efficiently detected in complex displays by 3- and 4-month-old infants, confirming that young infants are sensitive to some of the same fundamental features that are believed to direct adult attention (Quinn & Bhatt, 1998). In the line crossing condition, 3- and 4-month-old infants were habituated with homogenous arrays of either Ls, or +s. They were then tested with two concurrently presented test stimulus arrays, one of which contained a single novel character amid 24 familiar distractors, and the other contained a single familiar character amid 24 novel distractors (Figure 27). The authors hypothesized that if infants exhibit perceptual pop-out, the individual discrepant element (e.g., L or +s) should be detected amid the homogeneous distractors, holding the infants' attention. Then infants would perceive the array with the novel discrepant element as the novel one, even though 24 out of the 25 elements in the array are familiar. The same result was obtained in the orientation condition. These findings provided evidence of pop out based on line crossing and orientation information in 3- and 4-month-old infants.

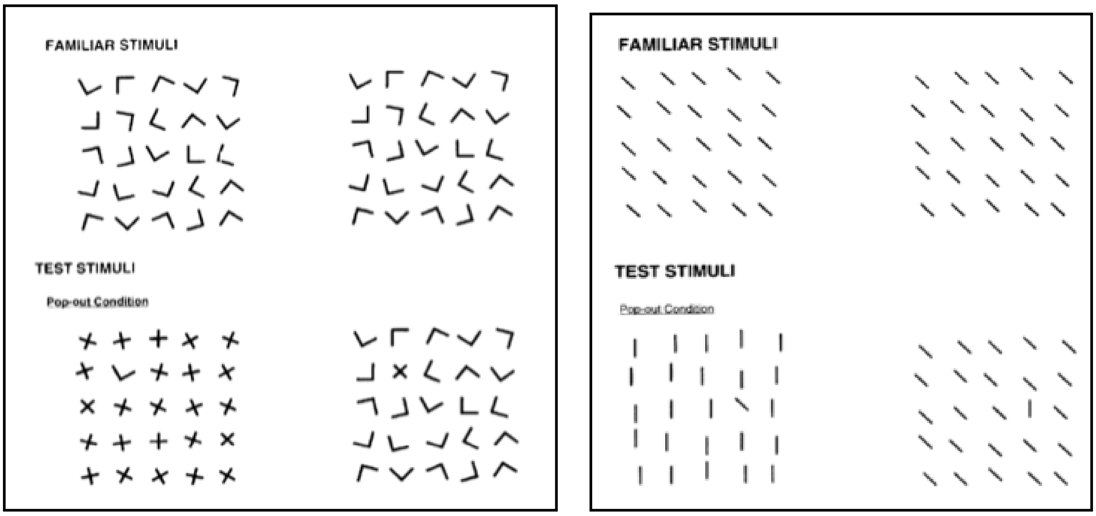


Figure 27: Visual stimuli employed to study visual search in young infants (from Quinn & Bhatt, 1998).

Support for the presence of the pop out phenomenon in infancy, using novelty preference paradigms, comes also from a study by Colombo and colleagues (1995). Three- and four-month-old infants were exposed to two arrays simultaneosly, one containing a homogenous array of objects (O) and another containing a single discrepant object (a Q target amidst the Os) (Figure 28). The visual preference was recorded by measuring the looking time to each array. Result showed that infants looked longer at the array that contained a discrepant object, than to the homogeneous array.

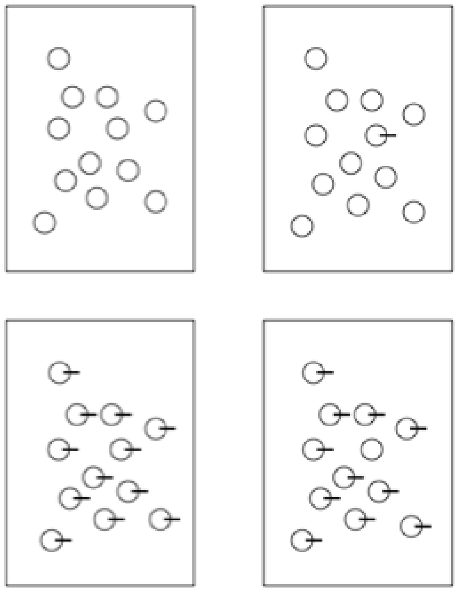


Figure 28: Arrays simultaneously presented to infants, one containing a homogenous array of objects (O) and another containing a single discrepant object (a Q target amidst the Os) (from Colombo et al., 1995).

Overall, the studies just described and others seem to indicate that infants as young as 3 months exhibit the phenomenon of pop out. This would further suggest that the mechanisms for selective attention are functioning in early infancy.

However, these studies have two important methodological limitations. The first limitation concerns the use of the total fixation time as a dependent variable to measure the pop out phenomenon. If infants has exhibited pop out and their attention had been automatically guided by the pop out target in these looking studies, then it should have been evident in their first looks. However, none of the studies reported here have considered any data concerning infants' first looks or the direction of the first fixation. The second important limitation concerns the fact that previous studies do not investigated, as well as adults' studies do, if the number of distractors affects infants' visual search performance. Indeed, if the target stimulus draws attention automatically, then the number of distractors stimuli in the array will have a minimal or null effect on search time (Treisman & Gelade, 1980).

To overcome these limitations, two recent studies employed an eye-tracker system to measure infants' and adults' saccade latencies to visual arrays that contained a visual geometrical stimulus as target among a variable number of distractor elements (Adler & Orprecio, 2006; Bulf et al., 2009).

Many studies have indicated a linkage between adults' eye movement and attentional processing in visual search tasks. For example, findings from these studies demonstrated that the number of distinct eye movements are positively correlated with search times (Zelinsky, 1996), or that the latency and accuracy of the initial saccade to a visual search target is a function of the spatial certainty of the target (Findlay, 1997) and the number of distractors in the visual array (McSorley & Findlay, 2003; Motter & Belky, 1998). These findings indicate that an assessment of eye movements can be used as an accurate measure of visual search, pop out and mechanisms of attentional processing.

Adler & Orprecio (2006) measured 3-month-olds' and adults' saccade latencies to visual arrays that contained either a+ among Ls (target-present condition) or all L (target-absent) with set sizes of 1, 3, 5 and 8 items (Figure 29).

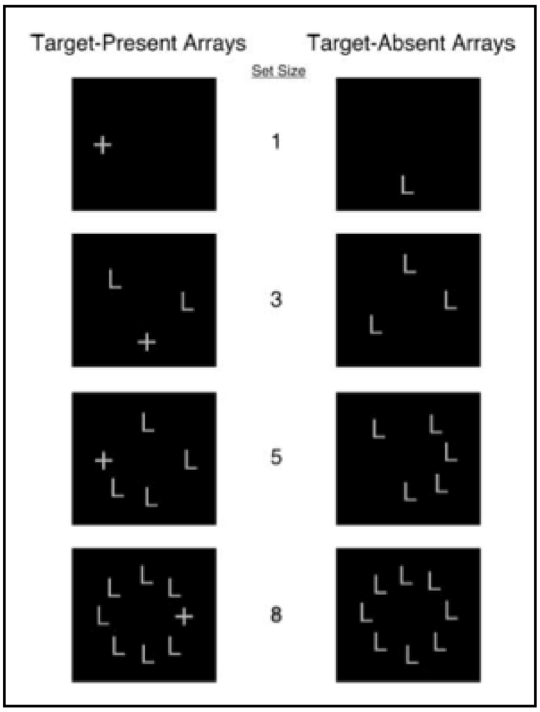


Figure 29: Example of the visual search arrays used in Adler & Orprecio study. Shown are target-present and target-absent search arrays with set sizes of 1, 3, 5 and 8 (from Adler & Orprecio, 2006).

The results indicated that infants' and adults' saccade latencies remained constant in the target-present conditions regardless of the number of distractors, whereas their latencies increased in the target-absent conditions as a set size increased. Importantly, this was the first study that, using an eye-tracker system, demonstrated that young infants manifest visual search strategies that are similar, if not the same, to those of adults, when a geometric stimulus is presented as target in complex arrays, regardless the number of distractors.

A more recent study, using an eye-tracker system, investigated whether infants and adults exhibit a pop-out effect with both a real figure and an illusory figure (i.e., a Kanizsa triangle) among distractor pacmen (Bulf et al., 2009) (Figure 30).

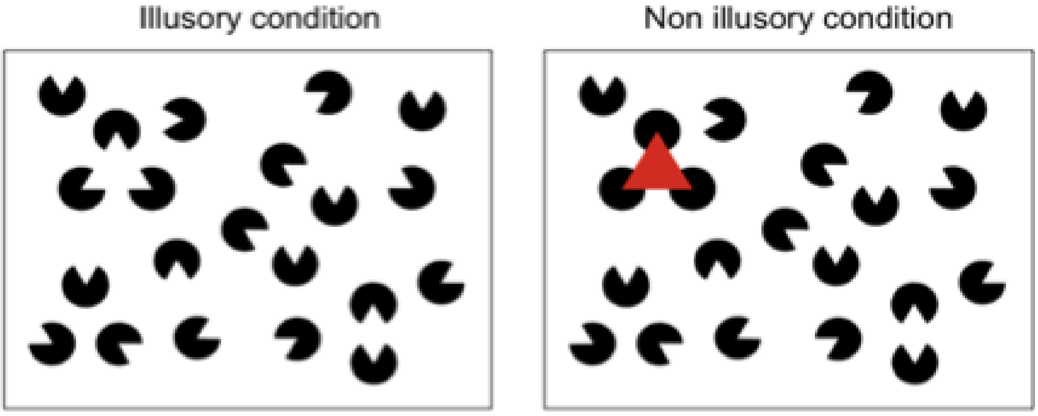


Figure 30: Examples of complex visual arrays employed to investigate visual search for both the Kanizsa illusory figure and for the real triangle figure (from Bulf et al., 2009).

The results showed that adults detected both the Kanizsa and the real figure efficiently regardless the number of the distractors, whereas 6-month-old infants showed a pop-out effect only for the real figure, demonstrating that at this age the Kanizsa figure do not grab infants' attention in an adult-like manner (Bulf et al., 2009).

Overall, these studies altogether seem to demonstrated that infants of few months of life, as well as adults, showed visual search ability when the stimulus target was a simple, geometric visual stimuli. Based on this evidence, it is important to investigate whether the same search abilities could be present when the target is a complex visual stimulus, such as a human face.

4.3 Face detection in complex displays in infancy

Despite a bulk of studies has demonstrated that infants exhibit efficient visual search performances, evidence on the extent to which they are able to explore a complex visual scene in order to attend to and to identify a face when other objects are present is very scarce.

Frank and colleagues (Frank, Vul, & Johnson, 2008) measured the extent to which faces within complex, dynamic scenes draw 3-, 6- and 9-month-old infants' attention. Using an eye-tracker, the authors recorded and measured where and how adults and infants were looking during the presentation of cartoon-video clips (i.e., A Charlie Brown Christmas, Figure 31).

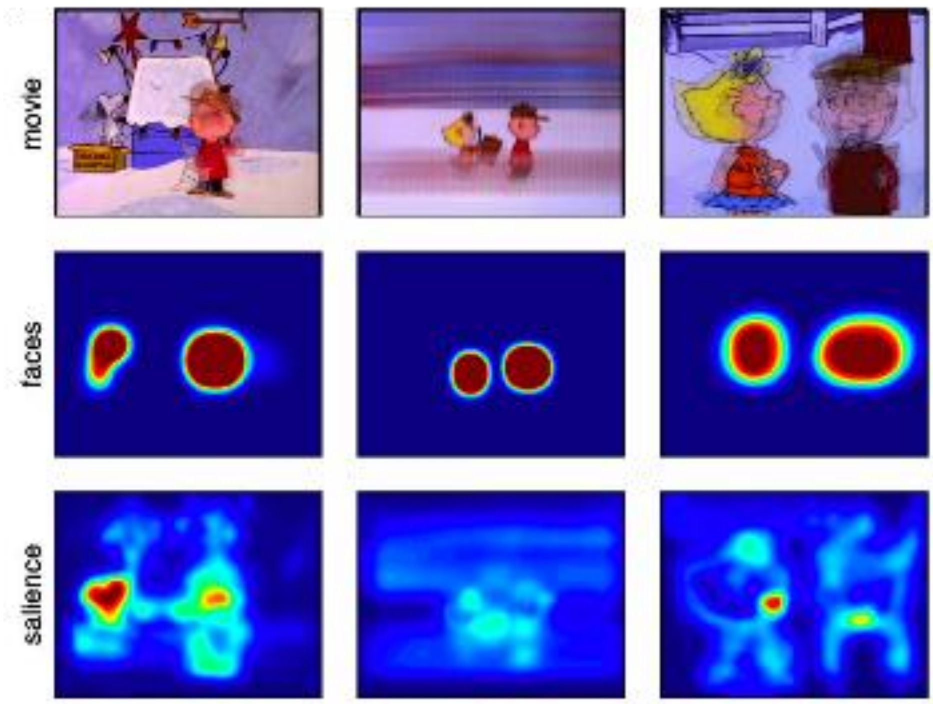


Figure 31: Example stimuli and models (averaged across time) for three different 4-s clips from *A CharlieBrown Christmas* (from Frank et al., 2008).

The study demonstrated that 3-month-old infants did not look at faces as much as other groups, but they were attending to a range of salient objects presents in the scene and that the tendency to look at faces increased with age (Figure 32). The authors suggested that at least three developmental changes might contribute in various degrees to the pattern of results observed: the development of a preference to look at faces as a social information source, the development of sensitivity to the intermodal coordination between faces and speech, and the development of attentional/inhibitory mechanisms allowing for the suppression of salient background stimuli in favor of faces (Frank et al., 2008).

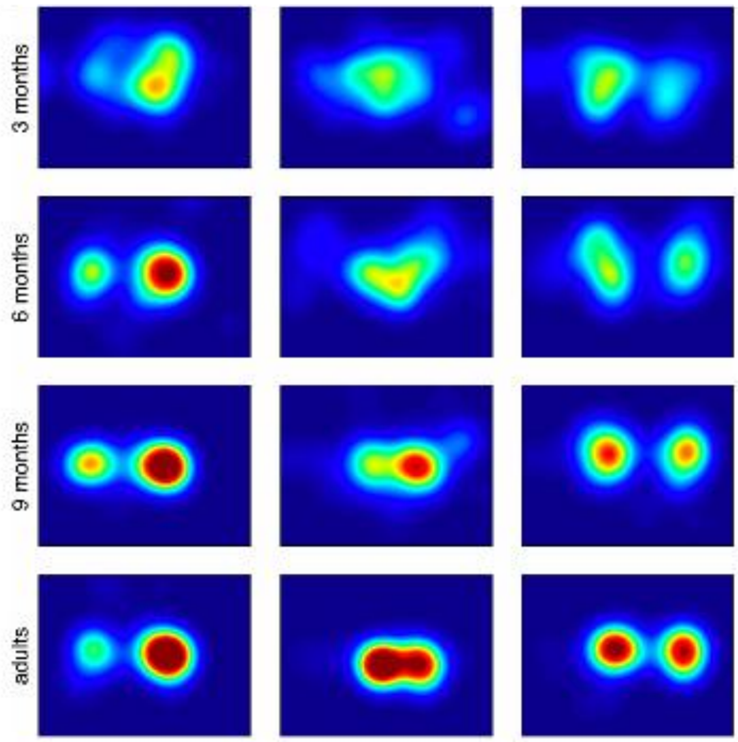


Figure 32: Rows are data from (top to bottom) 3-month-olds, 6-month-olds, 9-month-olds, and adults (from Frank et al., 2008).

However, the use of cartoon video-clips leaves open the possibility that 3-month-olds' failure to detect faces was due to their difficulty to follow the complex and rapid flow of information provided by the cartoon movies. Furthermore, the schematic nature of the faces in the cartoons might decrease young infants' ability to recognize them as faces.

To my knowledge, only one recent study demonstrated that faces capture 6-month-old infants' attention in complex display using a visual search task. Gliga and colleagues (Gliga et al., 2009) investigated whether a face could capture and maintain 6-month-old infants' attention when presented among other 5 various objects as distractors (e.g., alarm clocks, mobile phones, birds, cars and shoes) (Figure 33). Six-month-old infants were presented with 12 slides, each one lasted 12 seconds and Infants' eye-movements were recorded to measure both the direction of the first saccade towards face and the total amount of fixations directed to faces (i.e., attention getting and attention holding; Cohen, 1972).

Figure 33: Complex visual arrays employed to study visual search for faces in 6-month-old infants (from Gliga et al., 2009).

When an upright face was presented among five upright objects, the target face captured and maintained infants' attention compared to other object categories presented (Experiment 1). However, when infants were presented with slides containing an upright face and an inverted face among 4 objects, it has been demonstrated that the face detection advantage is not selective to upright faces, because, as for the first fixation, the difference between upright and inverted faces did not reach the significance (Experiment 2). On the contrary, when the total amount of fixations was considered, upright faces were observed more than inverted faces and more than objects. Finally, it has been demonstrated that the attention-grabbing effect of face requires the presence of internal facial features, because faces whose internal features has been phase-scrambled (i.e., to create a noise stimulus) did not attract nor maintain infants' attention (Experiment 3).

To my knowledge this study is the first that investigated attention capture by faces within complex visual arrays in infants of few months of life using a paradigm usually employed with adults (i.e., visual search). However, this study has some limitations: i.) the number of objects-distractors within the displays was keep constant and the authors did not examine whether and how the number of distractors affects infant' search performance for faces and ii.) the authors did not compare six-month-old infants' search performance neither with adults nor with younger infants.

Therefore, the main aim of Study 3 will be to overcome these limitations testing 3- and 6-month-old infants as well as adults with the same visual search paradigm, in which the number of distractor objects will be manipulated.

4.4 Study 2

At present both the origin and the developmental time course of the ability to detect a face target among other objects as distractors and whether the mechanisms underlying 6-month-old infants' ability to search efficiently a face in complex visual arrays are the same or different from those of newborns and adults are still largely unknown. From a developmental point of view, it appears relevant to investigate whether the ability to efficiently detect a face in a complex array is still present in 6 months infants when the number of distractors is variable and whether the same face detection advantage is present before 6 months of age thanks to the importance of the human face early in life.

To this purpose, the current study investigated the origins and the time course of visual search for a target face in complex displays in adults (Experiment 8) and in 3- and 6-

month-old infants (Experiments 9 and 10) through the use of a modified version of the visual search paradigm and the recording of eye-movements. Importantly, in the classic visual search task participants are asked to search for a specific target stimulus that is presented among a different number of distractors stimuli. In this study the classic visual search paradigm used with adults was modified in order to be adapted to infants, who are unable to comprehend written or verbal instructions and to provide manual response and all participants were tested under free viewing conditions. Each participant was presented with complex displays consisting of a target face stimulus among a variable number of objects as distractors. It has been used an eye-tracker system to measure the direction of the first fixation and the number of fixations toward a target face, both considered as measure of an early attentional orienting mechanism (e.g., attention-getting mechanism, Cohen, 1972). In addition, the total amount of fixations directed to face, was recorded because considered an index of maintenance of attention (e.g., attention-holding mechanism, Cohen, 1972).

Experiment 8 tests the validity of our modified visual search paradigm with adults, whereas Experiments 9 and 10 are aimed at investigating whether a target face presented among objects capture and maintain 3- and 6-month-old infants' attention. Since the stimuli, the apparatus and the procedure are the same for adults and infants, I describe the method one time and then I describe the results.

Experiment 8

Method

Participants

Fourteen undergraduate students were selected from the Department of Psychology at the University of Padova to participate in the experiment. Two participants were excluded from the sample because of no interpretable eye movements due to poor calibration (N = 2). The final sample consisted of 12 adults (9 female, mean age = 22, 5 years). All participants had no previous experience with eye-movements studies and are naive to the experimental conditions and hypotheses of the study. Finally, all of them had normal or corrected-to-normal vision.

Stimuli

The stimuli were digitized, high-quality grey-scale images of both faces and objects. Four Caucasian female full-front faces, posing with a neutral expression and placed on a light background with no hair were employed as target stimuli. Four different exemplars from each of the five following categories were created and employed as distractors: alarm clocks, cars, houses, shoes and telephones. To the greatest extent possible we tried to equate the stimuli for contrast and luminance. Using Adobe Photoshop 7.0 software we created sixteen displays of 4 stimuli, each embedding one face target and three stimuli as distractors (e.g., a car, a shoe and an alarm clock) and sixteen displays of 6 stimuli with a face target and five stimuli as distractors (e.g., a car, a shoe, an alarm clock, a telephone and a house), for a total of 32 complex displays (Figure 34). The stimuli, comparable for size, were arranged on a circular grid at an equal distance from the center of the screen, on a light background. Further, when placed at 60 cm from the adult and infant participants, the images on each display had an eccentricity of 9.5° and covered an approximate area of 5.8° X 7.5°.

Apparatus

Adults were seated in a seat at a distance of about 60 cm from the computer screen where the stimuli were presented. A system for the automatic registration of eye movements made by Applied Science Laboratories (ASL) was employed (see Chapter 3).

Procedure

Each participant was tested on a single occasion in a quiet and dark room, seated approximately 60 cm from a 19-inch (1024 x 768 pixels) computer screen. Importantly, no instructions were given to adults, except that participants had to watch the images appearing on the computer screen moving their eyes freely. The experiment started with a calibration phase immediately followed by the test phase. After the calibration phase, each participant was presented with 32 displays randomly selected. Sixteen displays comprised of 4 items (e.g., a target face among three different objects) and the other sixteen displays comprised 6 items (e.g., a target face among 5 different objects). Across all displays, for each set size, the participant was randomly presented with the target face occurring once in each of the four or six possible positions. Each display presentation lasted 5 seconds and in between the displays a fixation point was presented in the center of the screen, ensuring that adult participant's gaze was directed to the center before the next display was presented. Rectangular areas of interest (AOIs) were defined manually around each image in the displays, and for each participant we calculated the direction of the first fixation directed to a certain category AOI and the number of fixations and the total fixation times within an AOI. Only adult participants that looked at 32 out of 32 displays were included in the analysis, whereas only infants that looked at least 16 out of 32 displays were included in the analysis.

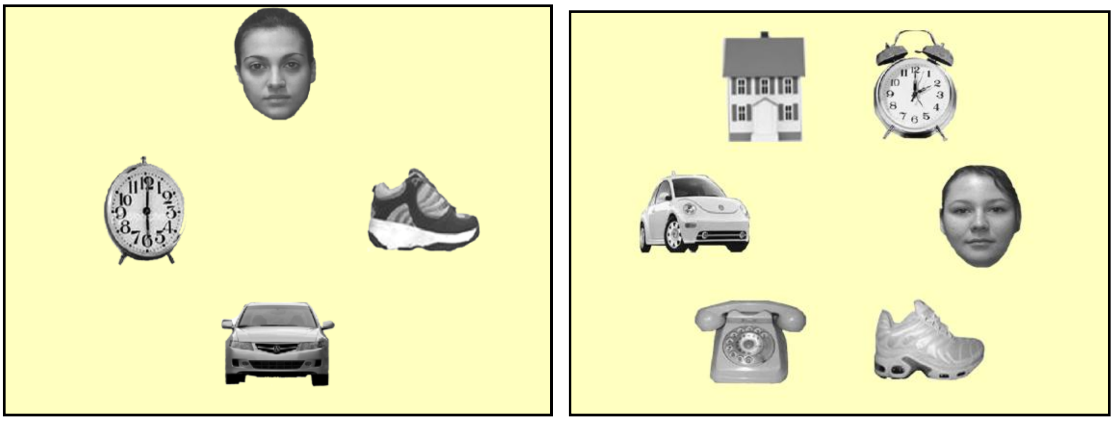


Figure 34: Examples of stimuli employed in Experiments 8, 9 and 10.

Results and Discussion

A first series of statistical analyses were performed on each dependent variable (e.g., direction of the first fixation, number of fixations and total fixation time), to determine whether a target face captures and maintains adults' attention when presented among 3 and 5 objects as distractors.

Four item displays: Chance level

One-sample t-tests were conducted on each dependent variable (i.e., direction of the first fixation, the number of total fixations and total fixation time) to examine whether the percentage of each variable toward the target face differed from what would be expected by chance 1/4 (25%) for displays with 4 item. Adults' first fixations were directed to the face (M = 58.3%, SD = 22), t (11) = 5.2, $p < .001$ (Cohen's d = 1.5), whereas all the other categories were under the chance level of 25%. Furthermore, number of fixations were above the chance level for faces (M = 33.8% SD = 12.3), t (11) = 2.5, $p < .05$ (d = .71), compared to other objects that were all below the chance level. Faces maintain adults' attention, as showed by the percentage of total fixation time toward the face target (M =

36.1% *SD* = 15.2), with *t* (11) = 2.5, $p < .05$ (d = .73), compared to the other objects that were all under the chance level (Figure 35).

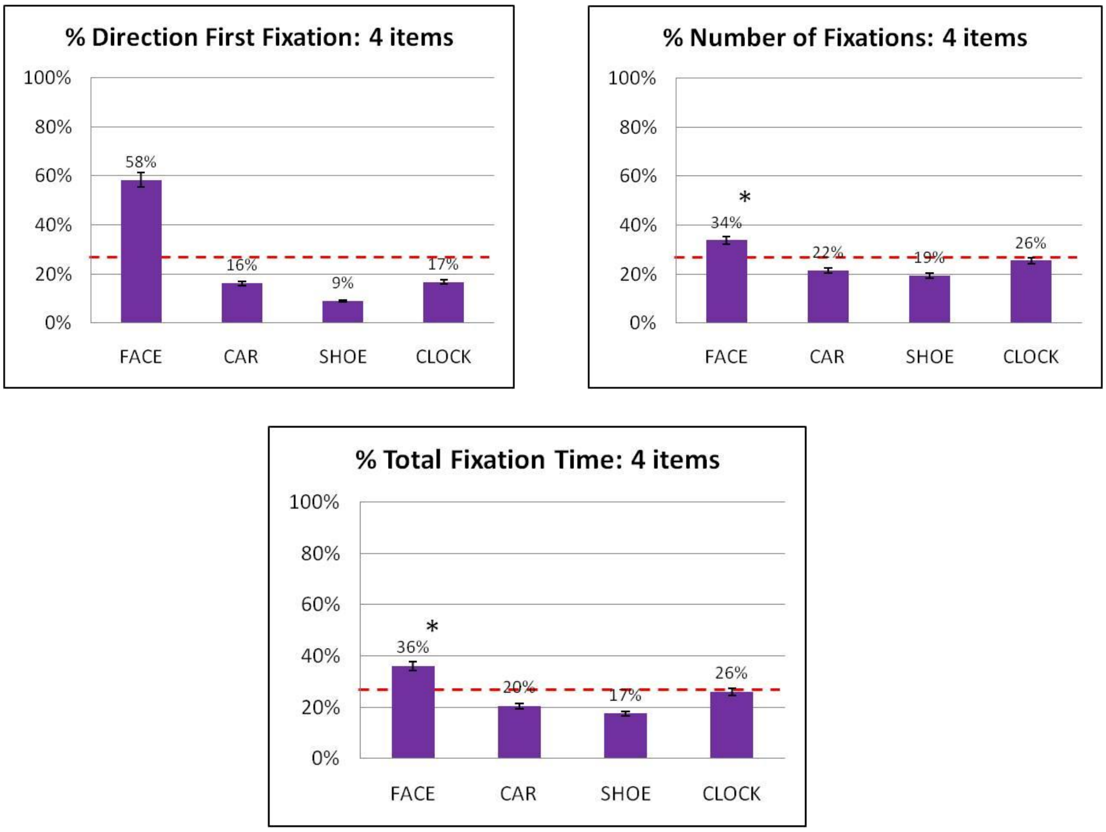


Figure35: Percentage of each variable toward each visual stimulus compared to the chance level (25%).

Six item displays: Chance level

The same results were observed when the same analyses were conducted on the displays with 6 items (chance level 1/6, 16.6%). Faces attracted adults' attention over other object for both the direction of the first fixation (*M* = 51%, *SD* = 21.3), *t* (11)= 5.7, $p < .001$ (d = 1.6), and the number of fixations toward the target face (*M* = 26.5%, *SD* = 12.4), *t* (11)= 2.9, $p < .05$ (d = .84), whereas the percentage of the objects were under the chance level of 16.6%. Also the percentage of the total fixation time toward face was above the chance level (M = 28.2%, SD = 17.3), t (11)= 2.4, p < .05 (d = .71) compared to the other objects presented (Figure 36).

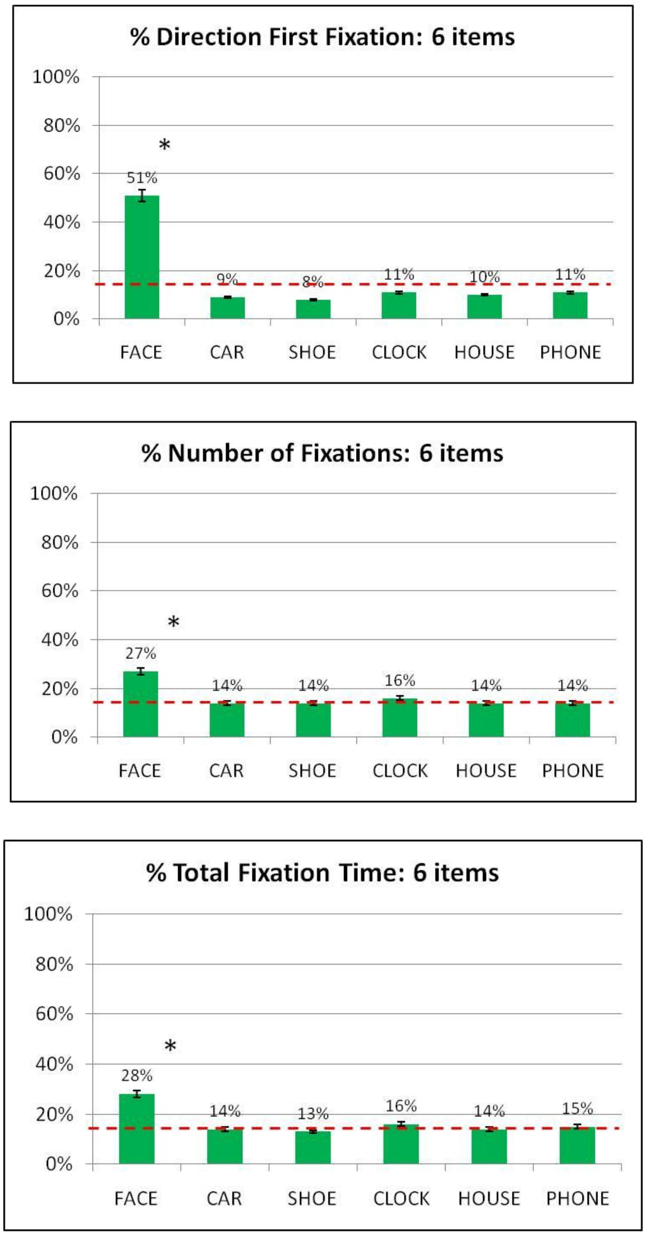


Figure 36: Percentage of each variable toward each visual stimulus compared to the chance level (16.6%).

To determine whether a target face had a detection advantage compared to other objects, one-way repeated measure analyses of variance (ANOVAs) were performed on each dependent variable and for both kind of displays (i.e., with 4 and 6 items). These analyses were the same that Ro et al., (2001) and Palermo & Rhodes (2003) performed in their studies.

Four item displays: face vs. each object

A main effect of Stimulus (i.e., face) was observed for the direction of the first fixation, F (3, 33) = 23, $p < .001$, $\eta^2 = .68$, for the number of fixations, F (3, 33) = 6.7, $p < .001$, $\eta^2 = .38$, and also for the total fixation time F (3, 33) = 6.9, $p < .05$, $\eta^2 = .36$. Planned *t*-tests for dependent sample showed that the target face (*M* = 9.3, *SD* = 3.5) received more first fixations compared to cars (*M* = 2.6, *SD* = 1.7), *t* (11) = 4.8, $p < .001$ (d = .72), to shoes (*M* = 1.4 *SD* = 1.5), *t* (11)= 5.7, $p < .001$(d = .6), and to alarm clocks (*M* = 2.7 *SD* = 1.7), *t* (11) = 4.8, $p < .01$ (d = .71). *T*-tests for the number of fixations showed that face (*M* = 59.6 *SD* = 21.3) received more fixations compared to cars (*M* = 38, *SD* = 9.8), *t* (11) = 2.6, $p < .05$ (d = 1.3), and compared to shoes (*M* = 34.2, *SD* = 9.5), *t* (11)= 3.1, $p < .05$ (d = 1.1), whereas there was no difference between faces and alarm clocks (*M* = 45.1 *SD* = 11), *t* (11)= 1.8, n.s. Moreover, as regard to the total fixation time, *t*-tests revealed that the target face (*M* = 20201.1 ms, *SD* = 9987.9) was observed more than cars (*M* = 11178 ms, *SD* = 3134.9), *t* (11)= 2.5, $p < .05$ (d = 1.4), and more than shoes (*M* = 9576.7 ms, *SD* = 2801.3), *t* (11)= 2.9, $p < .05$ (d = 1.2), but not more than alarm clocks (*M* = 14260.9 ms *SD* = 3542.5), *t* (11)= 1.6, n.s. (Figure 37).

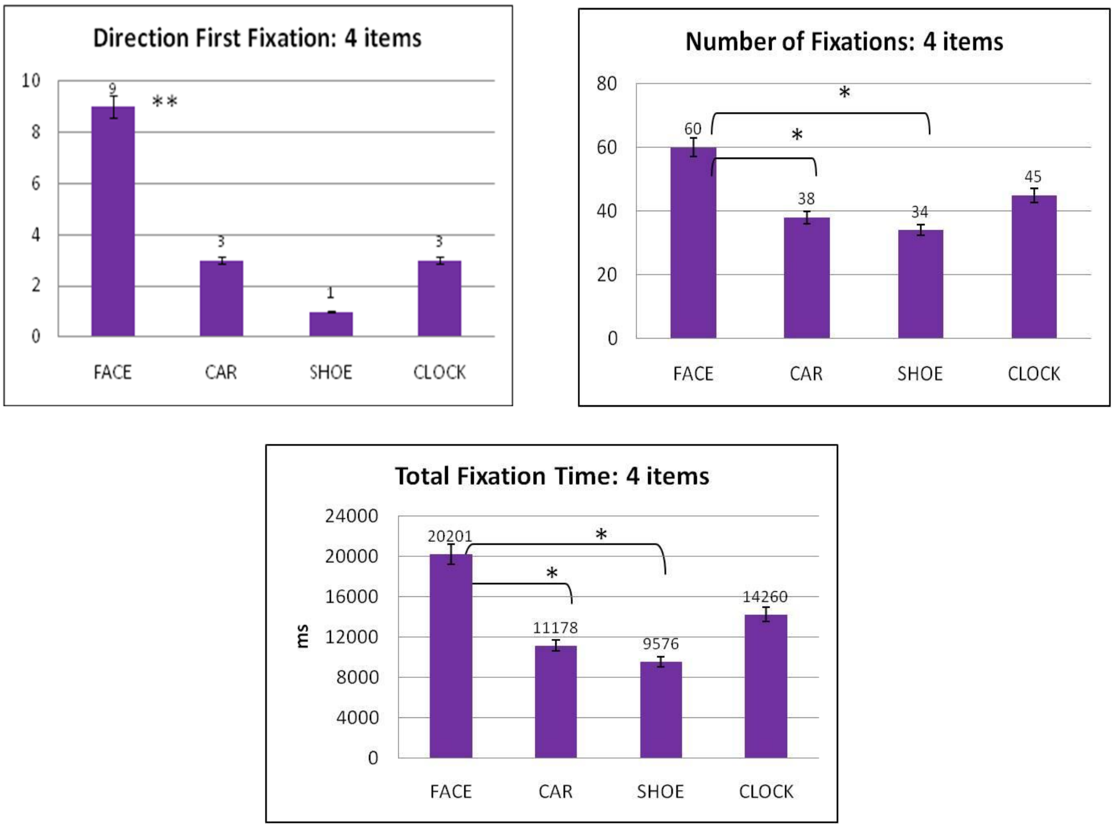


Figure 37: Four item displays: comparison between face target and each object as regard to each dependent variable.

Six item displays: face vs. each object

Similar results were obtained when the same analyses were performed for 6 items display, since a main effect of the Stimulus was obtained for the direction of the first fixation, F (5, 55) = 20.8, $p < .001$, $\eta^2 = .65$, for the number of fixations, F (5, 55) = 7.1 $p < .05$, $\eta^2 = .39$, and also for the total fixation time F (5, 55) = 4.8, $p < .01$, $\eta^2 = .30$. Planned *t*-tests for dependent sample showed that the target face received more first fixations (*M* = 8.2 *SD* = 3.4) compared to all the other objects presents (*t* tests, *p* <. 01). Moreover, faces were observed more frequently (*M* = 53.3 *SD* = 25.3) than the other objects (t tests, *p* < .05). Finally, as regard to the total fixation time, faces (*M* = 15510.9 ms, *SD* = 9957.5) were observed longer than cars (*M* = 7575 ms, *SD* = 1992.2), *t* (11)= 2.4, *p* <. 05 (d = 1.4) and more than shoes (M = 7025.7 ms, SD = 1967), t (11)= 2.6, $p < .05$ (d = 1.3). However, the difference between face and houses (M = 7799.8 ms SD = 2904.4), alarm clocks (M = 8893.7 ms, SD = 2667.3), and telephones (M = 7963.9 ms, SD = 2825.7) did not reach the significance (t tests, n.s.) (Figure 38).

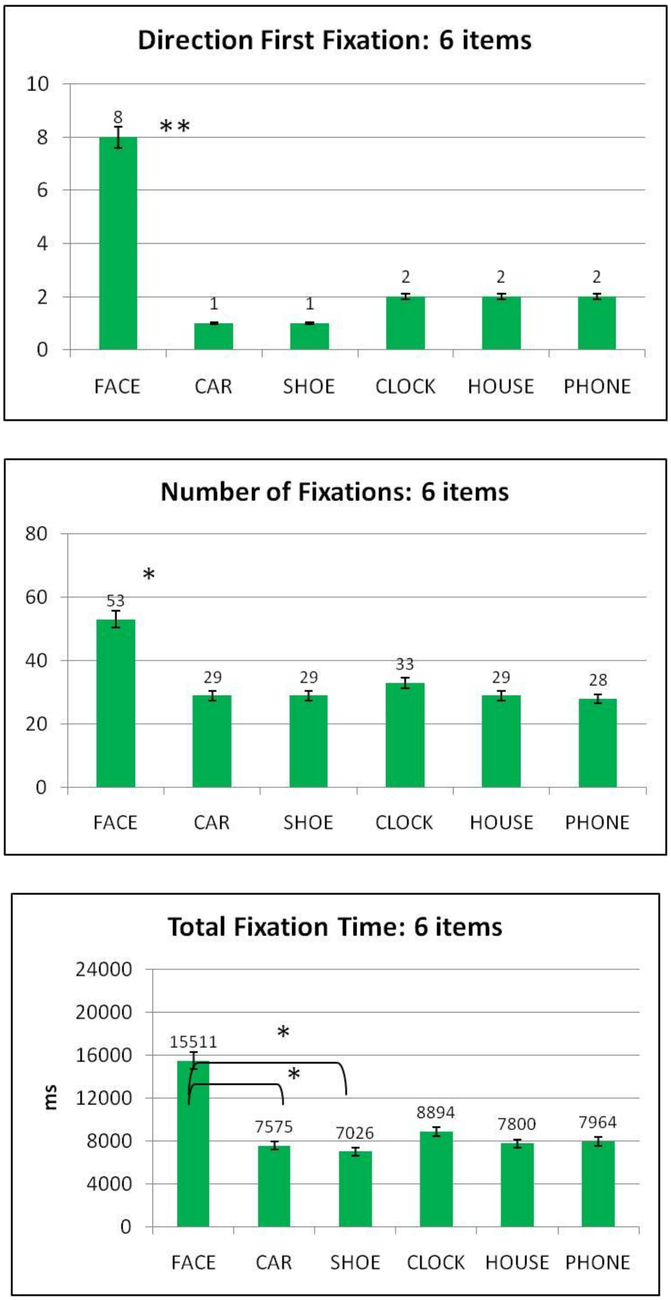
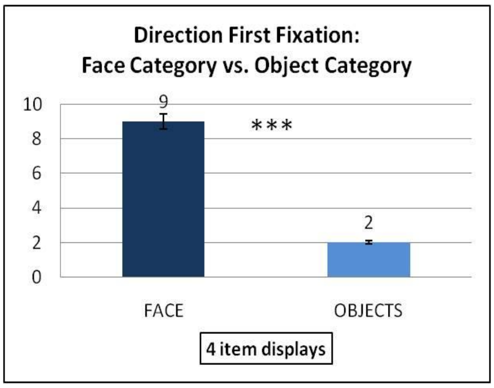


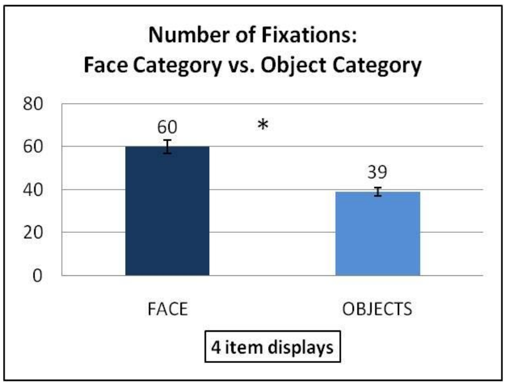
Figure 38: Six item displays: comparison between face target and each object as regard to each dependent variable.

A series of *t*-tests for dependent sample were performed to compare Face category to Object category for each dependent variable measured for each condition (i.e., 4 vs. 6 display items) This is the type of analysis used by Ro et al. (2001) and Palermo & Rhodes (2003) to demonstrate a face detection advantage.

Four item displays: face category vs. object category

As for the direction of the first fixation, comparing the Face category (*M* = 9.3, *SD* = 3.5) to the pooled first fixations for Object category (*M* = 2.2, *SD*= 1.2) revealed a Face category advantage with t (11)= 5.2, p < .001 (d = .7). In the same vein, Face category received more frequent fixations (*M* = 59.6, *SD* = 21.2) compared to Object category (*M* = 39.1, *SD* = 8.4), t (11)= 2.6, p < .05 (d = 1.4). Faces were also looked longer (*M* = 20201.1 ms, *SD* = 9987.9) than objects (*M* = 11671.9 ms, *SD* = 2798.4), t (11)= 2.3, p < .05 (d = 1.5).





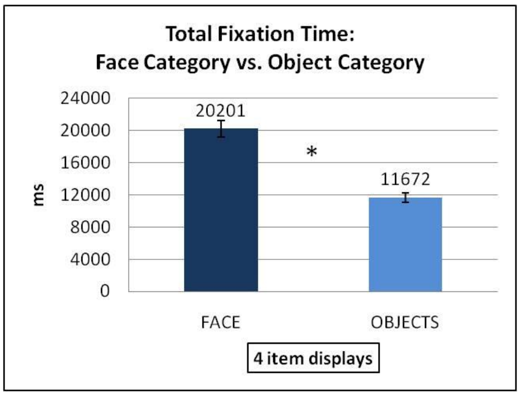


Figure 39: Four item displays: comparison between face category vs. objects category as regard to each dependent variable.

Six item displays: face category vs. object category

As for 4 item displays, Face category captured adults' attention more than the other objects, as we can see from both the direction of first fixations (Face category *M* = 8.2, *SD* = 3.4 vs. Object category *M* =1.6, *SD* = .7, *t* (11)= 5.6, *p* < .001, d = .6) and the number of fixations (Face category *M* = 53.3, *SD* = 25.3 vs. Object category *M* = 29.5, *SD* = 5.8, *t* (11) = 2.8, *p* < .05, d = .9). Finally, faces maintained adults' attention more than objects as showed by the significant difference in total fixation time between Face category (*M* = 15510.9 ms, *SD* = 9957.5) and Object category (*M* = 7851.6 ms, *SD* = 2000.3), *t* (11) = 2.2, *p* < .05 (d = 1.5).

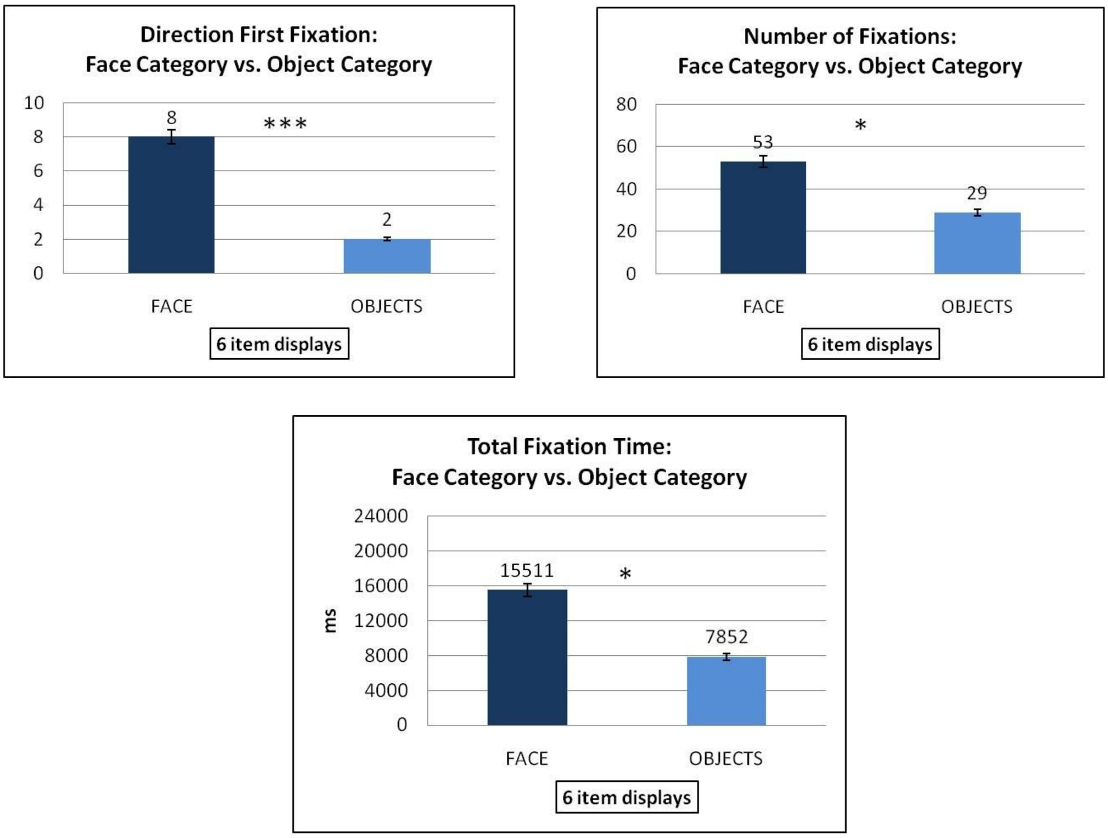


Figure 40: Six item displays: comparison between face category vs. objects category as regard to each dependent variable.

Comparison between four and six item displays: face category vs. object category

Finally, to examine whether adults' performance differed significantly between the four and the six item displays condition a two-way repeated measures ANOVA's were performed on each dependent variable, with Stimulus category (Face category vs. Object category) and Item (4 vs. 6) as within-subjects factors.

Results of the ANOVA on the direction of the first fixation showed a main effect of the Stimulus category F (1, 11) = 31.3, $p < .001$, $\eta^2 = .74$ and a main effect of the Item F (1, 11) = 21.4 $p < .01$, $\eta^2 = .66$, whereas the interaction Stimulus category X Item did not reach the statistical significance, F (1, 11) = .57, n.s., demonstrating that a target face (*M* = 8.8, *SD* = .9) captured adults' attention over other objects (*M* = 1.9, *SD* = .3) regardless of the number of distractors presented, even though the number of first fixation toward face is higher in the display containing four items (*M* = 5.8, *SD* = .3) than the displays containing six items (*M* = 4.9, *SD* = .4) (Figure 41).

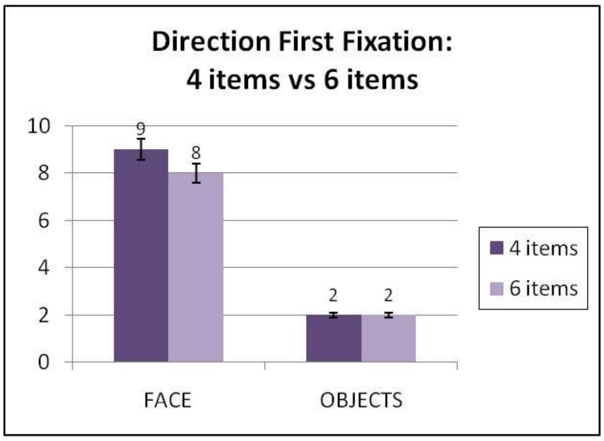


Figure 41: Adults' first fixations are oriented toward face compared to other object, regardless of the number of distractors.

Similar results were obtained for the other attention-getting index, that is the number of fixation, since the ANOVA showed a main effect of the Stimulus category, F (1, 11) = 7.5, $p < .05$, $\eta^2 = .68$ and a main effect of the Item F (1, 11) = 23.5 $p < .01$, $\eta^2 = .68$, with no Stimulus category X Item interaction, F (1, 11) = .91, n.s. Although Face category was observed more frequently in four item displays (*M* = 49.3, *SD* = 2.4) than in six item displays (*M* = 41.4, *SD* = 3.1), adult participants looked more frequently faces (*M* = 56.5, *SD* = 6.6) than objects (*M* = 34.3, *SD* = 2), and this regardless of the number of objects present (Figure 42). Finally, adults looked longer Face category (*M* = 17856 ms, *SD* = 2806.3) rather than Object category (*M* = 9761.8 ms, *SD* = 677.5), as revealed by the main effect of Stimulus category F (1, 11) = 5.5, $p < .05$, $\eta^2 = .33$. As for the other dependent variables measured, faces were looked longer in four item condition (*M* = 15936.5 ms, *SD* = 1084.5) than in six item condition (*M* = 11681.3 ms, *SD* = 1182.6), F (1,11) = 47.2, $p <$

.001, $\eta^2 = .81$, although the Stimulus category X Item was not significant $F(1, 11) = .37$, n.s. (Figure 43).

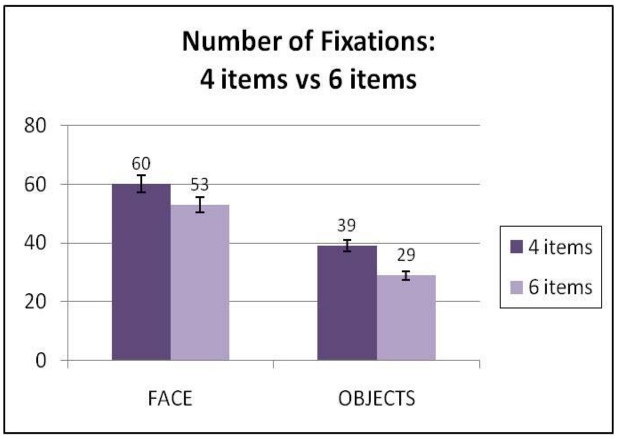


Figure 42: Adults' number of fixations is oriented toward face compared to other object, regardless of the number of distractors.

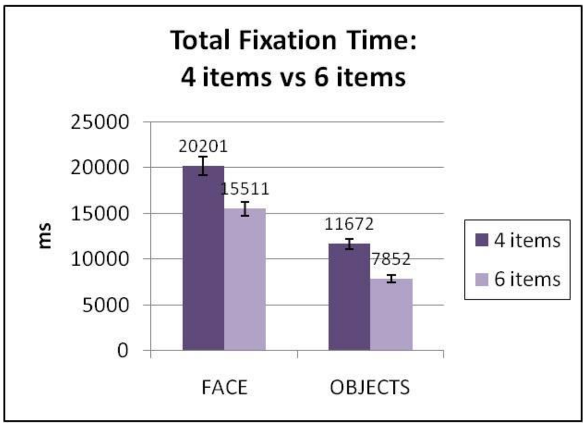


Figure 43: Adults look longer at target face compared to other object, regardless of the number of distractors.

Results obtained from this experiment demonstrated that a face among various and heterogeneous objects grab and maintain adults' attention, regardless of the number of distractors presents in the complex displays. These results seem to be in line with other studies in literature that showed how faces, when competing for attention with other non-face stimuli have an attention advantage (Ro et al., 2001; Langton et al., 2008). Importantly, this study differed from the others in literature because demonstrated that the measure of the eye-movements only is sufficient to investigate search performance for a complex stimulus like a human face, corroborating the hypothesis of a linkage between attention and eye movements (Zelinsky, 1996). Moreover, the data obtained here showed that the modified visual search employed could be a good paradigm to study visual search strategies in adults. With this in mind, the same procedure and the same paradigm were employed with 6- and 3-month-old infants to test whether a face could grab and hold attention in infants just as in adults.

Experiments 9 and 10

Method

Participants

Participants were twelve 6-month-old (7 females, mean age = 98.7 days) and nineteen 3-month-old (10 females, mean age = 99.2 days) healthy and full-term infants. They were middle-class infants and all of them were Caucasian. Eleven additional infants were excluded from the final sample for the following reasons: two six-month-old infants showed a strong position preference (i.e., they looked to one direction more than 90% of the time) and nine infants of three months of age did not complete testing due to fussiness. Infants were tested only if awake and in an alert state after parents gave their informed consent.

The *Stimuli, the Apparatus and the Procedure* were the same that were employed in the previous experiment, with only the exception that infants sat in an infant car seat. Furthermore, to be involved in the statistical analysis, infants have to look at least to half of the trials presented, that is 16 out to 32.

Results and Discussion

The same statistical analyses performed with adults were run with 6- and 3-month-old infants.

Four item displays: Chance level

One-sample *t*-tests were conducted on each dependent variable (e.g., direction of the first fixation, number of fixations and total fixation time) to examine whether the percentage of each variable towards the target face differed from what would be expected by chance 1/4 (e.g., 25%) for displays with four item.

Six-month-old infants. Infants' first fixations directed to the face (M = 21.4%, SD = 11.8) were not above the chance level of 25%, t (11) = 1.1, n.s. On the contrary, number of fixations were above the chance level for faces (M = 36.8% SD = 10.4), t (11) = 3.9, $p <$ .05 (d = 1.1), compared to other objects that were all below the chance level. Furthermore, faces maintain infants' attention, as showed by the percentage of total fixation time toward the face target (M = 38.9% SD = 11.1), with t (11) = 4.3, $p <$ .01 (d = 1.2), compared to the other objects that were all under the chance level (Figure 44).

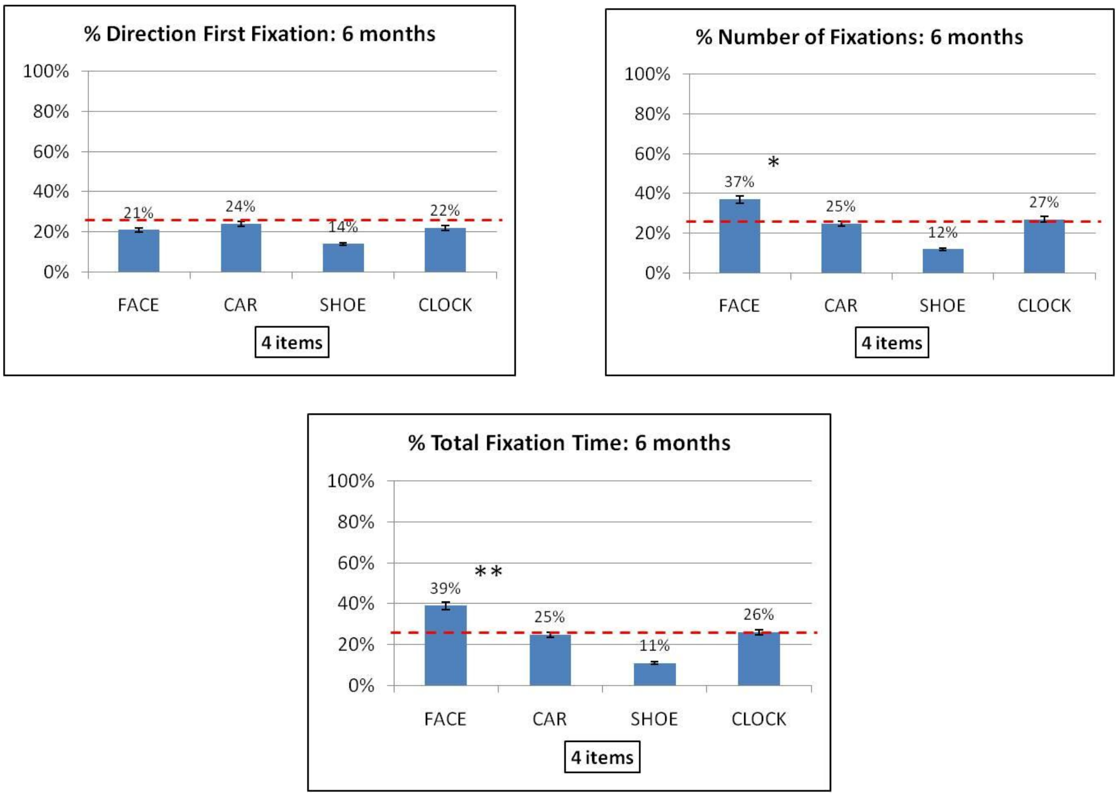


Figure 44: Percentage of each variable toward each visual stimulus compared to the chance level (25%) in 6-month-old infants.

Three-month-old infants. Different results were obtained for three-month-old infants, because the direction of the first fixation toward face (M = 14.3%, SD= 11.8, t (18) = 3.9, p < .01), the number of fixations (M = 20.3%, SD = 14.9, t (18) = 1.4, n.s.) and the total fixation time (M = 25.1%, SD = 16.7, t (18) = .9, n.s.) were not above the chance level, as well as the other objects (t-tests, n.s.) (Figure 45).

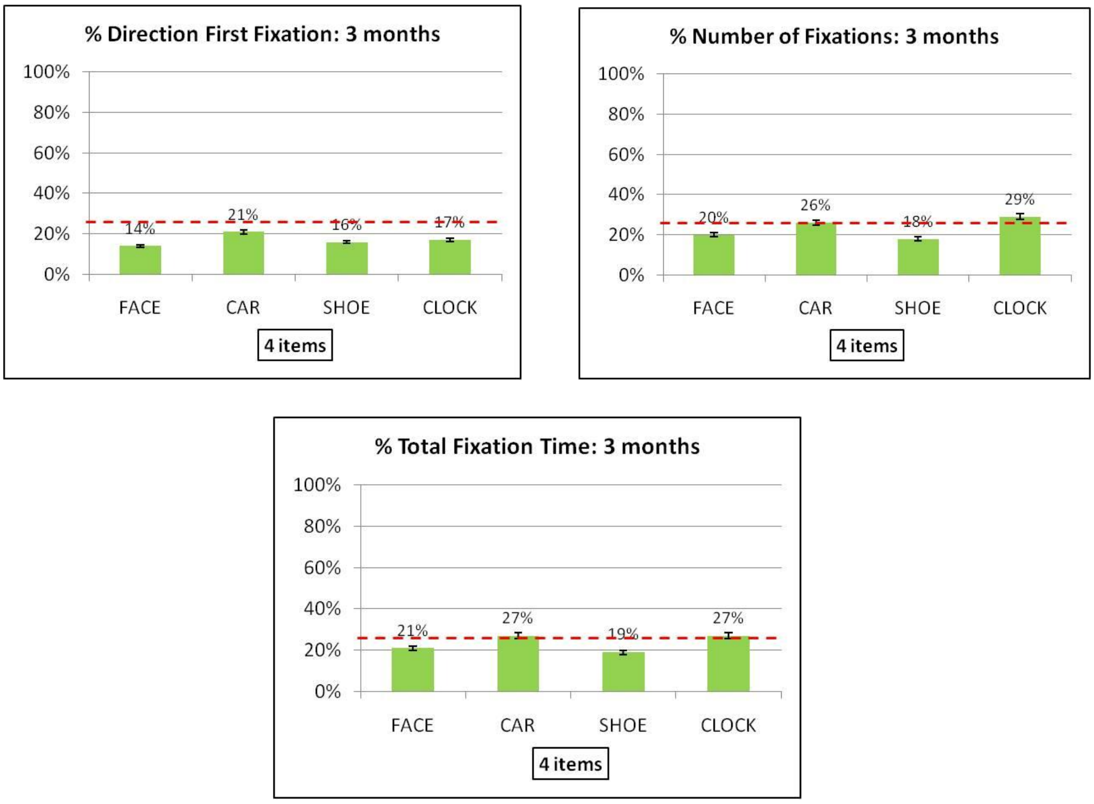


Figure 45: Percentage of each variable toward each visual stimulus compared to the chance level (25%) in 3-month-old infants.

Six item displays: Chance level

Six-month-old infants. Faces did not attract 6-month-old infants' attention over other object as revealed by the direction of the first fixation (M = 16.3% SD = 6.2), t (11)= .2, n.s. In contrast, the percentage of the number of fixations toward the target face (M = 30.2% SD = 9.6), t (11)= 5.1, p < .001 (d = 1.5) the percentage of the total fixation time toward face were above the chance level (M = 30.1% SD = 11.8), t (11)= 4.1, p <.05 (d =1.1)(Figure 46).

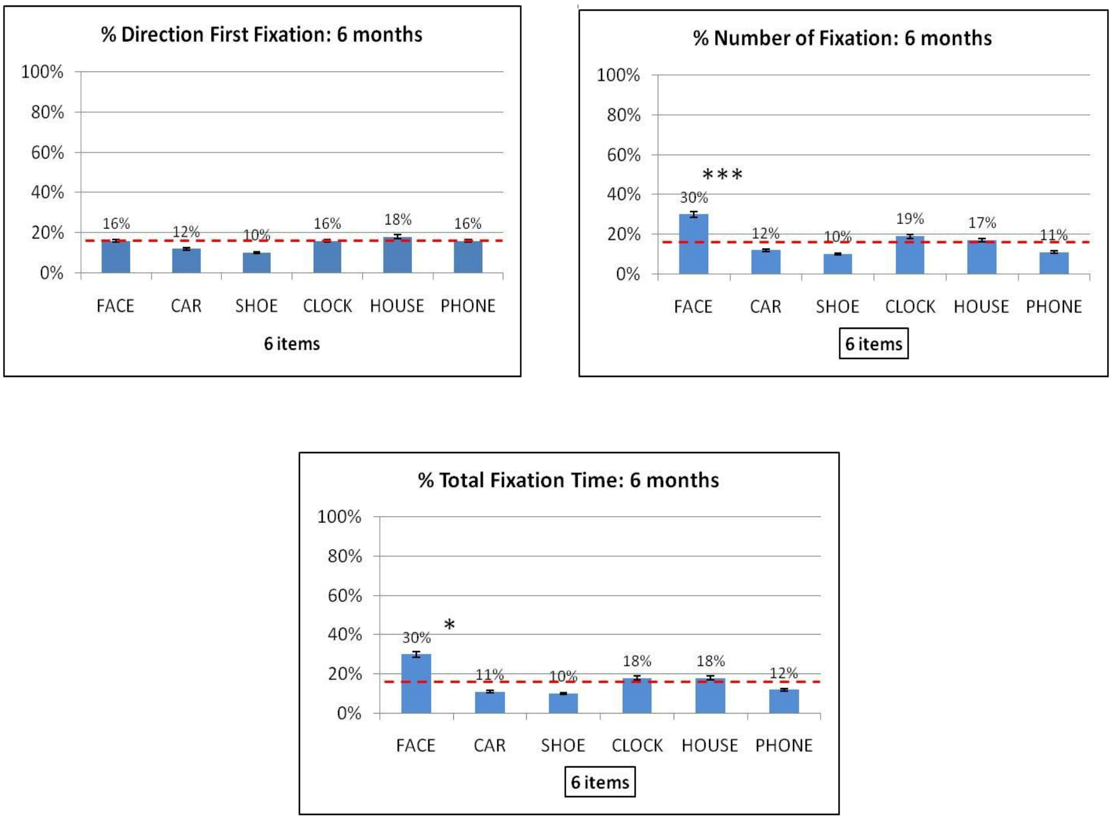


Figure 46: Percentage of each variable toward each visual stimulus compared to the chance level (16.6%) in 6-month-old infants.

Three-month-old infants. As for the four item displays, the face target did not grab nor maintain infants' attention, because the percentage of the direction of the first fixation toward face (M = 12.6%, SD = 8.6, t (18) = 1.7, n.s.), the percentage of the number of fixations (M = 18.3%, SD = 10.8, t (18) = .9, n.s.) and the percentage of the total fixation time (M = 17.3%, SD = 10.5, t (18) = .5, n.s.) were not above the chance level (Figure 47).

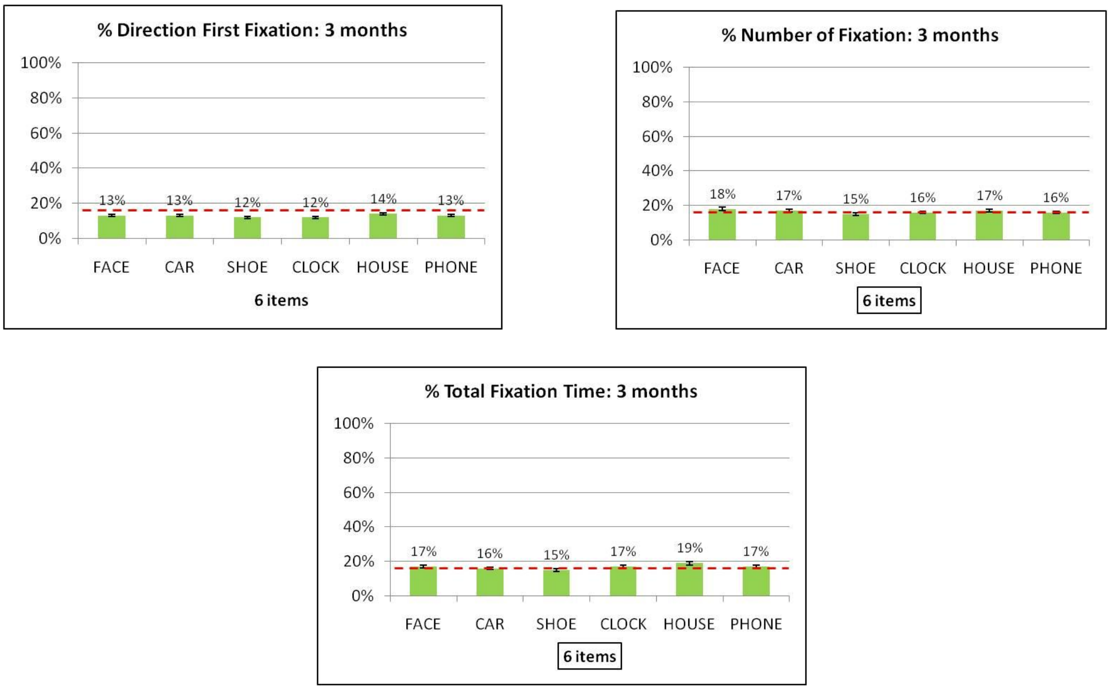


Figure 47: Percentage of each variable toward each visual stimulus compared to the chance level (16.6%) in 3-month-old infants.

Four item displays: face vs. each object

Six-month-old infants. One-way repeated measure analyses of variance (ANOVAs) on each dependent variable, revealed no main effect of the face target stimulus as for the direction of the first fixation, F (3, 33) = 2.5, n.s., showing that 6-month-old infants did not orient their attention first to the target face (Figure 48).

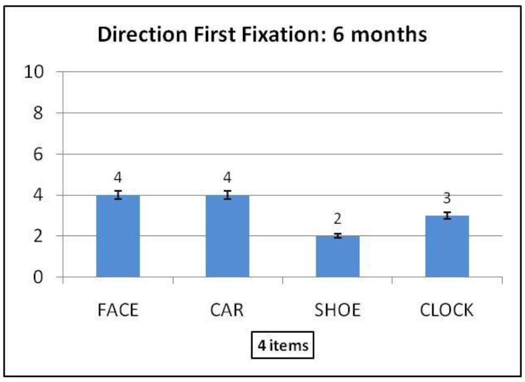


Figure 48: Four item displays: comparison between face target and each object as for the direction of the first fixation.

On the contrary, a main effect of face target stimulus was obtained both for the number of fixations, F (3, 33) = 11.8, $p < .001$, $\eta^2 = .52$, and also for the total fixation time F (3, 33) = 10.9, $p < .001$, $\eta^2 = .50$. Planned *t*-tests for dependent sample showed that the target face (*M* = 38.3, *SD* = 22.3) was observed more frequently than cars (*M* = 22.9, *SD* =12.8), *t* (11) = 2.8, *p* < .05 (d = 1.2), shoes (*M* = 11.8, *SD* = 8.8), *t* (11)= 4.8, *p* < .01(d = .7), and alarm clocks (*M* = 29.3, *SD* = 18.9), *t* (11) = 2.7, *p* < .05 (d = 1.2) (Figure 49).

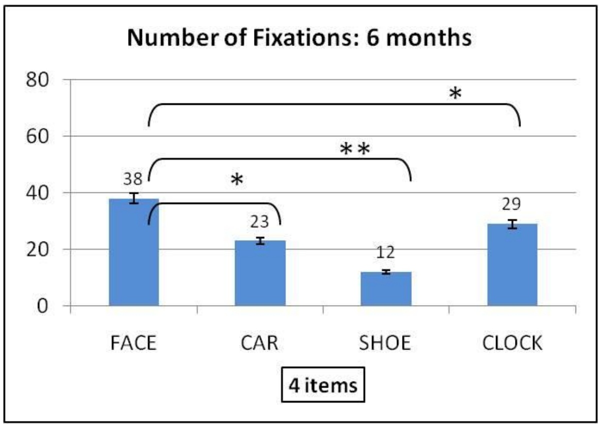


Figure 49: Four item displays: comparison between face target and each object as for the number of fixations.

T-tests for the total fixation time revealed that face (*M* = 9802.4 ms, *SD* = 5996.2) was looked longer than cars (*M* = 5728.3 ms, *SD* = 3860.8), *t* (11) = 3.1, *p* < .05 (d = 1.1), shoes (*M* = 2832.5 ms *SD* = 1461.1), *t* (11)= 4.5, *p* < 01 (d =.8) and alarm clocks (*M* = 7223.9 ms, *SD* = 5274.2), *t* (11)= 2.3, *p* < .05 (d = 1.4) (Figure 50).

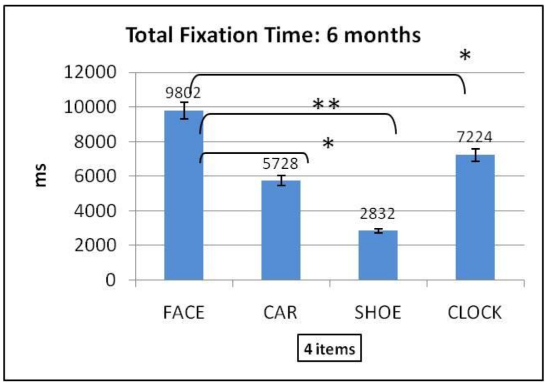
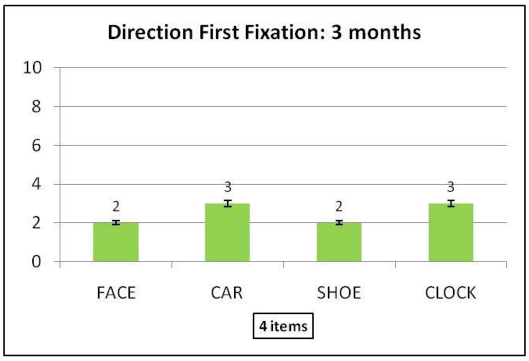
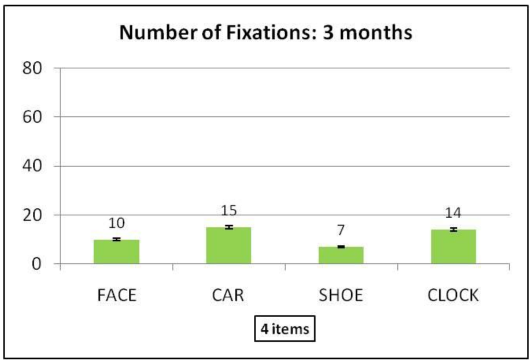


Figure 50: Four item displays: comparison between face target and each object as for the total fixation time.

Three-month-old infants. Results of the ANOVA revealed no main effect of the stimulus for the direction of the first fixation, $F(3, 54) = 1.5$, n.s., for the number of fixations, $F(3, 54) = 3.6$, n.s., and for the total fixation time, $F(3, 54) = 2.3$, n.s. (Figure 51).





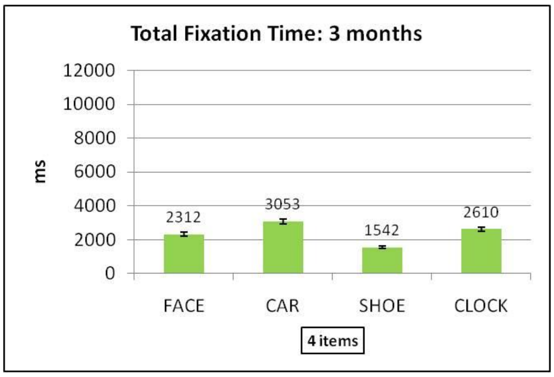


Figure 51: Four item displays: comparison between face target and each object as for each dependent variable in 3-month-old infants.

Six item displays: face vs. each object

Six-month-old infants. There was no main effect of the face target stimulus for the direction of the first fixation, F (5, 55) = 1.2, n.s. (Figure 52), whereas a main effect of face stimulus was observed for the number of fixations, F (5, 55) = 8.9 $p < .001$, $\eta^2 = .44$, and also for the total fixation time F (5, 55) = 5.8, $p < .001$, $\eta^2 = .35$.

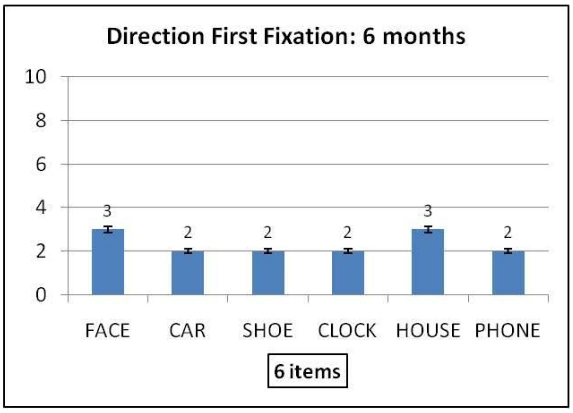


Figure 52: Six item displays: comparison between face target and each object as for the direction of the first fixation.

Planned *t*-tests for dependent sample showed that the target face (M = 35.4, SD = 20.5) was observed more frequently than all the other objects (*t* tests, $p < .05$)(Figure 53).

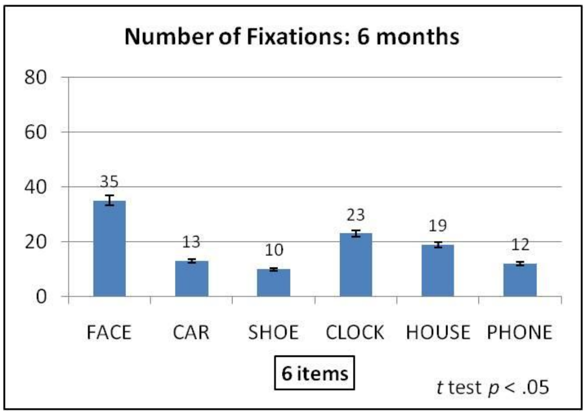


Figure 53: Six item displays: comparison between face target and each object as for the number of fixations.

Finally, as regard to the total fixation time, faces (*M* = 9267.1 ms, *SD* = 7883.4) were observed longer than cars (*M* = 2870.1 ms, *SD* = 2193.6), *t* (11)= 2.9, *p* <. 05 (d = 1.1), more than shoes (*M* = 2318.5 ms, *SD* = 1483.5), *t* (11)= 3.1, *p* < .05 (d = 1.1) and more than telephones (*M* = 3053.8 ms, *SD* = 2042.8), *t* (11) = 3.1, *p* < .05 (d = 1.1). However, the difference between the target face and alarm clocks (*M* = 5427.1 ms, *SD* = 5203.2) and houses (*M* = 4849.6 ms *SD* = 3533.5) did not reach the significance (*t* tests, n.s.) (Figure 54).

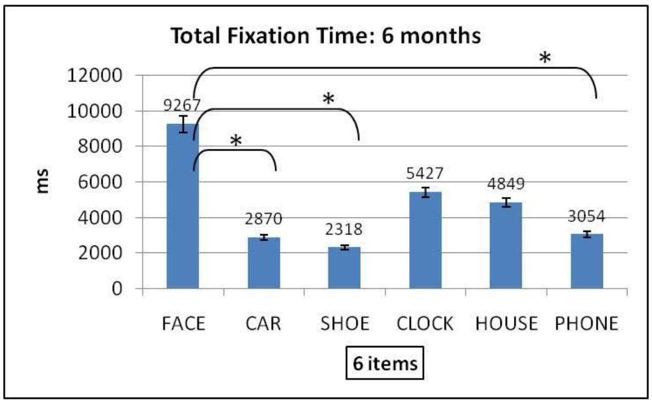


Figure 54: Six item displays: comparison between face target and each object as for the total fixation time.

Three-month-old infants. No main effects were obtained for any of the dependent variables, as revealed by the ANOVA for the direction of the first fixation F (5, 90) = .14, n.s., the number of fixations F (5, 90) = .40, n.s., and for the total fixation time F (5, 90) = .38, n.s (Figure 55).

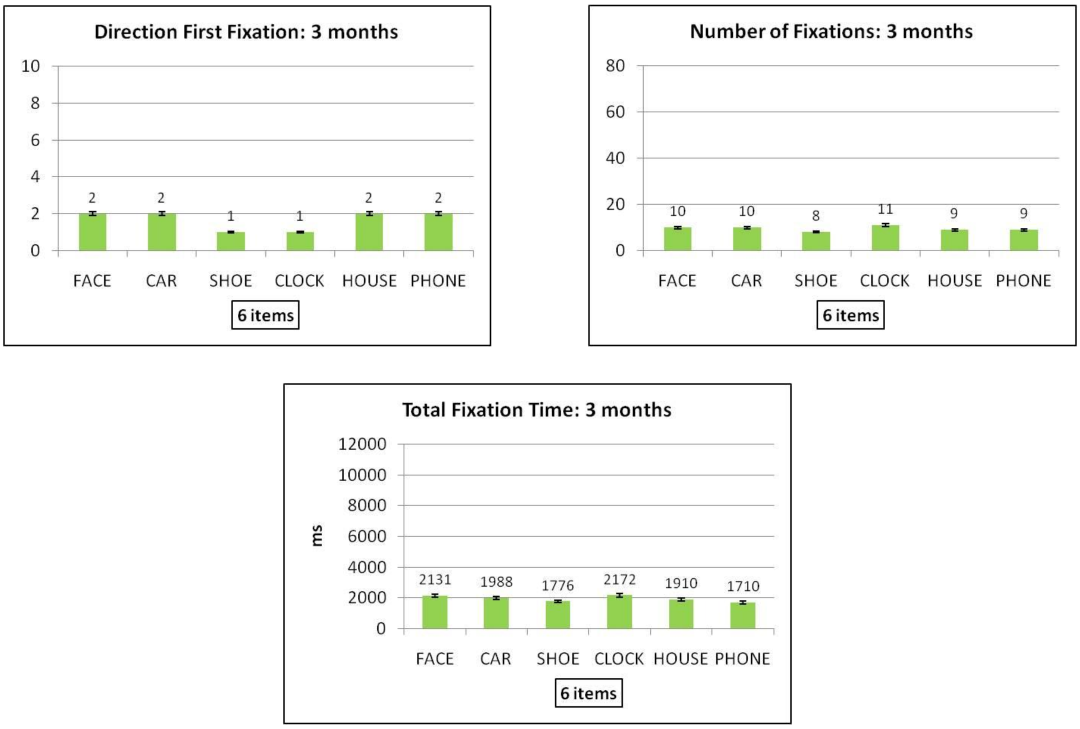


Figure 55: Six item displays: comparison between face target and each object as for each dependent variable in 3-month-old infants.

Four item displays: face category vs. object category

As for adults, a series of *t*-tests collapsing the data into Face and Objects categories for each condition (i.e., 4 vs. 6 display items) were performed.

Six-month-old infants. As for the direction of the first fixation, comparing the Face category (M = 4, SD = 1.6) to the pooled first fixations for Object category (M = 3.2, SD= 1.1) revealed that Face category did not reach any advantage, t (11)= 1.1, n.s (Figure 56).

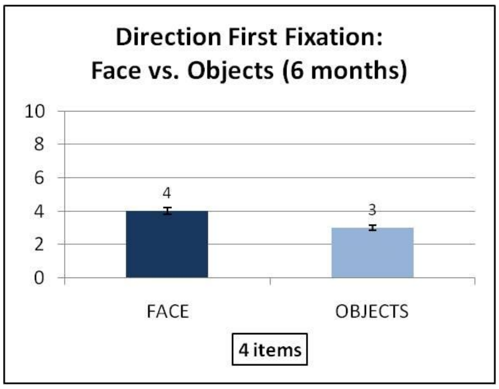


Figure 56: Four item displays: comparison between face category and object category as for the direction of the first fixation.

However, Face category received more frequent fixations (*M* = 38.3, *SD* = 22.3) as compared to Object category (*M* = 21.4, *SD* = 11.2), *t* (11)= 3.9, *p* < .01 (d =.8) (Figure 57).

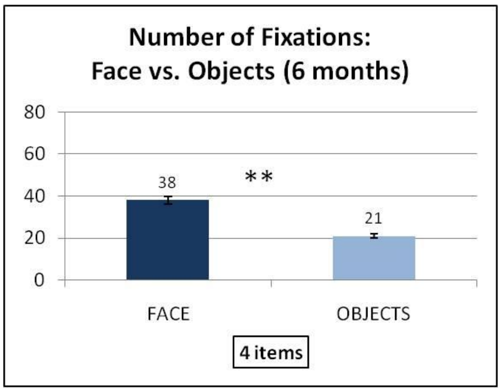


Figure 57: Four item displays: comparison between face category and object category as for the number of fixations.

In addition, infants looked longer to faces (*M* = 9802.4 ms, *SD* = 5996.2) than objects (*M* = 5261.6 ms, *SD* = 3325.1), *t* (11)= 3.9, *p* < .05 (d =.8) (Figure 58).

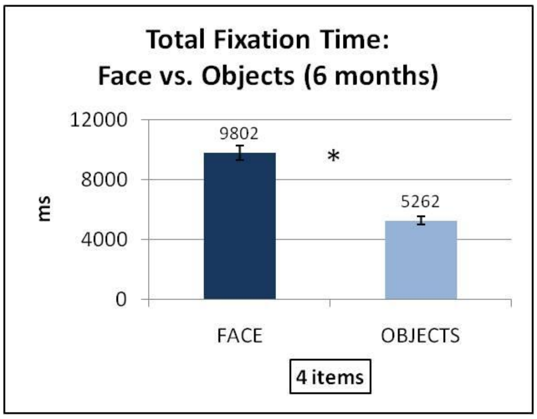


Figure 58: Four item displays: comparison between face category and object category as for the total fixation time.

Three-month-old infants. *T*-tests did not reach the significance for any dependent variable considered (*t*-tests, n.s.) (Figure 59).

Figure 59: Four item displays: comparison between face category and object category as for each dependent variable in 3-month-old infants.

Six item displays: face category vs. object category

Six-month-old infants. As for 4 item displays, Face category did not captured 6-month-old infants' attention more than the other objects, at least for the direction of the first fixation (Face category M = 2.6, SD = 1 vs. Object category M =2.5, SD = 1.2, t (11)= .2, n.s.) (Figure 60).

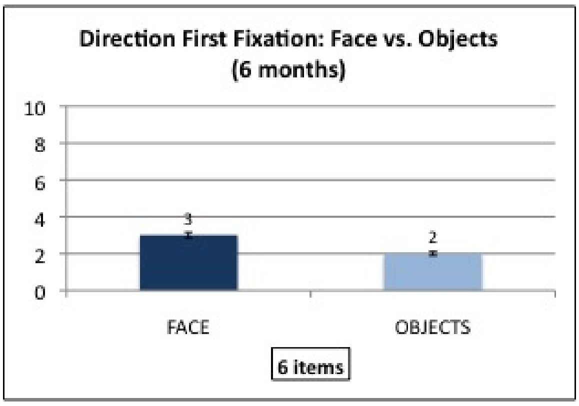


Figure 60: Six item displays: comparison between face category and object category as for the direction of the first fixation.

On the contrary the significance was observed at the level of the number of fixations (Face category M = 35.4, SD = 20.5 vs. Object category M = 15.5, SD = 7.8, t (11) = 3.9, $p < .05$, d =.8) (Figure 61).

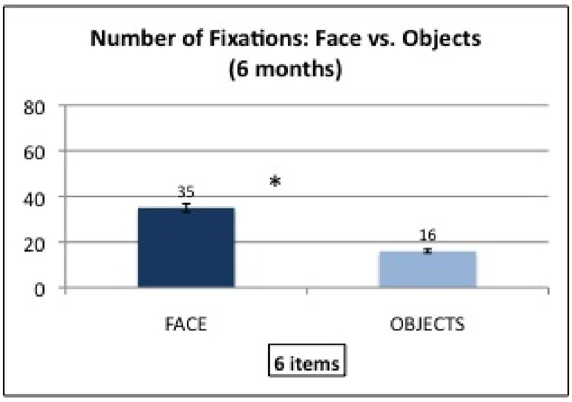


Figure 61: Six item displays: comparison between face category and object category as for the Number of fixations.

Finally, faces maintained infants' attention more than objects as showed by the significant difference in total fixation time between Face category (M = 9267.1 ms, SD = 7883.4) and Object category (M = 3703.8 ms, SD = 2137.3), $t(11) = 2.8$, $p < .05$ (d = .81) (Figure 62).

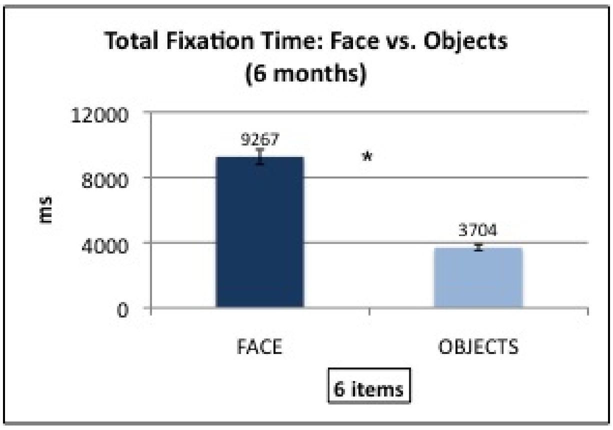
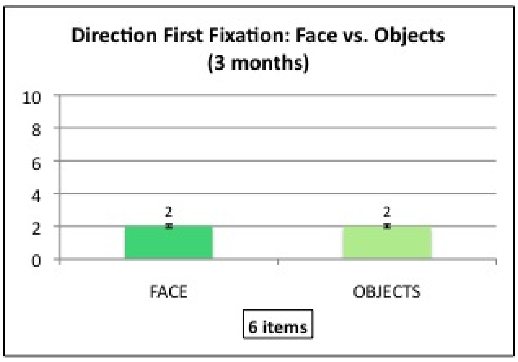
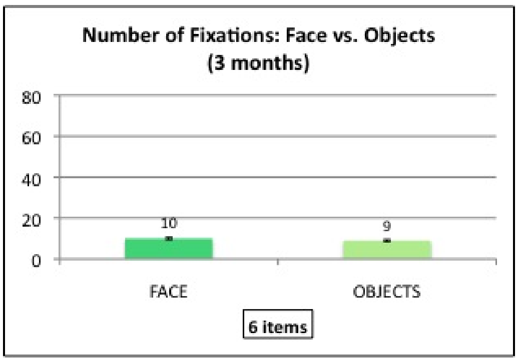


Figure 62: Six item displays: comparison between face category and object category as for the total fixation time.

Three-month-old infants. *T*-tests did not reach the significance for any dependent variable considered (t-tests, n.s.) (Figure 63).





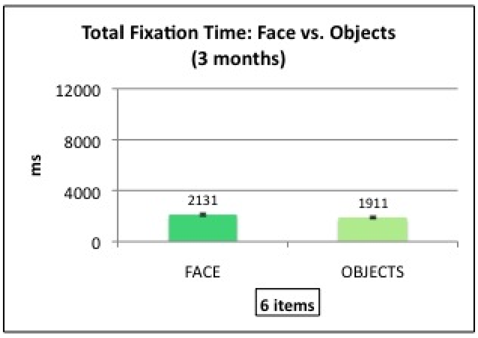


Figure 63: Six item displays: comparison between face category and object category as for each dependent variable in 3-month-old infants.

Comparison between four and six item displays

To examine whether 6- and 3-month-old infants' performance differed significantly between the four and the six item displays condition, a two-way repeated measures ANOVA' s were performed on each dependent variable, with Stimulus category (Face category vs. Object category) and Item (4 vs. 6) as within-subjects factors.

Six-month-old infants. Results of the ANOVA on the direction of the first fixation showed a main effect of the item only, $F(1, 11) = 22.1$, $p < .01$, $\eta^2 = .69$. No main effect of the Stimulus category factor was observed $F(1, 11) = 1.1$, n.s. neither the interaction between the stimulus category X item was significant, $F(1, 11) = .47$, n.s. (Figure 64).

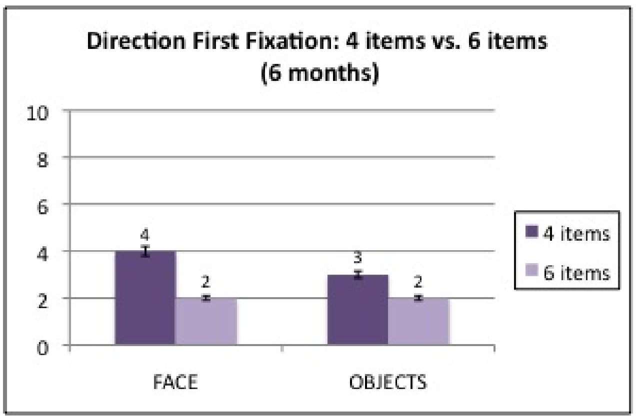


Figure 64: 6-month-old infants' first fixations toward face and objects

On the contrary, as regard to the other attention-getting index, that is the number of fixation, a main effect of the Stimulus category was observed, $F(1, 11) = 26.3$, $p < .001$, $\eta^2 = .71$, whereas the item factor $F(1, 11) = 3.3$, n.s. and the Stimulus category X Item interaction did not reach the significance, $F(1, 11) = .21$, n.s. This means that Face category was observed more frequently faces (*M* = 36.9, *SD* = 4.7) than Object category (*M* = 25.5, *SD* = 3.7), and this regardless of the number of objects present (Figure 65).

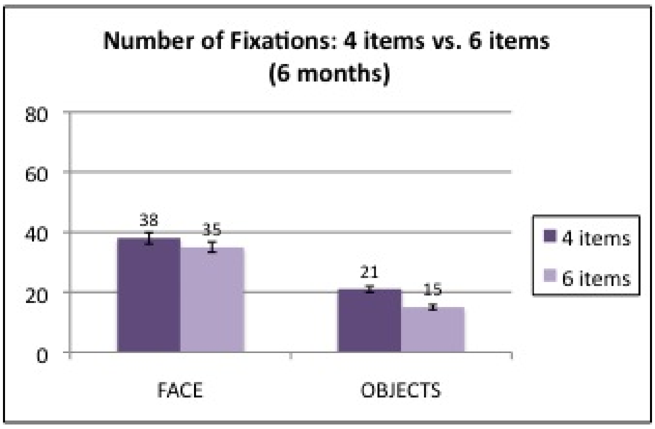


Figure 65: 6-month-old infants looked more frequently toward toward face compared to other object, regardless of the number of distractors

Finally, infants looked longer Face category (*M* = 9534.8 ms, *SD* = 1271.2) rather than Object category (*M* = 6485.5 ms, *SD* = 1326.9), as revealed by the main effect of Stimulus category $F(1, 11) = 11.9$, $p < .05$, $\eta^2 = .52$. Furthermore, as for the number of fixations, the main effect of the item factor $F(1, 11) = 3.0$, n.s. and the Stimulus category X Item interaction did not reach the significance, $F(1, 11) = .44$, n.s. (Figure 66).

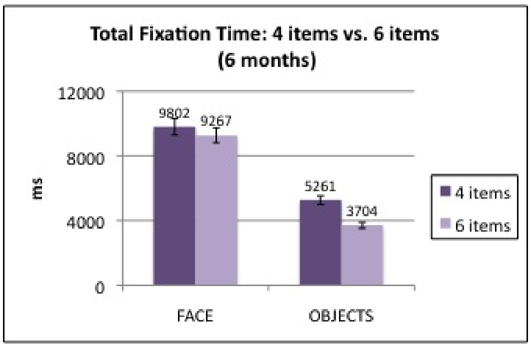


Figure 66: 6-month-old infants looked longer first fixations are oriented toward face compared to other object, regardless of the number of distractors.

Three-month-old infants. Results of the ANOVA on the direction of the first fixation showed a main effect of the item factor only, $F\ (1, 18) = 4.5$, $p < .05$, $\eta^2 = .20$. No main effect of the Stimulus category was observed neither the interaction Stimulus category X item was significant. Furthermore, neither main effects nor interactions were observed for both number of orientations and total fixation time (Figure 67).

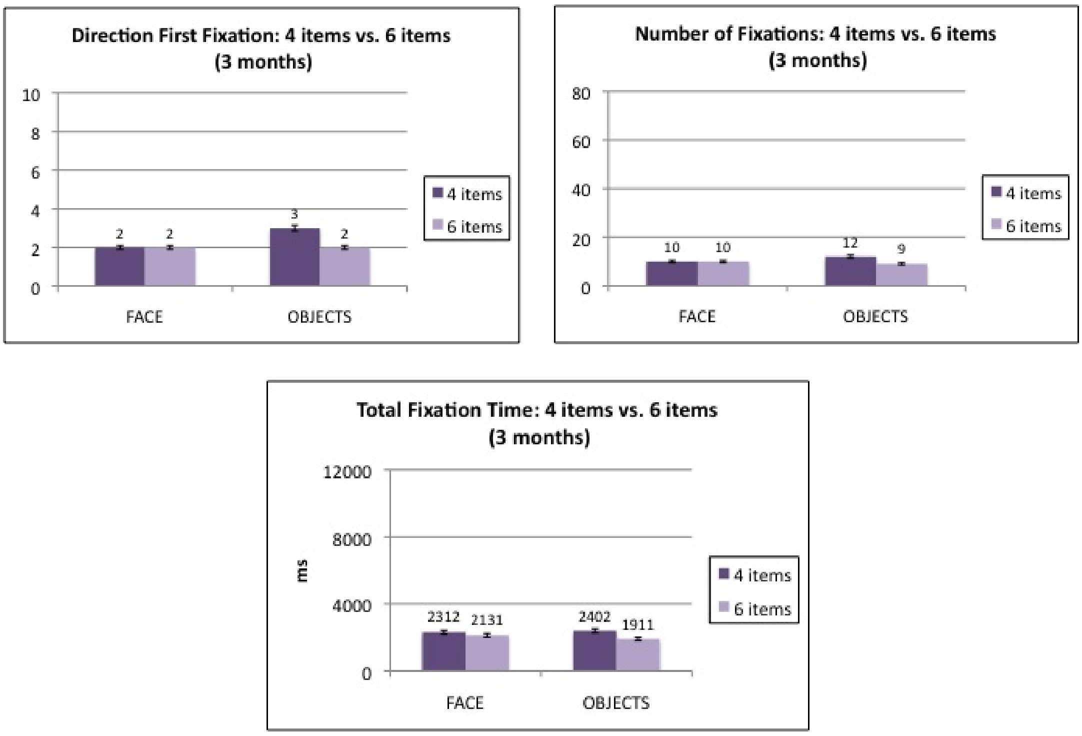
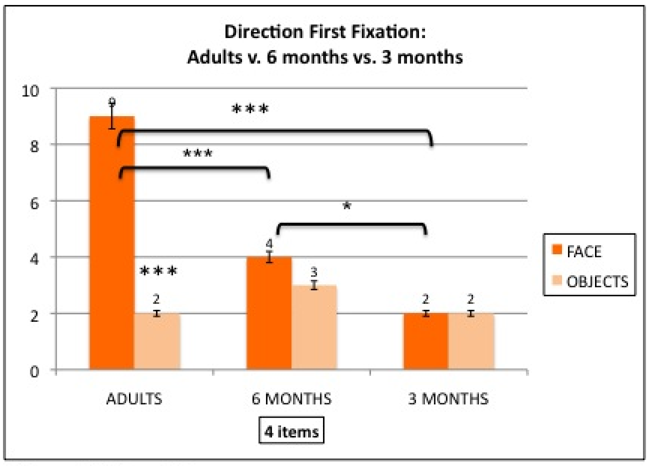


Figure 67: Data obtained with 3-month-old infants as for each dependent variable.

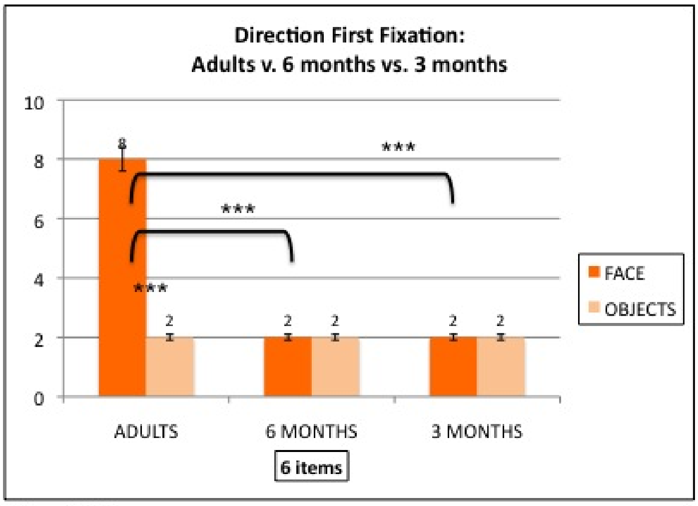
Age comparison

Finally, to compare the performance of each age group tested, a repeated -measures ANOVA was performed for each dependent variable with Age (adults vs. 6 months vs. 3 months) as between-subject factor and Stimulus (Face vs. Objects) and Item (4 vs. 6) as within-subject factors.

As for the direction of the first fixation, there was a main effect of Stimulus F (1, 40) = 37.3, $p < .001$, $\eta^2 = .48$ and a main effect of Item, F (1, 40) = 36.4, $p < .001$, $\eta^2 = .48$. The target face (*M* = 4.7, *SD* = .31) received more first fixations than the other objects (*M* = 2.3, *SD* = .11) and 4 item displays (*M* = 3.9, *SD* = .15) received more first fixations than 6 item displays (*M* = 3.1, *SD* = .14). The only significant interaction was between Stimulus X Age, F (2, 40) = 31.9, $p < .001$, $\eta^2 = .62$. The target face (*M* = 8.7, *SD* = .57), compared to objects (*M* = 1.9, *SD* = .21) received more first fixations by adults, compared to 6 month-old-infants (Face *M* = 3.3, *SD* = .57 vs. Objects *M* = 2.7, *SD* = .21) and three-month-old infants (face *M* = 2.1, *SD* = .45 vs. Objects *M* = 2.4, *SD* = .17). Planned *t*-test showed that adults' performance differed from 6- and 3-month-old infants' performance and that 6-month-old infants' looking behavior differed from that of 3-month-old infants (Figure 68). No other interactions did reach the level of significance.



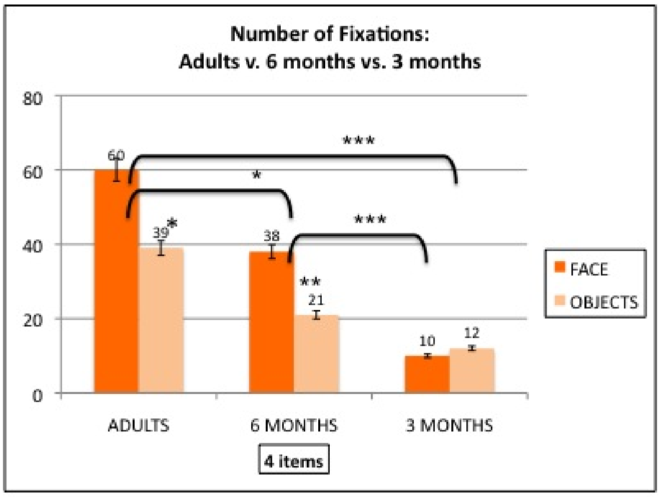
*** $p < .001$, * $p < .05$



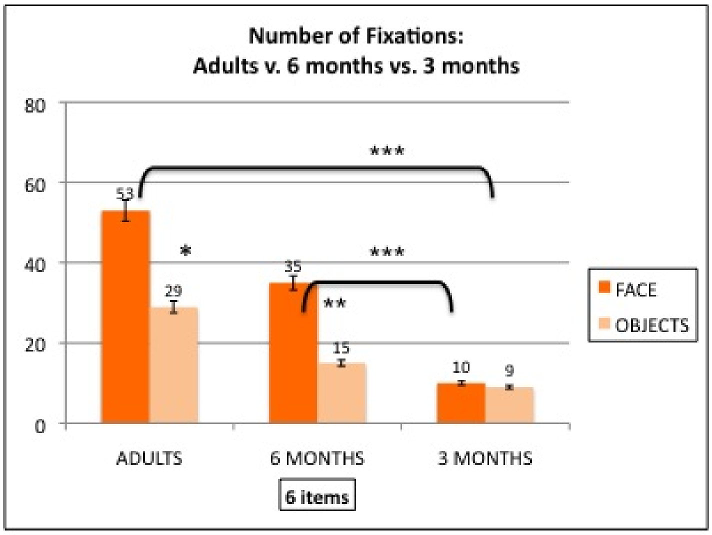
*** $p < .001$,

Figure 68: Comparison between adults, 6- and 3-month-old infants as for the direction of the first fixation.

As for the number of fixations, there was a main effect of Stimulus F (1, 40) = 26.1, $p < .001$, $\eta^2 = .39$ and a main effect of Item, F (1, 40) = 23.1, $p < .001$, $\eta^2 = .37$. The target face ($M = 34.4$, $SD = 2.6$) received more fixations than the other objects ($M = 21.2$, $SD = 1.1$) and 4 item displays ($M = 30.1$, $SD = 1.6$) received more fixations than 6 item displays ($M = 25.6$, $SD = 1.4$). The interaction between Stimulus X Age was significant F (2, 40) = 8.8, $p < .01$, $\eta^2 = .31$. The target face ($M = 56.5$, $SD = 4.7$), compared to objects ($M = 34.3$, $SD = 2$) received more fixations by adults, compared to 6 month-old-infants (Face $M = 36.9$, $SD = 4.7$ vs. Objects $M = 18.4$, $SD = 2$) and three-month-old infants (face $M = 9.9$, $SD = 3.8$ vs. Objects $M = 10.9$, $SD = 1.6$). Planned *t*-test showed that adults' performance differed from 6- and 3-month-old infants' performance and that 6-month-old infants' looking behavior differed from that of 3-month-old infants. Moreover, also the interaction Item X Age reached the significance, F (2, 40) = 4.8, $p < .05$, $\eta^2 = .19$. Each age group tested looked more frequently 4 item displays (adults M = 49.3, SD = 3.1, 6 months M = 29.8, SD = 3.1, 3 months M = 10.9, SD = 2.4) compared to 6 item displays (adults M = 41.4, SD = 2.7, 6 months M = 25.5, SD = 2.7, 3 months M = 9.9, SD = 2.1) and the difference between each group tested reached the significant level (Figure 69). No other interactions did reach the level of significance.



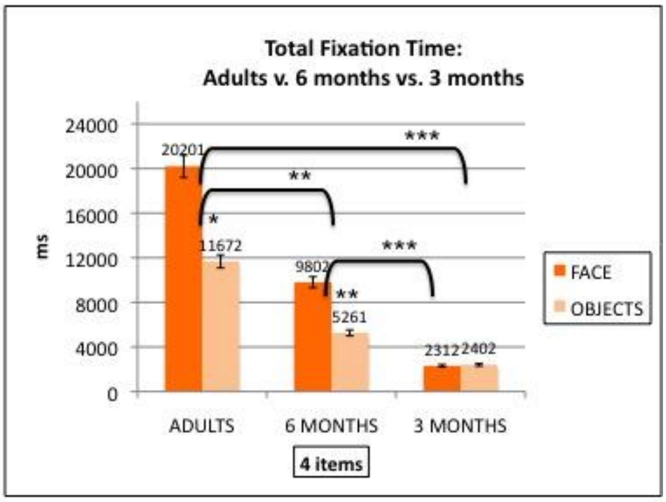
*** $p < .001$; ** $p < .01$; * $p < .05$



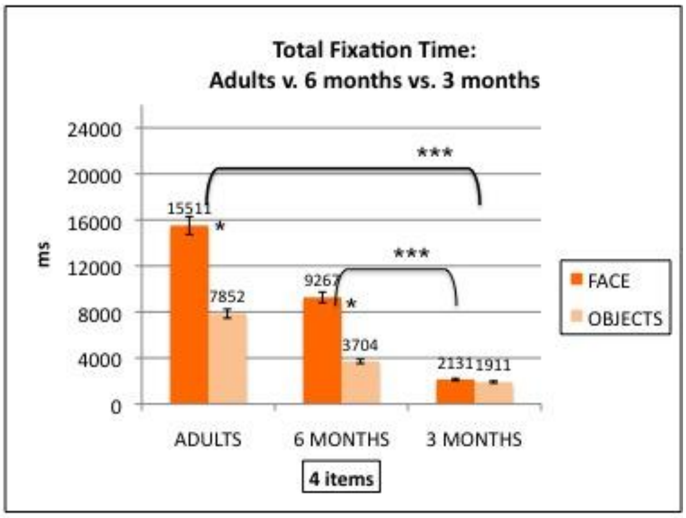
*** $p < .001$; ** $p < .01$; * $p < .05$

Figure 69: Comparison between adults, 6- and 3-month-old infants as for the number of fixations.

Finally, for the total fixation time, there was a main effect of Stimulus F (1, 40) = 16.9, $p < .001$, $\eta^2 = .29$ and a main effect of Item, F (1, 40) = 49.9, $p < .01$, $\eta^2 = .21$. The target face (*M* = 9870.7 ms, *SD* = 986.9) was looked longer than the other objects (*M* = 5467 ms, *SD* = 327.2) and 4 item displays (*M* = 8608.4 ms, *SD* = 515.5) were looked longer than 6 item displays (*M* = 6729.3 ms, *SD* = 526.5). The interaction between Stimulus X Age was significant F (2, 40) = 5.4, $p < .001$, $\eta^2 = .56$. The target face (*M* = 17856 ms, *SD* = 1825), compared to objects (*M* = 9761.8 ms, *SD* = 6059) was looked longer by adults, but not by 6 month-old-infants (Face *M* = 9534.8 ms, *SD* = 1825 vs. Objects *M* = 4482.7 ms, *SD* = 605) and three-month-old infants (face *M* = 2221.2 ms, *SD* = 1450.4 vs. Objects *M* = 2156.7 ms, *SD* = 480.8). Planned *t*-test showed that adults' performance differed from 6- and 3-month-old infants' performance and that 6-month-old infants' looking behavior differed from that of 3-month-old infants. Moreover, also the interaction Item X Age reached the significance, F (2, 40) = 20.4, $p < .001$, $\eta^2 = .51$. Each age group tested looked longer 4 item displays (adults *M* = 15936.5 ms, *SD* = 953.3, 6 months *M* = 7531.9 ms, *SD* = 953.3, 3 months *M* = 2356.8 ms, *SD* = 757.6) compared to 6 item displays (adults *M* = 11681.3 ms, *SD* = 973.5, 6 months *M* =6485.5 ms, *SD* = 973.6, 3 months *M* = 2021.1 ms, *SD* = 773.8) and the difference between each group tested reached the significance (planned t-test). No other interactions did reach the level of significance (Figure 70).



*** p <.001, ** p < .01, * p < .05



*** p <.001, * p < .05

Figure 70: Comparison between adults, 6- and 3-month-old infants as for the total fixation time.

Overall, results obtained from this experiment demonstrated that a face among various and heterogeneous objects grab and maintain 6-month-old, but not 3-month-old infants' attention, regardless of the number of distractors presents in the complex displays. These results not only replicated the results obtained in a previous study (Gliga et al., 2009) demonstrating that 6-month-old infants could detect a face among objects, but also extended this previous study in manipulating the number of distractors among the visual scenes and in testing different age groups with the same paradigm.

However, before to conclude with a general discussion in regard to these results, I'll present in the following section a relatively recent approach to analyze data.

4.4.1 Mixed effects model approach to analyze data

We introduce a relatively recent approach to analyze data, called mixed effects model approach, based on maximum likelihood methods that are now in common use in many areas of science, medicine, and engineering and specifically in eye tracking studies (e.g., Faraway, 2006; Goldstein, 2005; Malcom, Lanyon, Fugard, & Barton, 2008). Since the number of trials was not the same for each participant, Generalized Mixed-Effects Models were used to test the effect of age and number of items (e.g., fixed effects, controlled by experimenter) and the two-way interaction between item (four vs. six) and age (adults vs. 6 months vs. 3 months) on the proportion of first fixation and the proportion of total fixation time and number of orientation towards face, considering participants and display as random variables (Baayen, Davidson, & Bates, 2008; Pinheiro & Bates, 2000).

Essentially four are the main advantages for using these models for our data set: i.) to overcome the problem that the number of trials was not the same for each participant, conducting the analyses on the number of observation (N = 1167) rather than on the number of participants (N = 43), ii.) to provide more statistical power eliminating the need to average across trials, iii.) to insert and to compare within the same model infants' and adults' performance in the modified visual search task and, iv.) compared to the classic ANOVA calculation, to allow the researcher to simultaneously consider all factors that potentially contribute to the understanding of the structure of the data, such as random effects related to subjects or display presented. The data analysis was conducted using lme4 package (Bates, 2007) in R (www.r-project.org).

Results for each dependent variable are presented in the following section.

Proportion of the Direction of the First Fixation: Logistic Mixed Effects Model

We used a logistic mixed effects model because the dependent variable is a dichotomic variable, where the proportion of the direction of the first fixation towards the face target has value 1, whereas the proportion of the direction of the first fixation towards another object in the visual display has value 0.

The model containing all the fixed effects and the random effect of the participants was the best-fitting model for all participants. The best-fitting model was selected using the BIC criteria (Raftery, 1995), i.e. the model with the smallest BIC is considered the most appropriate model for reproducing the observed data. Odds ratios are reported as a measure of effect size. Results showed that adults made significantly more first saccades towards faces compared to 6- ($z = -5.3$, $p <. 001$, $or = .22$) and 3-month-old infants ($z = -6.9$, $p < .001$, $or = .16$), regardless of the number of items as distractors (e.g., the interaction between Age X Item was not significant) (Figure 71).

In other words, from this result it appears that a face among objects do not capture 6- and 3-month old infants' attention in an efficient way like in adults.

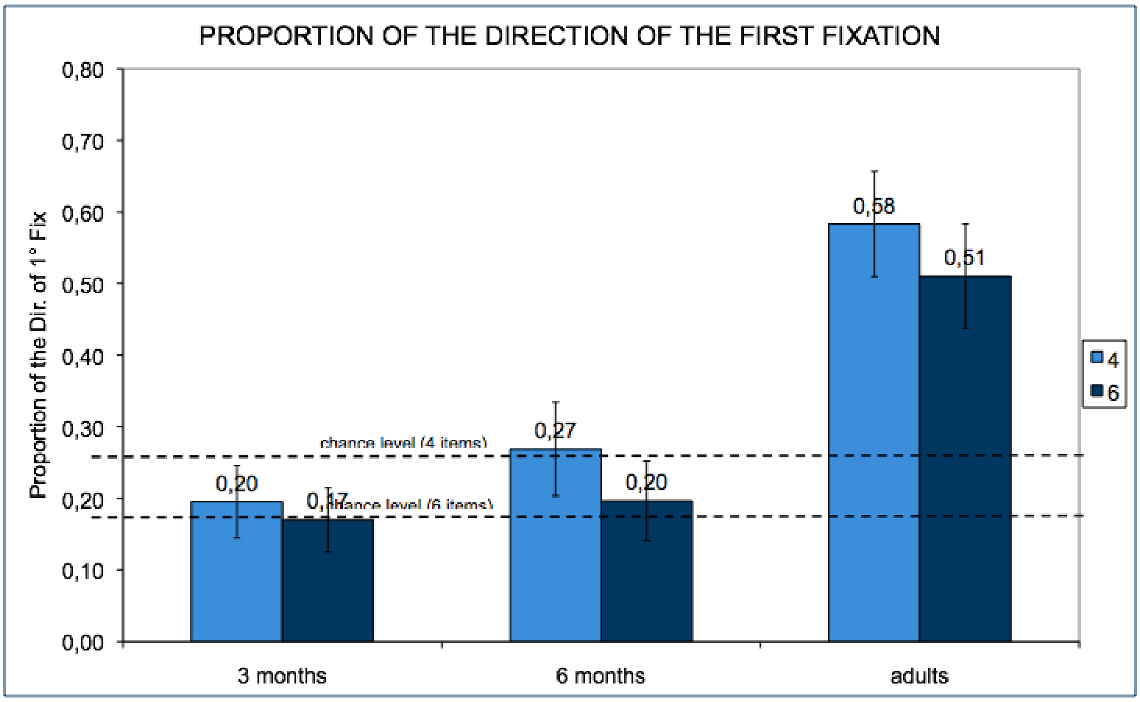


Figure 71: Proportion of the first fixations toward face compared to objects in adults, 6- and 3-month-old infants.

Proportion of the number of fixation: Linear Mixed Effects Model

This variable is quantitative, therefore a linear mixed effects model was employed. The model containing all the fixed effects and the random effects was the best to explain the data of this variable. In this case, as effect size, we used the unstandardized regression coefficient (B). The model containing all the fixed effects and the random effects was the best to explain the data of this dependent variable. The results demonstrated that adults and 6-month-old infants looked more frequently towards the face target among object in the complex displays (z = 0.41, ns, B = .01) and that their performance was statistically different from the 3-month-old infants' performance (z = -3.27, $p < .001$, B = - 0.11) (Figure 72).

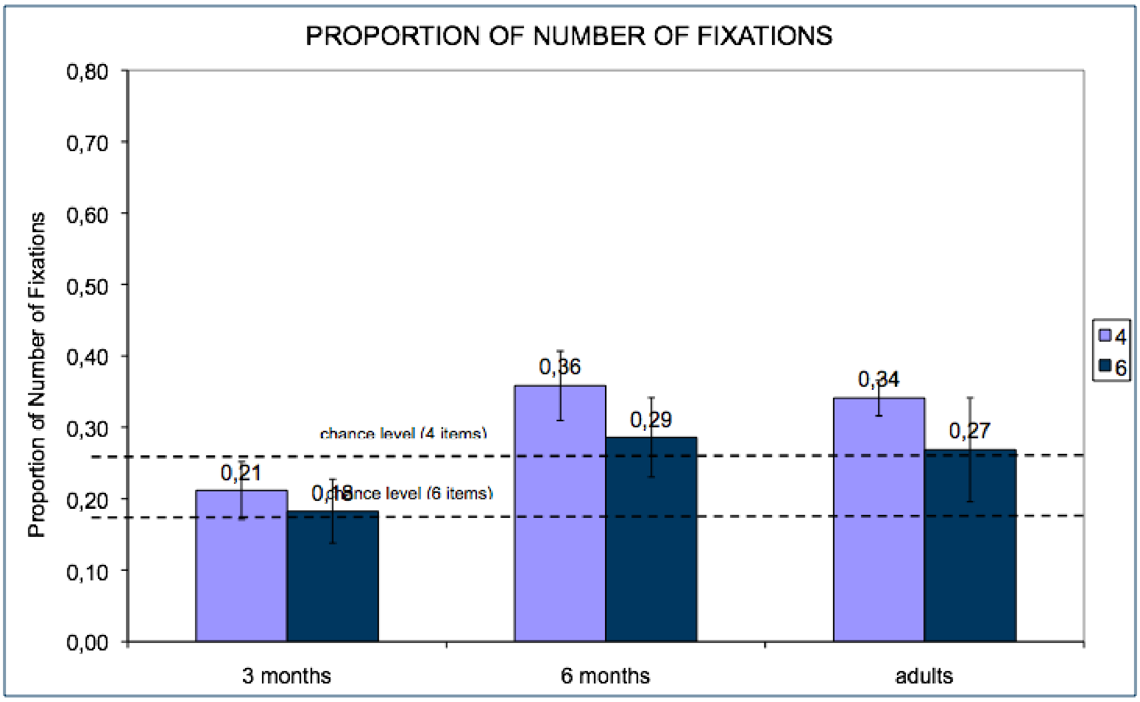


Figure 72: Proportion of the number of fixations toward face compared to objects in adults, 6- and 3- month-old infants.

Proportion of the total fixation time: Linear Mixed Effects Model

This variable is a quantitative variable, therefore a linear mixed effects model was employed and unstandardized regression coefficient (B) was used as effect size measure.

The model containing all the fixed effects and the random effects was the best to explain the data of this variable. As regard of the proportion of total fixation time towards the target face, 6-month-old infants' and adults' performances are similar (z = .08, B = .00), and differed from 3-month-old infants' performance (z = -3.4, *p* <. 001, B = - 0.13). In other words, face maintains adults' and 6-month-old infants' attention, but not 3-month-old infants' attention, once it has been detected among objects. Furthermore, the fixed effect of Item is significant (z = -2.20, *p* < .05, B = - 0.1), but not the interaction between Age and Item, demonstrating that the displays formed by 4 Items were looked longer than displays formed by 6 Items and that this effect is constant within all participants (Figure 73).

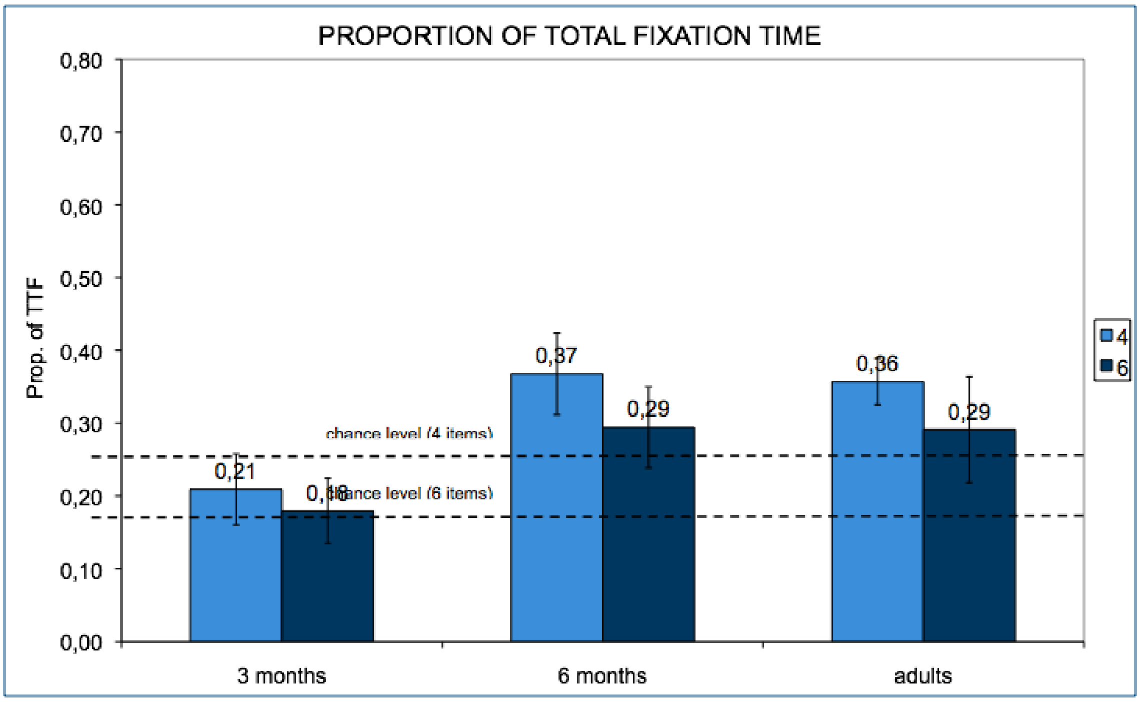


Figure 73: Proportion of the total fixation time toward face compared to objects in adults, 6- and 3- month-old infants.

Overall, the present experiment demonstrated that a target face attracts and maintain adults' and 6-month-old infants' attention when embedded among other objects. These results are in line with the recent study by Gliga and colleagues (2009) that showed how a face among objects attracts 6-month-old infants' attention, but also enlarge the knowledge about the developmental trajectory of this phenomenon testing both infants of few months of life and adults with the same modified visual search paradigm.

However, it is important to note that in this experiment a target face did not grab and maintain 3-month-old infants' attention. One possible reason for this could be find in the nature of the distractor stimuli. Indeed, it has been suggested that the nature of the stimuli around the target affects the visual search performance in adults (Duncan & Humphreys, 1989). That is, more the distractors are similar to each other and different from the target stimulus, more efficient is the detection of the target, whereas more the distractors are dissimilar from each other, more difficult will be the detection of the stimulus target. Therefore, it is possible that 3-month-old infants perceived the visual displays of the previous experiment as complex and that they did not find a target face among the other heterogeneous and complex visual stimuli presented as distractors.

To investigate whether the nature of the distractor stimuli could affect 3-month-old infants' performance in the modified visual search paradigm, an experiment in which the complex visual displays were formed by an upright target face among inverted faces as distractors was conducted. It was predicted that, since the distractors are similar to each other and share with the upright target face all the low-level perceptual characteristics (i.e., structure, luminance, contrast, complexity), 3-month-old infants' should be able to detect efficiently the upright target face, regardless of the number of distractors.

Experiment 11 and 12

Method

Participants

Participants were twenty-five undergraduate students selected from the Department of Psychology at the University of Padova. Four participants were excluded from the sample because of the presence of not interpretable eye movements due to poor calibration (N = 4). The final sample consisted of 21 adults (14 female, mean age = 23,7 years). All participants had no previous experience with eye-movements studies and are naive to the experimental conditions and hypotheses of the study. Finally, all of them had normal or corrected-to-normal vision. Furthermore, fourteen 3-month-old (5 females, mean age = 97.4 days) healthy and full-term infants were tested. They were middle-class infants and all of them were Caucasian. Six additional infants were excluded from the final sample because they did not complete testing due to fussiness. Infants were tested only if awake and in an alert state after parents gave their informed consent.

Stimuli

The stimuli, created as well as in the previous experiment, were 32 complex visual displays comprising an upright female target face among 3 or 5 inverted female faces (Figure 74).

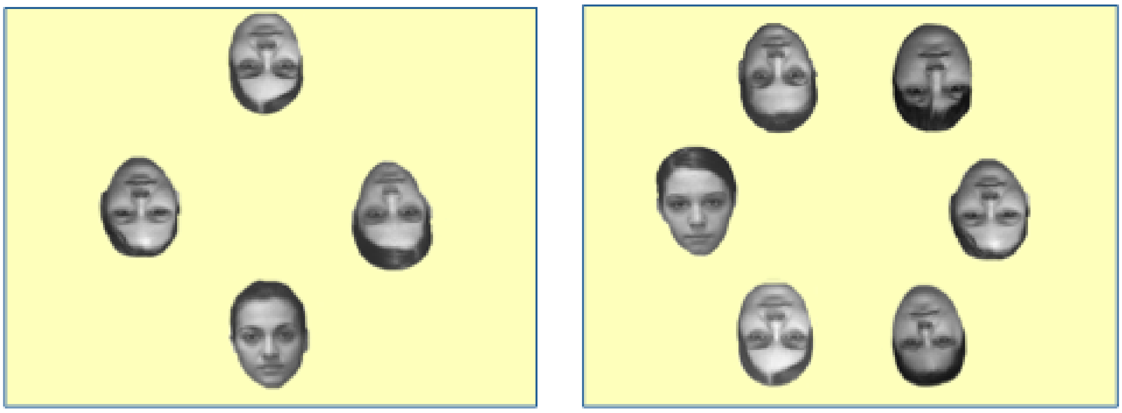


Figure 74: Visual arrays employed in Experiments 11 and 12.

The *Apparatus and the Procedure* were the same that were employed in the previous experiment.

Results and Discussion

Comparison between four and six item displays

To examine whether adults' and 3-month-old infants' performances differed significantly between the four and the six item display condition, a two-way repeated measures ANOVA' s were performed on each dependent variable, with Stimulus (Upright face vs. Inverted face) and Item (4 vs. 6) as within-subjects factors.

Adults. Results of the ANOVA on the direction of the first fixation showed a main effect of the Stimulus, F (1, 20) = 20.1, $p < .001$, $\eta^2 = .50$ and a main effect of Item, F (1, 20) = 61.3, $p < .001$, $\eta^2 = .75$. Importantly, there is a significant interaction between Stimulus and Item, F (1, 20) = 4.5, $p < .05$, $\eta^2 = .18$. This data indicated that upright face grabs adults' attention (*M* = 5.9, *SD* = .36) more than inverted faces (*M* = 2.9, *SD* = .12). Furthermore, 4 item displays received more first fixations (*M* = 4.6, *SD* = .12) than 6 item displays (*M* = 3.2, *SD* = .18). As regard to the interaction Stimulus X Item, the data demonstrated that the number of distractors affected the adults' performance. Specifically, upright target face received more first fixations (*M* = 5.9, *SD* = .36) than inverted faces (*M* = 3.3, *SD* = .17) in the 4 item display compared to the number of first fixation that the target face (*M* = 3.8, *SD* = .47) received in the six item displays compared to the inverted faces (*M* = 2.5, *SD* = .13) (Figure 75).

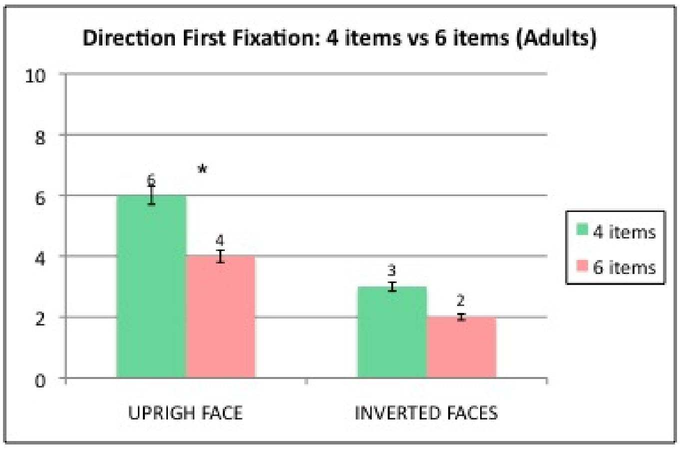


Figure 75: Adults' first fixations are oriented toward face than other objects, but the number of distractors affects the performance.

As regard to the number of fixation, the ANOVA showed a main effect of the Stimulus, F (1, 20) = 12.3, $p < .01$, $\eta^2 = .38$ and the main effect of the item factor F (1, 20) = 15.7, $p < .01$, $\eta^2 = .44$. However, the interaction between them did not reach the statistical significance. This means that the upright face (M = 52.6, SD = 4.7) was looked more frequently than inverted faces (*M* = 32.9, *SD* = 1.7), regardless of the number of distractors presents. Furthermore, 4 item displays (*M* = 46.6, *SD* = 2.3) received more number of fixations compared to 6 item displays (*M* = 38.9, *SD* = 2.4) (Figure 76).

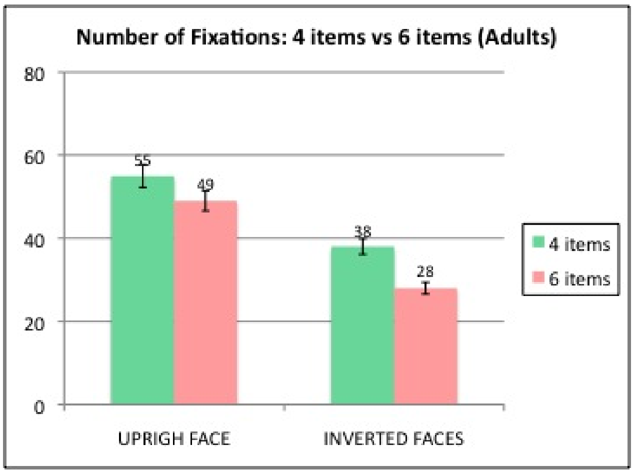


Figure 76: Adults' number of fixations are oriented toward face than other objects, regardless of the number of distractors.

Finally, adults looked longer the upright target face (*M* = 15561.5 ms, *SD* = 874.3) rather than Inverted faces (*M* = 9230.3 ms, *SD* = 599.9), as revealed by the main effect of stimulus F (1, 20) = 23.2, $p < .001$, $\eta^2 = .54$. Furthermore, the main effect of the item factor F (1, 20) = 18.8, $p < .001$, $\eta^2 = .48$, revealed that adults looked longer the 4 item displays (*M* = 14083.3 ms, *SD* = 530.8) compared to the 6 item displays (*M* = 10708.5 ms, *SD* = 532). However, as for the number of fixations, there was no interaction between stimulus and item (Figure 77).

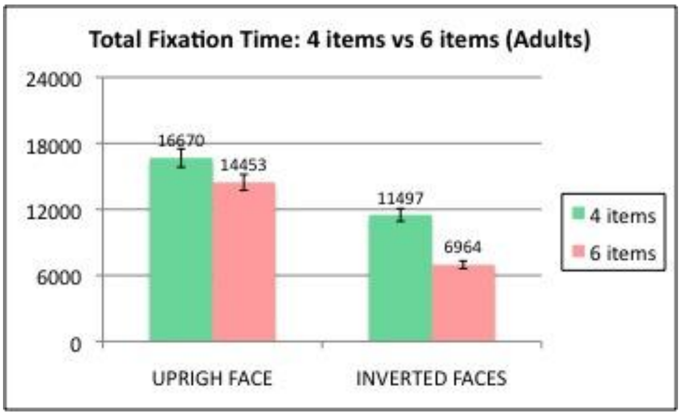


Figure 77: Adults looked longer toward a target face than other objects, regardless of the number of distractors.

Three-month-old infants. Results of the ANOVA on the direction of the first fixation showed a main effect of the item factor only, F (1, 13) = 14.1, $p < .05$, $\eta^2 = .52$. No main effect of the stimulus factor was observed neither the stimulus X item interaction was significant (Figure 78).

As for the number of fixation, that is the other attention-getting index, results showed a main effect of both Stimulus, F (1, 13) = 8.3, $p < .05$, $\eta^2 = .39$ and Item factor, F (1, 13) = 7.4, $p < .05$, $\eta^2 = .36$, but their interaction was not significant. This means that 3-month-old infants looked more frequently the upright face (*M* = 18.2, *SD* = 3.6) compared to inverted faces (*M* = 12.5, *SD* = 1.9), regardless of the number of distractors presented. Moreover, 4 item displays received more number of fixations (*M* = 18.1, *SD* = 3.6) compared to 6 item displays (*M* = 12.6, *SD* = 2) (Figure 79).

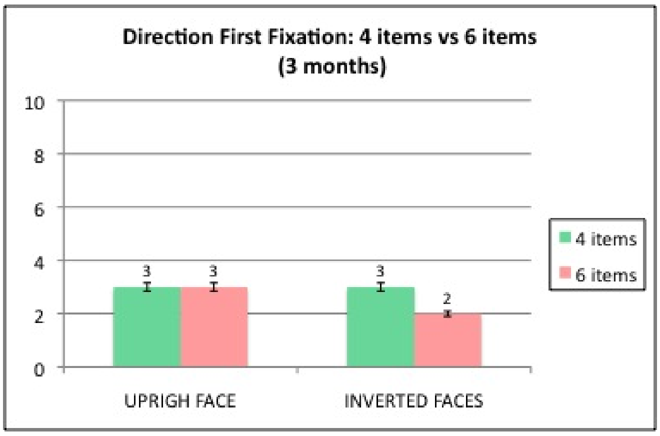


Figure 78: Results as for the direction of the first fixation in 3-month-old infants.

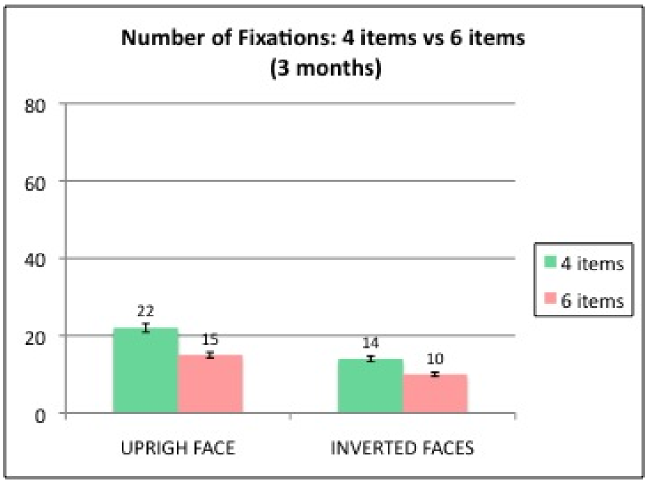


Figure 79: Results as for the number of fixations in 3-month-old infants.

Finally, as regard to the total fixation time, infants looked longer the upright face (*M* = 3509.9 ms, *SD* = 766.3) rather than inverted faces (*M* = 2289.9 ms, *SD* = 370.9) as revealed by the main effect of Stimulus, F (1, 13) = 6.8, $p < .05$, $\eta^2 = .35$. Furthermore, there was a main effect of Item F (1, 13) = 6.4, $p < .05$, $\eta^2 = .33$: infants looked longer 4 item displays (*M* = 3401.8 ms, *SD* = 688.8) rather than 6 item displays (*M* = 2398.1 ms, *SD* = 468.9). However, the interaction between Stimulus and Item did not reach the significance (Figure 80).

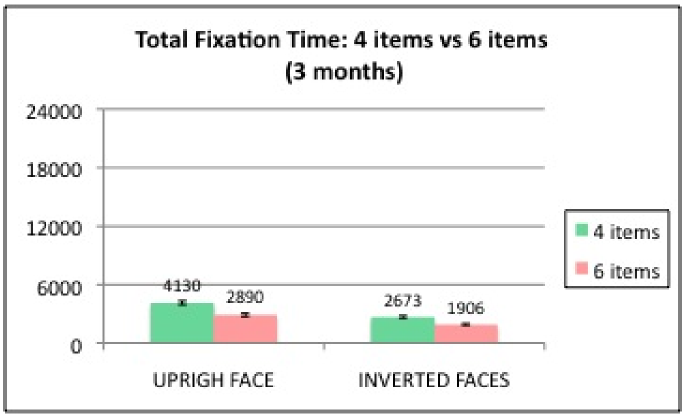


Figure 80: Results as for the total fixation time in 3-month-old infants.

Age Comparison

To compare the performance of each age group tested, repeated-measures ANOVA was performed for each dependent variable with Age (adults vs. 3 months) as between-subject factor and Stimulus (Upright Face vs. Inverted Faces) and Item (4 vs. 6) as within-subject factors.

As for the direction of the first fixation, there was a main effect of Stimulus F (1, 33) = 16.9, $p < .001$, $\eta^2 = .34$ and a main effect of Item, F (1, 33) = 61.9, $p < .001$, $\eta^2 = .65$. The target face (*M* = 3.9, *SD* = .26) received more first fixations than inverted faces (*M* = 2.7, *SD* = .09) and 4 item displays (*M* = 3.9, *SD* = .13) received more first fixations than 6 item displays (*M* = 2.8, *SD* = .13). The interaction between Stimulus X Age was significant, F (1, 33) = 4.8, $p < .05$, $\eta^2 = .13$. The upright target face received more first fixations (adults *M* = 4.9, *SD* = .32, 3 months *M* = 3, *SD* = .39) compared to other inverted faces (adults *M* = 2.9, *SD* = .12, 3 months *M* = 2.4, *SD* = .15). Planned *t*-test showed that adults' performance differed from 3-month-old infants' performance. Furthermore, Item X Age interaction was significant, F (1, 33) = 6.3, $p < .05$, $\eta^2 = .16$. The 4 item displays received more first fixations (adults *M* = 4.6, *SD* = .17, 3 months, *M* = 3.1, *SD* = .21) rather than 6 item displays (adults *M* = 3.2, *SD* = .21, 3 months, *M* = 2.4, *SD* = .20). No other interactions did reach the level of significance (Figure 81).

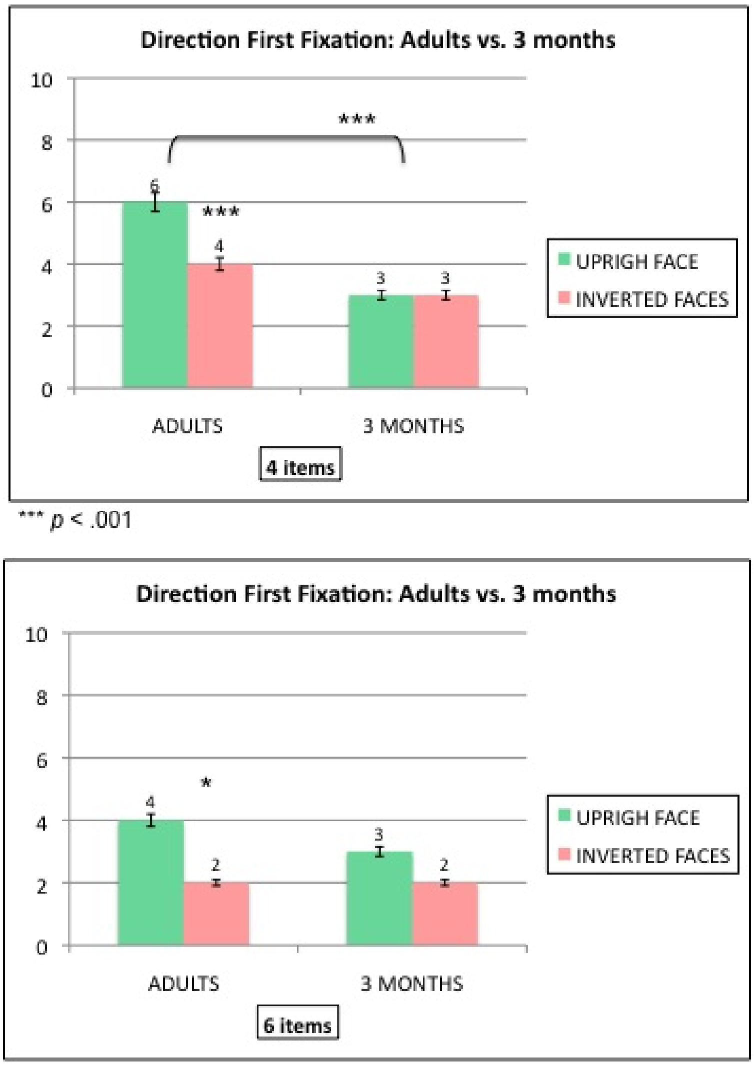


Figure 81: Comparison between adults and 3-month-old infants as for the direction of the first fixation.

As for the Number of fixations, the upright face received more fixations (*M* = 35.4, *SD* = 3.2) compared to inverted faces (*M* = 26.1, *SD* = 1.1) as revealed by the main effect of Stimulus $F(1, 33) = 6.1$, $p < .05$, $\eta^2 = .16$. Moreover, 4 item displays (*M* = 34.5, *SD* = 1.8) were looked more frequently compared to 6 item displays (*M* = 27, *SD* = 1.6), as showed by the main effect of Item, $F(1, 33) = 28.7$, $p < .001$, $\eta^2 = .47$. Only the interaction between Stimulus X Age was significant, F (1, 33) = 7.9, $p < .01$, $\eta^2 = .19$. The upright target face received more fixations (adults M = 52.6, SD = .4.1, 3 months M = 18.2, SD = .5) compared to inverted faces (adults M = 32.9, SD = 1.4, 3 months M = 19.4, SD = 1.7). Planned t-test showed that adults' performance differed from 3-month-old infants' performance (Figure 82). No other interactions did reach the level of significance.

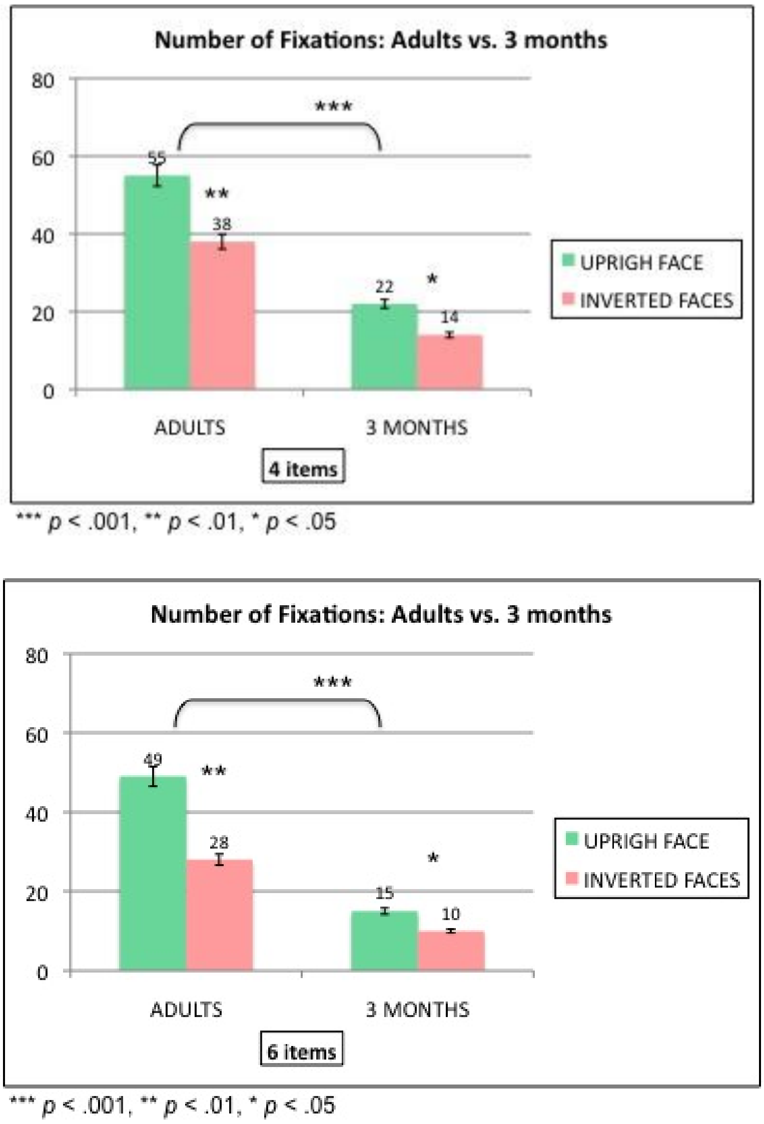
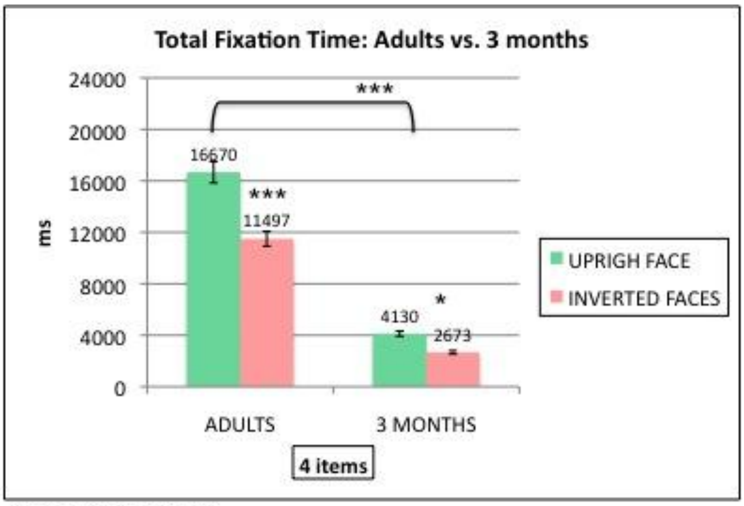
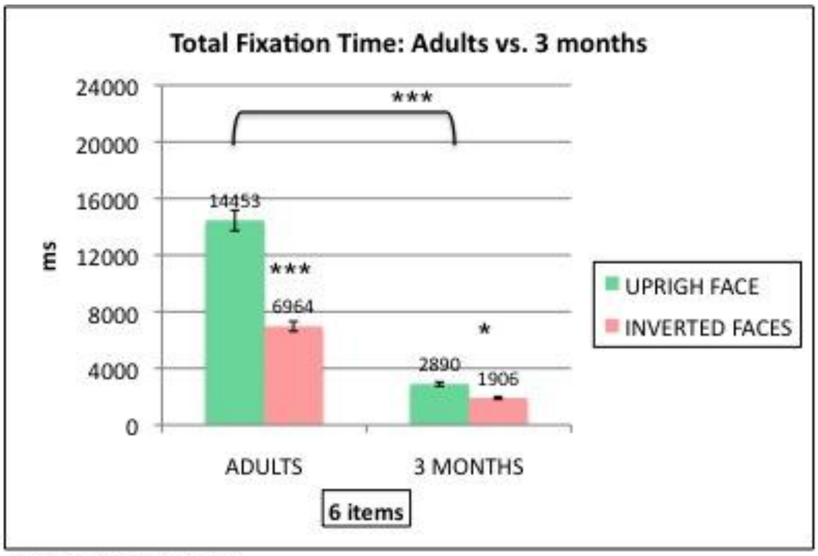


Figure 82: Comparison between adults and 3-month-old infants as for the number of fixations.

Finally, the upright face was looked longer (M = 9535.7 ms, SD = 621.2) than inverted faces (M = 5760.1 ms, SD = 398.7) as showed by the main effect of Stimulus, F (1, 33) = 20.7, $p < .001$, $\eta^2 = .39$. Furthermore, 4 item displays (M = 8742.5 ms, SD = 429.7) were looked longer than 6 item displays (M = 6553.3 ms, SD = 378.6) as revealed by the Item main effect, F (1, 33) = 18.8, $p < .001$, $\eta^2 = .36$. Moreover, the interaction Stimulus X Age was significant F (1, 33) = 9.5, $p < .01$, $\eta^2 = .22$, showing that adults looked longer upright face than inverted faces (Upright M = 15561.5 ms, SD = 785.8, Inverted M = 9230.3 ms, SD = 504.3) compared to 3-month-old infants (Upright, M = 3509.9 ms, SD = 962.4, Inverted M = 2289.9 ms, SD = 617.6). Also the interaction between Item X Age was significant F (1, 33) = 5.5., $p < .05$, $\eta^2 = .14$, showing that adults looked longer 4 item displays than 6 item displays (4 items, M = 14083.3 ms, SD = 543.5, 6 items, M = 10708.5 ms, SD = 478.8) compared to 3 months (4 items, M = 3401.7 ms, SD = 665.6, 6 items M = 2398.1 ms, SD = 586.5) (Figure 83). No other interactions were significant.



*** $p < .001$, * $p < .05$



*** $p < .001$, * $p < .05$

Figure 83: Comparison between adults and 3-month-old infants as for the total fixation time.

Taken together, the present results demonstrated that when the distractors are homogeneous, the upright target face is able to grab and maintain three-month-old infants' attention, as well as adults' attention, and that this phenomenon is independent from the number of stimuli distractors presented in the complex visual arrays.

Conclusion

Study 2 was aimed at investigating whether infants of few months of life, as well as adults, could detect a target face among other objects, as demonstrated by a recent study (Gliga et al., 2009). Experiments 8, 9 and 10 showed that a face target among heterogeneous objects as distractors grab and maintain adults' and 6-month-old infants' attention regardless of the number of stimulus distractors presented in the visual display. On the contrary, the same target face when embedded among objects did not capture and maintain 3-month-old infants' attention. Interestingly, Experiments 11 and 12 demonstrated that the nature of the distractors affects 3-month-old infants' capacity to detect a face, since they are able to detect an upright target face only when it is among homogeneous distractors, that are inverted faces that share with the target face the complexity, high contrast areas and luminance, but not the social relevance.

To my knowledge, the current study is the first that, using a modified visual search with adults and infants of few months of life and recording the eye-movements of participants, demonstrated a developmental trajectory of the attention capture by faces within complex displays. Six-month-old infants' performances are similar to adults' performance, and differed from the 3-month-old infants' performance. A possible interpretation of these data could be that it is harder for young infants to detect a complex visual stimulus, like a human face, among other complex and novel visual stimuli as distractors. Indeed, one perceptual cue that guides infants' visual preference in the first months of life is the complexity of the visual stimuli (Easterbrook et al., 1999). Indeed, Experiments 12 demonstrated that it is easier for young infants to detect a target stimulus that differs from the distractor only for one perceptual characteristic, in this case the orientation (e.g., upright face vs. inverted faces).

To conclude, the modified visual search paradigm employed in this study proved to be a reliable measure of the capacity of face stimuli to capture and maintain infants' and adults' attention. Future studies should explore whether the attention-getting and the attention-holding mechanisms become more selective with the age to specific kind of faces (i.e., monkey faces vs human faces, caucasic faces vs asiatic faces, and so on).

CHAPTER 5

THE ORIGIN AND THE DEVELOPMENTAL TIME COURSE OF HOLISTIC FACE PROCESSING

Introduction

Face detection is the first step in the processing of a face, since detection allow infant to select and orient attention toward salient stimuli to efficiently process them. In previous chapters of my thesis, I described how newborns and infants detect a face in both simple arrays (i.e., when only two stimuli are presented simultaneously) and complex visual arrays (i.e., when faces are embedded among other complex visual stimuli). There is no doubt that infants, to identify a target face among other visual stimuli (Chapter 4), had to perceive the face as a whole, employing a holistic face processing strategy. Faces, unlike many other objects, are processed holistically, and this means that they are encoded as one inseparable unit, rather than as a group of individual features or parts (Tanaka & Farah, 1993). The concept was probably first introduced by Francis Galton, who noticed that facial features were not perceived and analyzed separately; that is, the face stimulus was processed as a whole unit or as a Gestalt (Galton, 1883). Although rudimentary ability to perceive faces holistically is present at birth (Leo & Simion, 2009), the developmental time course of this face processing is still unclear.

The aim of the present chapter is to investigate the origin and the development of holistic face processing in newborns and infants of few months of life by employing a classical behavioral task, called the composite face paradigm, that was used to tap this specific face processing in adults and older children (Young et al., 1987; Mondloch et al., 2007). The use of the same task, throughout development, from early infancy to adulthood, allows researchers to highlight both differences and similarities in the cognitive processes underlying face processing, and to highlight the changes of the system during lifespan to raise the adult face specialized level. Based on this, the current chapter is focused on holistic processing, investigating through the testing of the composite face illusion newborns' and 3-month-old infants' sensitivity to holistic face information.

5.1. The study of holistic face processing in adults

As described in Chapter 2, evidence of holistic processing in adults can be observed in part-whole paradigms, in which subjects perform better to match or recognize individual facial features presented within the context of a whole face than features that are presented separately (Tanaka & Farah, 1993). Evidence of part versus whole effects is observed in adults and in typically developing children of four years of age (Pellicano & Rhodes, 2003).

Holistic face processing can be also tap with the *composite face task* by examining the effects of spatial misalignment on the ability to attend selectively to specific portions of faces. In the typical composite face paradigm, composite faces are created by combining the top half of one famous or familiar face with the bottom half of another face, and subjects are then asked to identify only the person depicted in the top or the bottom half of the face (Young, et al., 1987). When the two face halves are presented in alignment with one another, they join to form a new face configuration and the stimulus is encoded holistically. In this case, recognition of the individual parts of the face is difficult because the new configuration interferes with the recognition of the individual features within each half. By contrast, a new overall facial configuration does not result when the two halves of the composite face are spatially misaligned with one another. In this case, there is no interference due to holistic encoding of the stimulus and subjects recognize the source images more easily (Young et al.,1987). Discrimination of unfamiliar faces is similarly disrupted by holistic processing in composite tasks (Hole, 1994; Hole, George, & Dunsmore, 1999; Le Grand et al., 2003). In these tasks, subjects are presented with two composite faces and are asked to make same or different judgments based on only one half of the faces. When the two halves of the composite face are aligned, the face is processed holistically. However, when the two halves of the composite face are spatially misaligned, holistic processing is disrupted, allowing better selective attention to the attended half of the face, and consequently, better performance in the misaligned relative to the intact condition. In sum, holistic processing is characterized by the encoding of the face as single stimulus, with difficulty attending selectively to individual features or parts of the face. Selective attention to features can be improved by misaligning sections of the face because the misalignment disrupts holistic processing.

It is important to note that in the composite task, spatial misalignment of the face halves disrupts the first-order configuration of the stimulus (two eyes centered directly above a mouth). This configural disruption interferes with the binding of the two halves into a gestalt and as a result, the face is not encoded holistically and the unattended half exerts less influence on perception of the attended half. By contrast, when faces are intact and perceived holistically, information in the unattended half strongly affects judgments of the attended half. This characterization agrees with recent proposals that holistic processing is a subtype of configural processing that is dependent upon the first-order configuration of the face (de Heering, Houthuys, & Rossion, 2007; Maurer et al., 2002).

5.2 Developmental studies on face processing in infants

The functional face processing specialization seen in adults is generally considered as due to the extensive visual experience with faces during the life time. Indeed, it has been widely accepted that although experience-based developmental processes progressively refine early configural face recognition abilities, available evidence demonstrates that configural processing emerges during the first months of life rather than undergoing a long developmental trajectory. Moreover, it is yet unclear whether infants simply process faces less efficiently than adults (i.e., a quantitative difference) or whether qualitatively different processes are used by adults and infants.

Sensitivity to first-order configural information is demonstrated by newborns' preference for faces as compared to equally complex non-face visual stimuli (Johnson & Morton, 1991; Valenza et al., 1996). A further demonstration of the sensitivity to first-order relations comes from a recent study with newborns that employed Mooney-faces, stimuli that preclude focusing on local features, thus impairing analytic processing, and completing the second-order configural stage, as features are not distinguishable. Newborns preferred an upright Mooney-face when contrasted with the same inverted Mooney-face, demonstrating the capacity to integrate the patches of intense light and shadow of a Mooney-face into a Gestalt representation by extracting the configural relational properties that define the first-order relational information of a face (Leo & Simion, 2009).

As regard to sensitivity to second-order relational informations, it has been demonstrated that newborns and infants can discriminate faces on the basis of second-order configural changes in the spatial relations between facial features (Bhatt, Bertin, Hayden, & Reed, 2005; Deruelle & de Schonen, 1998; Hayden, Bhatt, Reed, Corby, & Jospeh, 2007; Thompson, Madrid, Westbrook, & Johnston, 2001). For instance, Bhatt and colleagues (2005) found that 5- and 6-month-old infants show a phenomenon analogous to the Thatcher illusion found in adults, because they discriminate a thatcherized schematic face (e.g., where the eyes and the mouth are reversed within the face) when the stimuli were presented upright but not when they were inverted. A more recent study demonstrated that also newborns were able to discriminate Thatcher faces from nonthatcher faces only when presented in the upright condition and not when they were presented upside-down (Leo & Simion, 2009). Moreover, it has been demonstrated that newborns, as well as 4-month-old infants (Turati, Sangrigoli, Ruel, & de Schonen, 2004), were able to recognize upright faces either when faces were fully visible (i.e., when both inner and outer features are present) or when only the inner and outer features were present. In contrast, newborns failed to recognize an inverted face when only the inner features were presented. The presence of recognition for the upright face but not for the inverted one in the inner condition have been interpreted as due to sensitivity to second-order relational information just for the upright face, since inversion affected all kind of configural processing (Turati, Macchi Cassia, Simion, & Leo, 2006). Overall, these studies seem to indicate that the ability to process second-order relational information is available at birth and that inversion affects the processing of the configural information.

5.3 Holistic face processing in children and infants

Compared to many studies that investigated first- and second-order relation information processing in children and infants, the processing of holistic face information has received far less attention. As described in previous paragraphs, compelling examples of holistic face processing come from two behavioral paradigms widely used to evaluate the existence of holistic face processing in adults and in children: the whole-part paradigm (Tanaka & Farah, 1993) and the composite face paradigm (Young et al., 1987; Hole et al., 1994).

As regard to the whole-part paradigm, only one study provided evidence that 4-year-olds manifest a part-whole effect, indicating that they recognize faces holistically. Four- to six-year-old children and adults were administered a whole-part face recognition task. Children below the age of 6 recognized parts from upright faces better when tested in the whole-face condition rather than in isolation condition and this effect was presented only when faces were presented upright but not when they where presented upside-down (Pellicano & Rhodes, 2003). Interestingly, the different age groups showed similar patterns of performance indicating that young preschoolers, like older children and adults, are able to recognize faces holistically.

As regard to the composite face paradigm, that is considered the most convincing demonstration of holistic face processing, it has been used only in few studies with school and preschool aged children. Specifically, evidence for a composite face effect for both familiar (i.e., faces of classmates) and unfamiliar faces was found in 6- and 10-year-old children, with the magnitude of the effect remaining constant across the two age groups and into the adulthood (Carey & Diamond, 1994; Mondloch et al., 2007). At present, only two studies have investigated holistic face processing in preschool-aged children using this paradigm. The first study tested adults and 4- to 6-year-olds with the same composite paradigm and demonstrated that holistic face processing is already mature at 4 years of age, that is, performance was more accurate in the misaligned condition than in the aligned condition. The second study compared the development of holistic processing for faces and non-face visual objects by testing for the composite effect for faces and frontal images of cars in 3- to 5-year-old children and adults (Macchi Cassia, Picozzi, Kuefner, Bricolo, & Turati, 2009) (Figure 84).

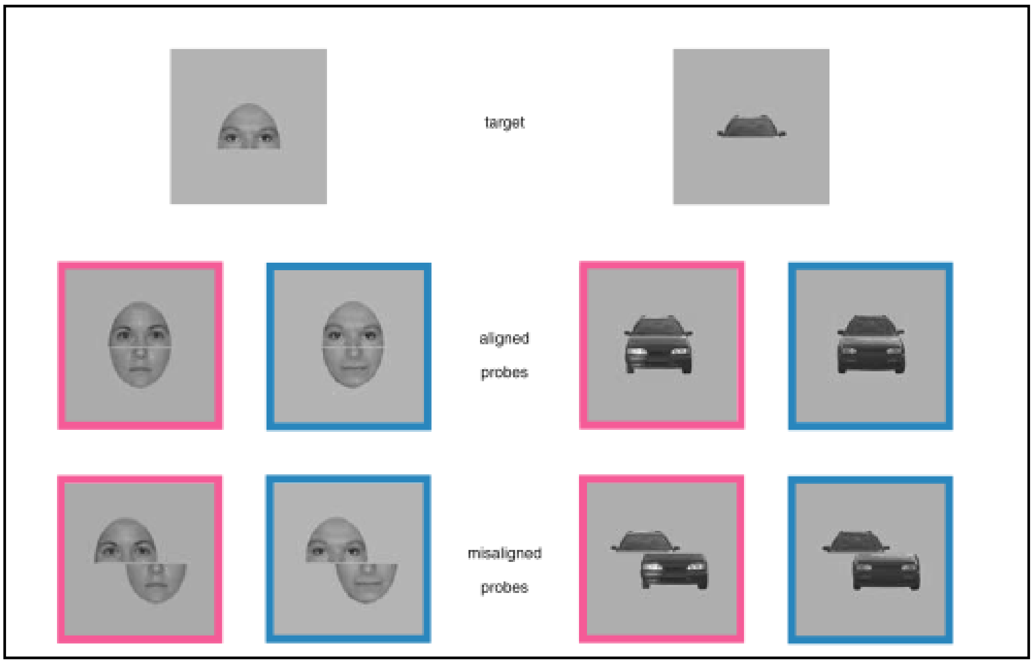


Figure 84: Stimuli of faces and cars used in the composite face task with 3 and year old children (from Macchi Cassia et al., 2009).

Examples of the face and car stimuli used in the study of Macchi Cassia and colleagues (2009). As one can see, top halves of the stimuli were used as targets, and composite aligned and misaligned stimuli were used as probes. Using a two-alternative forced-choice recognition task, participants responded indicating which of the probes contained the target top half in both aligned and misaligned conditions. Results showed that a composite effect for faces was present as early as 3.5 years and none of the age groups tested showed the composite effect for cars. These findings provide the evidence that holistic face processing is already selective for faces in early childhood.

As for infants, only one study showed that 4-month-olds look longer at a "switched" face made up of the internal features of a familiar face and the external features of a different familiar face than at each whole familiar face, indicating that they process the configuration made up of internal and external features (Cashon & Cohen, 2001, 2003). Using the so-called "switch design", the authors contrasted holistic processing with featural processing. First, they habituated the infants to two adult female faces. Then the infants were tested with a familiar habituation face, a "switch-face", and a novel face. The switch-face was a composite of the two habituation faces, consisting of the internal features or a subset of internal features of one face and the external features of the other face. The faces in the habituation and test phases were presented either upright or inverted (Figure 85).

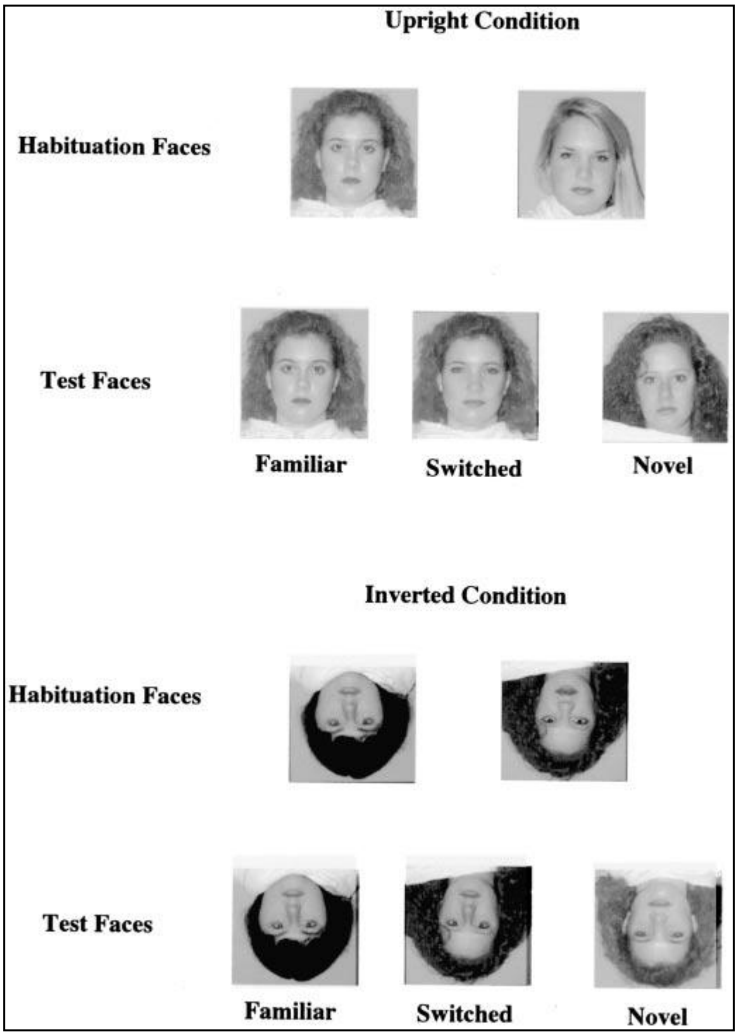


Figure 85: Examples of the switch design: habituation and test face photographs presented to infants in either the upright or inverted conditions (from Cashon & Cohen, 2001).

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To assess whether infants used featural or holistic processing, it was critical to determine whether they looked longer at the switch-face compared to the familiar test face. The authors reasoned that infants would look longer at the switch-face only if they were processing more than the independent features and were integrating at least some of the internal and external features. On the other hand, if they were processing the facial sections independently the infants would not respond to the switch-face. The results showed that holistic processing followed an N-shaped developmental pattern for upright faces and an inverted U-shaped pattern for inverted faces in the age range of 3 to 7 months of age. In more detail, this means that the youngest age group, i.e. 3-month-olds, processed upright and inverted internal and external sections of faces independently of each other. The 4-month-olds, in contrast, processed both upright and inverted sections holistically, while the 6-month-olds again processed both upright and inverted external and internal sections independently of each other. Finally, the 7-month-old infants showed an adult-like pattern of response, since they processed the internal and external facial features holistically when faces were upright, whereas when faces were inverted they process internal and external elements featurally. Neverthless, such studies focused exclusively on the correlations between outer and inner face features. Yet, the inner part of the face per se contains sufficient cues to support 4-month-old infants' face recognition. For example, newborns, as suggested before, use information about internal facial features in making preferences based on attractiveness (Slater et al., 2000). Furthermore, thirty-five- to 40-day-old infants are able to discriminate their mother from a stranger even when the whole line between face and hair is masked by a scarf, thus relying mostly on the inner portion of the face (Bartrip, Morton, & de Schonen, 2001). Following familiarization to unfamiliar faces, similar results have been obtained at 1, 3, and 6 months of age (de Haan, Johnson, Maurer, & Perrett, 2001; Pascalis, de Haan, Nelson, & de Schonen, 1998). Nevertheless, holistic processing of internal features per se, rather than in relation with outer features, has never been tested in infants. Also, the "switch" paradigm used with infants highly differs from the paradigms commonly employed to test holistic face processing abilities in older children and adults, specifically the part-whole paradigm and the composite paradigm. At present, no study has yet examined infants' ability to process the multiple features of a face as a perceptual unit using the classical paradigms employed with older children and adults.

5.4 Study 3

The current study addressed holistic face processing in 3-month-old infants (Experiment 13), newborns (Experiment 14a and 14b), and adults (Experiment 15) by employing a modified version of the face composite task and the recording of eye movements (Turati, Di Giorgio, Bardi, & Simion, 2010). The classical composite face paradigm used with adults and preschool- or school-age children was modified to be adapted to infants, who are unable to comprehend written or verbal instructions and to provide a manual response. The same paradigm was applied also to adult participants (Experiment 15), because, in spite of the rich literature on the composite effect in adults, only a single study recorded adults' eye-movements during the composite task (de Heering, Rossion, Turati, & Simion, 2008). Thus, Experiment 15 tested whether gaze behavior in adults is affected by employing holistic face processing strategies in a composite paradigm analogous to that employed with infants. Newborns, 3-month-old infants and adults were tested using a visual paired-comparison task (VPC). Eye movements (duration and number of fixations) toward the top and bottom halves of the composite faces were recorded in three-month-olds (Experiment 13) and adults (Experiment 15) using an eye-tracker system. Newborns were tested through a classical habituation paradigm in which the duration of visual fixations is coded by human expert observers. During the habituation/familiarization phase, all participants were presented with a top half of a face. The test phase involved the presentation of a pair of composite face stimuli. In one face stimulus of the pair, the top half of the face was identical to the one shown during familiarization, and the top of the other face was new. Half of the participants was tested in the Aligned condition, in which the left/right margins of the top and bottom face parts were properly aligned, and the other half was tested in the Misaligned condition, in which the top and bottom face parts were offset horizontally.

Experiment 13

Method

Participants

Participants were 20 3-month-old healthy and full-term infants (13 males, mean age = 99 days). They were middle-class infants and all of them except one were Caucasian. Seven additional infants were tested but not included in the final sample because they showed a strong position preference (i.e., they looked to one direction more than 90% of the time). Infants were tested only if awake and in an alert state after parents gave their informed consent.

Stimuli

The original stimuli were digitized, high-quality grey-scale images of 12 Caucasian female full-front faces, posing with a neutral expression and placed on a black background with no hair. All faces were unfamiliar to participants. Face images were split into two parts at the level of the middle of the nose, generating a top and a bottom segment. Composite faces were created by joining the top segment of one face to the bottom segment of a different face image (Young et al., 1987). By that matching, 6 pairs of faces were created. Within each pair, the bottom face half was the same. In the Aligned condition, the top and the bottom face segments were properly horizontally aligned, whereas in the Misaligned condition the top half of each face was shifted horizontally to the left, so that the middle of the nose in the bottom segment was positioned next to the extreme right side of the top segment. In both conditions, the two halves of each composite face were separated by a gap of 3 mm. When projected onto the screen, the top part presented in the habituation phase was 8 x 12 cm (about 8° x 11° of visual angle). Aligned faces were 15.5 x 12 cm (about 15° x 11° of visual angle). Misaligned faces were 15.5 x 17.5 cm (about 15° x 17° of visual angle). The distance between the centre of the screen and the vertical median line of each stimulus was about 13.5 cm (about 13° of visual angle).

Apparatus

As in the previous experiments described in my thesis, a system for the automatic registration of eye movements made by Applied Science Laboratories (ASL) was employed.

Procedure

Infants were tested with an infant control habituation paradigm. During the habituation phase, the top half portion of a face was presented at the centre of the screen. The infant was judged to have habituated when, from the fourth fixation on, the sum of any three consecutive fixations was 50 percent or less than the total of the first three. In the test phase, each infant was given two paired presentations of the test stimuli, in which the left-right stimulus position was reversed. In one face of the pair the top half was identical to that shown during habituation, in the other face the top half was new. Both top halves were matched with the same bottom half of a third new face. Each presentation lasted when a total of 10 s of looking at the novel and/or familiar stimuli had been accumulated. Half of the infants were tested in the Aligned condition, the other half was tested in the Misaligned condition (Figure 86).

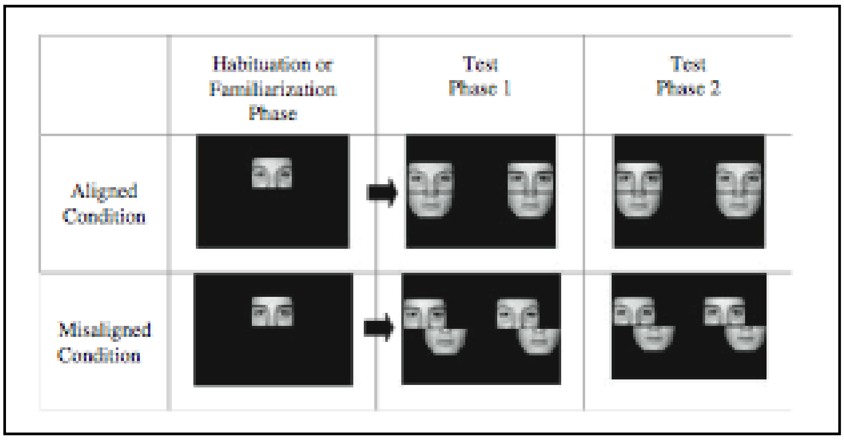

Figure 86: Procedure employed with 3-month-old infants, newborns and adults for the composite face task (from Turati et al., 2010).

Number of fixations and total fixation times were calculated by computing the sum of all fixations within four areas of interest of the composite faces presented in the test phase (AOIs, Figure 87), which corresponded to the face halves that appeared on the left and right side of the screen: AOI 1 and AOI 2 for the top halves of faces presented respectively on the left and on the right of the screen; AOI 3 and AOI 4 for the bottom halves of faces presented on the left and on the right on the screen.

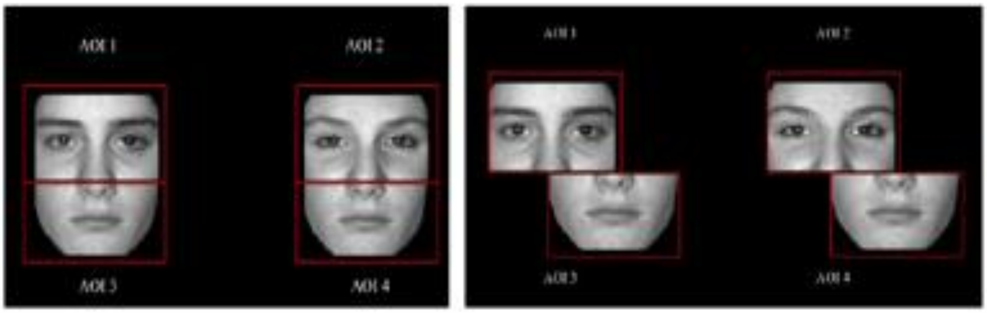

Figure 87: Areas of Interest (AOIs) used in Experiments 13 and 15 (from Turati et al., 2010).

Results and Discussion

All infants reached the habituation criterion. A paired-sample t-test was run to compare total fixation times to reach the habituation criterion in each condition, Aligned Condition, *M* = 27180 ms, *SE* = 5755 vs. Misaligned Condition, *M* = 19618 ms, *SE* = 3553, *t* (18) = 1.1, *n.s.* The difference was not significant.

To understand if infants' gaze behavior differed depending on the alignment vs. misalignment of the top and bottom face portions, total looking times and number of fixations toward the top and bottom parts of the faces in the test phase were analyzed. The face that comprised the top half presented in the habituation phase was considered as familiar whereas the other was considered as novel. Preliminary Analyses of Variance (ANOVAs) on number of fixations and total fixation times toward the stimuli revealed that no main effect or interactions involved the factor Presentation (First vs. second). Therefore, data were collapsed across this factor in two distinct three-way ANOVAs, performed on total fixation times and number of fixations, with Test (Novel vs. Familiar) and Face Half (Top vs. Bottom) as within-subjects factors and Testing Condition (Aligned vs. Misaligned) as between-subjects factor.

Results of the ANOVA on total fixation times showed a main effect of the Face

Half factor, F (1, 18) = 82.5, $p < .001$, $\eta^2 = .82$. Infants looked longer at the top face part (*M* = 3382 ms, *SE* = 206) than at the bottom face part (*M* = 720 ms, *SE* = 159). Furthermore, the main effect of Test indicated that the familiar face (*M* = 2322 ms, *SE* = 196) was fixated longer than the novel face (*M* = 1780 ms, *SE* = 110), F (1, 18) = 5.7, $p < .05$, $\eta^2 = .24$. This Test main effect could be explained in relation to the Test X Testing Condition significant interaction, F (1, 18) = 4.6, $p < .05$, $\eta^2 = .20$, which qualifies the main effect (Figure 88).

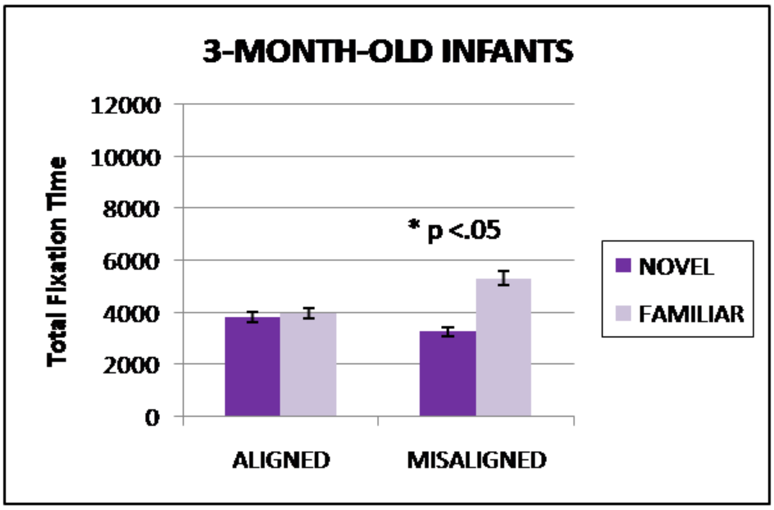

Figure 88: Total fixation time at the novel and the familiar stimuli as a function of test condition (Aligned vs Misaligned Condition) in Experiment 13.

Indeed, planned t-tests showed that, in the Misaligned test condition, infants looked longer at the familiar (*M* = 5326 ms, *SE* = 645) than at the novel (*M* = 3273 ms, *SE* = 366) composite stimulus, $t(9) = 2.7$, $p < .05$. On the contrary, in the Aligned test condition, looking time toward the novel (*M* = 3847 ms, *SE* = 244) and the familiar (*M* = 3963 ms, SE = 446) faces did not differ, $t(9) = 0.24$, n.s.

Results of the ANOVA on number of fixations showed a main effect of Face Half, F (1, 18) = 88.6, $p < .001$, $\eta^2 = .83$, and a significant Face Half X Testing Condition interaction, F (1, 18) = 4.6, $p < .05$, $\eta^2 = .20$, showing that the number of fixations infants oriented to the top face part (*M* = 40, *SE* = 2) was greater than the number of fixations toward the bottom face part (*M* = 11 ms, *SE* = 1), particularly in the Misaligned (*M* = 44, *SE* = 3 vs. *M* = 9, *SE* = 3) as compared to the Aligned test condition (*M* = 35, *SE* = 1 vs. *M* = 13, *SE* = 2).

According to previous evidence (Gallay et al., 2006; Turati et al., 2005), these findings showed that, in both the aligned and the misaligned conditions, infants' visual exploration was focused on the top portion of the face, that comprised the eye region. More interestingly, results revealed a discrepancy in infants' looking times according to the alignment or misalignment of the faces. Three-month-olds looked longer at the face with a familiar top half when the top and the bottom face halves were misaligned, thus revealing that they discriminated the two stimuli. Conversely, in the Aligned condition infants looked equally long to the familiar and novel stimuli, indicating that they did not differentiate between the two. This suggests that the bottom part of the composite faces affected infants' performance in both the Aligned and the Misaligned conditions. In the Aligned condition, the novel bottom-face halves impaired infants' discrimination of the two composite faces. In the Misaligned condition, the addition of the bottom face half determined a persistent and extensive re-exploration of the familiar top-face half. Indeed, previous studies that tested infants' ability to recognize a learned face over strong modifications -such as partial occlusion, or rotation- obtained a familiarity preference (Gava et al., 2008; Walton, Amstrong, & Bower, 1997; Sirois & Mareschal, 2002, 2004). In the current experiment, infants in the Misaligned condition recognized the familiarity of the top portion of the configuration, but also detected that a novel never-seen bottom face part was added to the familiar part. This induced infants' extensive re-exploration of the whole partially familiar stimulus.

The alignment vs. misalignment of faces also affected the trajectories of infants' eye movements, as infants' tendency to fixate the top- vs. the bottom-face halves was more evident in the Misaligned condition, that is when the top part of the faces are disjoined from the bottom parts. Thus, overall, evidence obtained employing an eye-movement recording VPC procedure supports the existence of the composite effect in 3-month-old infants.

Due to the presence from birth of the ability to process faces holistically, relaying on holistic face processing (Leo & Simion, 2009), it appears interesting to investigate whether holistic face processing could be observed employing the composite face paradigm in newborns.

Experiment 14a

Method

Participants

Participants were 28 (14 females) healthy, full term newborns (mean age 45 hr), recruited at the maternity ward of the Pediatric Clinic of the University of Padova. All of them were middle-class infants and Caucasian. Nine additional newborns were tested, but were not included in the final sample because one showed a strong position preference (i.e., he looked to one direction more than 80% of the time) and 8 did not complete testing due to fussiness. All of them met the screening criteria of normal delivery, a birth weight between 2460 and 4100 g, and an Apgar score between 8 and 10 at 5 minutes. Newborns were tested only if they were awake and in an alert state, after parents gave their informed consent.

Stimuli

The stimuli were identical to those presented in Experiment 13, except for dimensions expressed in visual angles that changed since 3-month-old infants were placed at a greater distance (60 cm) from the screen than newborns (30 cm). When projected on the screen, the two top parts presented in the habituation phase were 8 x 12 cm (about 15° x 23° of visual angle). Aligned faces were 15.5 x 12 cm (about 27° x 23°). Misaligned faces were 15.5 x 17.5 cm (about 27° x 33°). The distance between the center of the screen and the vertical median line of each figure was about 13.5 cm (about 26°).

Apparatus

The apparatus was the same of that described in Chapter 3 employing with newborns.

Procedure

Testing began when the newborn looked at the central flickering LED. The experiment was carried out using an infant-control habituation procedure (Horowitz et al., 1972). During the habituation phase, newborns were presented with two top halves of the same face presented bilaterally. Bilateral rather than central presentation was chosen because it is difficult for an observer to decide if newborns are actually looking at a centrally presented stimulus or if they simply do not move their eyes from the central position. Also, at birth photoreceptors in the central fovea are very immature, thus resulting in a poor vision in the central area of visual field (Abramov et al., 1982; Atkinson & Braddick, 1989).

The stimuli remained on the screen until the habituation criterion was established. During the habituation phase the same stimulus was presented on the left and on the right, so the amount of looking was recorded irrespective of the side. The habituation criterion was identical to the one used in Experiment 13. When the habituation criterion was reached, the stimuli were automatically turned off and the central flickering LED was turned on. When the infants' gaze was realigned to the central LED, a preference test phase started.

Each infant was given two paired presentations of the stimuli. During each presentation, newborns were simultaneously presented with a pair of composite faces. In one face of the pair the top half was identical to that shown during habituation, in the other face the top half was new. Both top halves were matched with the same bottom half of a third new face. The two-paired stimuli were always shown in both left and right positions, the position being reversed from presentation 1 to presentation 2. During the preference test phase, the experimenter recorded the duration of infant's fixations and the number of fixations on each stimulus by pressing two different push buttons depending on whether the infant looked at the right or the left position. Each presentation lasted until each stimulus had been fixated at least once and a total of 20 s of looking had been accumulated. The test presentations were kept longer in Experiment 14a (20 s of fixation time) than in Experiment 13 (10 s of fixation time), to give newborns more time to process the stimuli and eventually manifest a novelty preference. Half of the infants was tested in the Aligned condition, the other half was tested in the Misaligned condition.

Results and Discussion

All newborns reached the habituation criterion. A paired-sample t-test was run to compare total fixation times to reach the habituation criterion in each condition (Aligned Condition, M = 65210 ms, SE = 10456 vs. Misaligned Condition, M = 74886 ms, SE = 11220). The comparison did not reach statistical significance, $t(27) = 1.2$, n.s.

Preliminary ANOVAs on total fixation times and number of fixations toward the stimuli revealed that no main effect or interactions involved the factor Presentation (First vs. Second). Therefore, data were subsequently collapsed in two ANOVAs with Testing Condition (Aligned vs Misaligned) as between-subjects factor and Test (Novel vs. Familiar) as within-subjects factors, one for each dependent variable. The face stimulus that comprised the top half presented in the habituation phase was considered as familiar.

There was no main effect, F(1, 26) = .45, n.s., or interactions involving the factor Test, F(1, 26) = .99, n.s. (Figure 89).

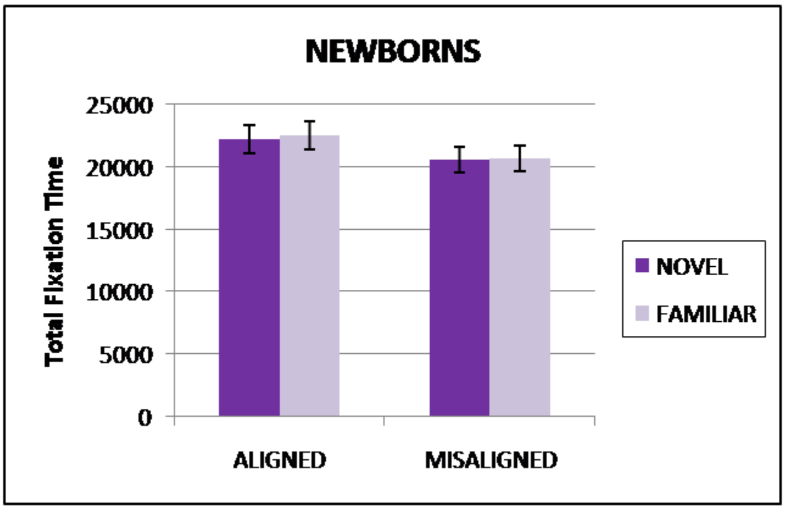

Figure 89: Total fixation time at the novel and the familiar stimuli as a function of test condition (Aligned vs Misaligned Condition) in Experiment 14a.

Results showed that newborns looked equally long to the novel stimulus as compared to the familiar stimulus in both the Aligned (*M* = 22248 ms, *SE* = 5458 vs. *M* = 22494 ms, *SE* = 8131) and Misaligned (*M* = 20542 ms, *SE* = 5834 vs. *M* = 20733 ms, *SE* = 7745) conditions. Furthermore, analyses with total number of fixations showed no main effect of the factor Test, F (1, 26) = .13, n.s. nor an interaction between the factor Test and Testing Condition, F (1, 26) = 1.9, ns. The results of Experiment 14a showed that neither newborns tested in the aligned condition nor newborns tested in the misaligned condition discriminated the familiar from the novel composite face. Different possible explanations of the obtained results might be provided. One possibility is that newborns based their response in the test phase on the bottom half of the composite faces, which was identical in both the stimuli that comprised the novel and the familiar top halves. This explanation is not plausible given that less salient and contrasted areas are embedded in the bottom as compared with the top face part (Gava et al., 2008; Turati, 2004). Alternatively, newborns may have reacted to the significant perceptual change that occurred between the habituation phase (in which only one top half of a face was presented) and the test phase (in which two faces were presented, each comprising a novel bottom half) and showed a persistent and comparable exploration of both the "familiar" and the "novel" composite face. Finally, newborns might be unable to recognize a portion of a face -i.e., only the top part rather than the full face-, given that first-order face information is absent and second-order face information is poorly represented, the spatial relations between eyes and nose and eyes and mouth being disrupted. The aim of Experiment 14b was to explore this issue by presenting newborns with the top-face part (i.e., without the bottom-part of the face) not only in the habituation phase, but also in the test phase.

Experiment 14b

Method

Participants

The final sample comprised 13 (8 females) healthy, full term newborns (mean age 43 hr), recruited at the maternity ward of the Pediatric Clinic of the University of Padova. All of them were middle-class infants and Caucasian. Four additional newborns were tested, but were not included in the final sample because they did not complete testing due to fussiness. All of them met the screening criteria of normal delivery, a birth weight between 2620 and 3850 g, and an Apgar score between 9 and 10 at 5 minutes. Newborns were tested only if they were awake and in an alert state, after parents gave their informed consent.

Stimuli

The stimuli were identical to those presented in Experiment 13 and 14a, except for the fact that only the top halves of faces were presented both in the habituation and in test phases.

When projected on the screen, the two top parts were 8 X 12 cm (about 15° x 23° of visual angle). The distance between the center of the screen and the vertical median line of each figure was about 13.5 cm (about 26°) (Figure 90).

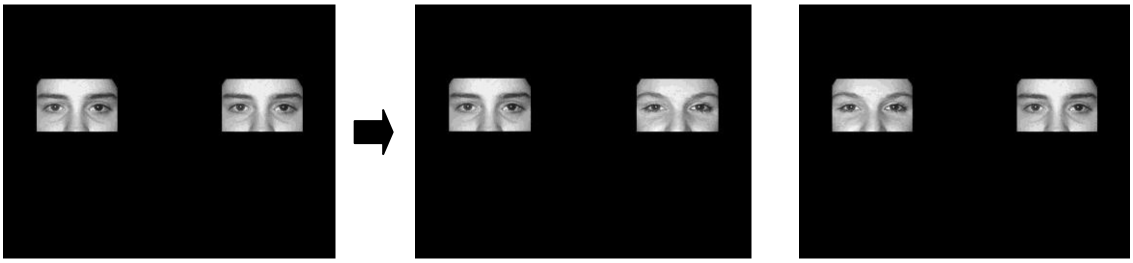

Figure 90: Procedure employed with newborns in Experiment 14b.

Apparatus and Procedure

The apparatus and the procedure were the same as with newborns in Experiment 14a.

Results and Discussion

After all newborns reached the habituation criterion, to test whether newborns were able to recognize and discriminate the novel stimulus from the familiar one, a novelty preference score (percentage) was computed. Each infant's looking time at the novel stimulus during the two test presentations was divided by the total looking time to both test stimuli over the two presentations, and subsequently converted into a percentage score. Hence, only scores significantly above 50% indicated a preference for the novel stimulus. The mean novelty preference score was 55,24% (SD = 17,41) but did not differed significantly from the chance level of 50%, t (12) = 1,09, n.s.

The outcome demonstrates that newborns are not able to discriminate two faces only from the top part, although it has been demonstrated that the face top-half, specifically the eyes, contains important perceptual informations. As suggested before, newborns are not able to recognize a portion of a face -i.e., only the top part rather than the full face-, given that first-order face information is absent and second-order face information is poorly represented, the spatial relations between eyes and nose and eyes and mouth being disrupted.

Experiment 15

To ground the results obtained in Experiments 13 and 14 in an adult model, Experiment 15 tested a group of adults in a similar VPC task. In adults, the active control of eye fixations plays an important functional role in a wide variety of cognitive and perceptual tasks (Henderson, 2006). Adults' eye fixations during face perception and recognition are predominantly directed to internal facial features, particularly the eyes, then nose and mouth (Althoff & Cohen, 1999; Henderson, Falk, Minut, Dyer, & Mahadevan, 2001; Stacey, Walker, & Underwood, 2005). Recently, a functional relationship between eye movements and face perception has been demonstrated, in that a deficit in recognition emerged when participants were required to keep their eyes fixated in one central position (i.e., restricted viewing condition) rather than to move their eyes freely (i.e., free viewing condition) (Henderson, Williams, & Falk, 2005). Finally, Williams and Henderson (2007) found that the same features of a face were fixated regardless of whether the face was right side up or upside down and interpreted their findings as indicating that the face inversion effect is not the result of a different pattern of eye movements.

Through the recording of adults' eye movement during a composite task, Experiment 15 was aimed to test gaze behavior during holistic face processing. Despite numerous studies on adults' composite face illusion, only a single study recorded eye-movements while adults performed a delayed matching task of top halves of faces aligned or misaligned with bottom face halves (de Heering, Rossion, Turati, & Simion, 2008). Results showed that participants fixated longer the top parts of aligned than misaligned faces, suggesting the presence of a difference in eye-movements strategies between the aligned and misaligned condition. However, manual reaction time data were strictly linked to eye-recording data, as suggested by the high correlations between participants' manual response time and ocular fixation time in aligned and misaligned conditions. When the effect of participants' manual response time was controlled, considering the variable as a covariate, the difference in mean fixation time on the top parts of aligned and misaligned faces disappeared, suggesting that longer fixation time on the top parts of aligned versus misaligned faces was due to the time devoted to respond manually at aligned vs. misaligned faces, aligned faces being processed more slowly.

Considering this result, in the current experiment adults' eye movements were recorded in a free-viewing task that does not require a manual response. In parallel with the experimental paradigm used with three-month-old and newborn infants in Experiments 13 and 14 and with studies that used the VPC task with adults (Richmond, Sowerby, Colombo, & Hayne, 2004), participants were familiarized with the top half of a face in a single fixed 15-sec presentation. In the subsequent two fixed 10-s presentation test phases a pair of composite faces was shown in which one of the face top halves was identical to the top half of the face presented during familiarization and the other top half was new. Half of the participants was tested in the aligned condition, and the other half was tested in the misaligned condition, so that alignment of the composite stimuli was varied between subject as in Experiments 13 and 14. No instructions were given, except that participants had to watch the images appearing on the computer screen moving their eyes freely.

Method

Participants

Twenty-two undergraduate middle-class, Caucasian students (17 females, M = 22.8 years) from the Department of Psychology at the University of Padua (Italy) participated in the study. Seven additional participants were tested, but excluded from the final sample due to failure to reach criteria established for data analyses (their fixation time toward stimuli was less than 70% of the total presentation time during both first and second test phases). All of them had normal or corrected-to-normal vision.

Stimuli

The stimuli were identical to those used in Experiments 13 and 14a.

Apparatus and procedure

The apparatus and the procedure were the same as with 3-month-old infants in the previous experiment, with one exception. Following the calibration phase, instead of the habituation phase, participants were familiarized with a top half of a face projected in the center of the screen for a fixed presentation period of 15 s. Half of the participants was tested in the Aligned condition, while the other half in the Misaligned condition. Participants were given no instructions except that they had to watch the images appearing on the screen.

Results and Discussion

To compare total fixation times in the Aligned and Misaligned conditions during the familiarization phase, a paired-sample t-test was run (Aligned Condition, M = 11773 ms, SE = 762 vs. Misaligned Condition, M = 12709 ms, SE = 434), $t(20)$ = 1.06, n.s. As expected, the difference was not significant.

As with infants in Experiment 13, the aims of the statistical analyses performed on the data were carried out to understand i.) Whether adults' ability to discriminate the familiar from the novel composite face varied as a function of the alignment or misalignment of the face halves, and ii.) Whether the pattern of adults' fixation durations to the top and bottom halves of the composite faces varied between the two alignment conditions.

The face stimulus that comprised the top half presented in the habituation phase was considered familiar while the other was considered novel. Two distinct mixed-model ANOVAs were performed on total fixation times and number of fixations with Presentation (First vs. Second), Test (Novel vs. Familiar), and Face Half (Top vs. Bottom) as within-subjects factors and Testing Condition (Aligned vs. Misaligned) as between-subject factor.

Results of the ANOVA on total fixation times showed that adults looked longer at the top face halves (M = 2869 ms, SE = 121) than at the bottom face halves (M = 1062 ms, SE = 107) as showed by the main effect of Face Half, $F(1, 20) = 65.3$, $p < .001$, $\eta^2 = .76$. More importantly, there was a significant interaction between the factors Test and Testing Condition, $F(1, 20) = 6.5$, $p < .05$, $\eta^2 = .24$ (Figure 91).

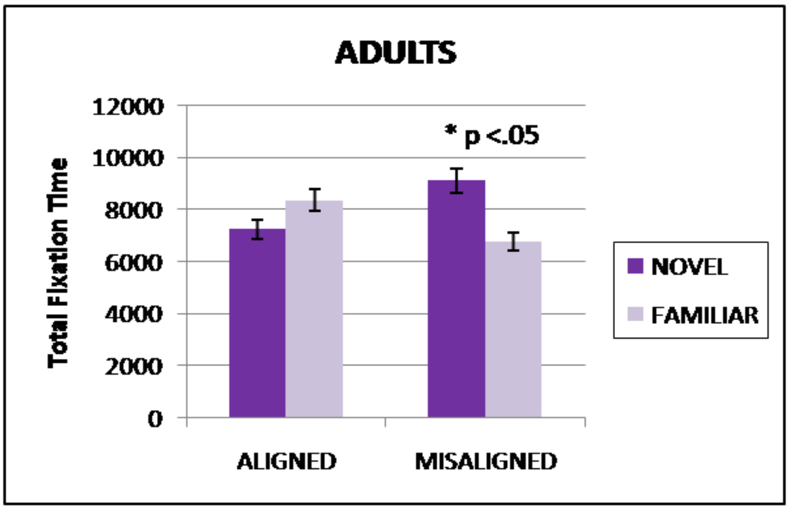

Figure 91: Total fixation time at the novel and the familiar stimuli as a function of test condition (Aligned vs. Misaligned Condition) in Experiment 15.

Planned t tests showed that, in the misaligned test condition, adults looked longer at the novel (*M* = 9107 ms, *SE* = 516) than at the familiar stimulus (*M* = 6762 ms, *SE* = 498), $t(10) = 2.4$, $p < .05$. On the contrary, in the Aligned test condition, mean fixation time toward the novel (*M* = 7229 ms, *SE* = 435) and the familiar faces (*M* = 8356 ms, *SE* = 539) did not differ, $t(10) = 1.2$, n.s.. This suggests that, in the Aligned condition, the bottom part of the composite faces affected adults' performance, impairing their face recognition ability.

Finally, the interaction between the factors Presentation and Test also reached statistical significance, $F(1, 20) = 9.6$, $p < .05$, $\eta^2 = .32$. Specifically, planned t tests showed that adults looked longer at the novel stimulus (*M* = 4556 ms, *SE* = 257) than at the familiar one (*M* = 3320 ms, *SE* = 243) during the first test phase, $t(21) = 2.5$, $p < .05$, in contrast no differences in looking behavior between the novel (*M* = 3612 ms, *SE* = 231) and the familiar stimulus (*M* = 4239 ms, *SE* = 285) was observed in the second test phase $t(21) = 1.2$, n.s.

The ANOVA on number of fixations revealed no main effect or interactions involving the factor Presentation (First vs. second). Therefore, data were collapsed across this factor in a subsequent three-way ANOVA with Test (Novel vs. Familiar) and Face Half (Top vs. Bottom) as within-subjects factors and Testing Condition (Aligned vs. Misaligned) as between-subjects factor.

Results indicated a main effect of Face Half, F (1, 20) = 90.3, $p < .001$, $\eta^2 = .82$. The number of fixations adults made to the top part of the face (*M* = 36, *SE* = 2) was greater than the number of fixations toward the bottom part of the face (*M* = 13, SE = 1). Furthermore, the significant interaction between Face Half and Testing Condition, F (1, 20) = 5.4, $p < .05$, $\eta^2 = .21$, showed that the difference between fixations to the top part of the face and the bottom part of the face was greater in the Aligned test condition (*M* = 39, *SE* = 2 vs. *M* = 10, *SE* = 1) than in the Misaligned test condition (*M* = 34, *SE* = 2 vs. *M* = 17, *SE* = 3). Furthermore, there was a significant interaction between the factors Test and Testing Condition, F (1, 20) = 6.2, $p < .05$, $\eta^2 = .24$. Planned *t* tests showed that, in the Misaligned test condition, the number of fixations toward the novel stimulus (*M* = 29, *SE* = 2) was greater than the number of fixations toward the familiar stimulus (*M* = 22, *SE* = 2), $t(10) = 2.9$, $p < .05$. On the contrary, in the Aligned test condition, the number of fixations toward the novel (*M* = 24, *SE* = 2) and the familiar faces (*M* = 25, *SE* = 1) did not differ, $t(10) = .61$, n.s. Evidence from the present experiment appears in line with previous findings showing that adults' fixations toward faces are directed predominantly toward the eye regions (e.g., Althoff & Cohen, 1999; Henderson et al. 2001, 2005). Importantly, adults looked longer and directed a greater number of fixations toward the face with a novel top half in the Misaligned condition. Conversely, in the Aligned condition adults looked equally long and oriented their gaze approximately the same number of times toward the novel and familiar stimuli. This suggests that, in the Aligned condition, the bottom part of the composite faces affected adults' performance, demonstrating the presence of the composite face effect. Aligned vs. Misaligned stimulus conditions elicited differential looking times and numbers of fixations for the novel and the familiar composite face, providing evidence that eye movements may be affected by the encoding of holistic face information.

Overall, the present work is consistent with the idea that eye movements during face recognition are functional to face processing strategies (Henderson et al., 2005), but is partially in contrast with the findings reported by de Heering et al. (2008) on the composite effect and by Williams and Henderson (2007) on the inversion effect, according to which eye movement patterns are not able to reflect holistic processing strategies. The discrepancies between this study and previous work may be explained by at least three major methodological differences. First, in the present study participants were not required to provide a manual response. This may have avoided high correlations between participants' manual response time and ocular fixation time that could produce distortions in the results related to eye movements, since longer manual reaction times are associated with longer fixations. Second, with respect to the study by de Heering et al. (2008), participants were not explicitly required to look at the top part of a face in order to recognize it, but were allowed to freely move their eyes. According with de Heering et al. (2008), it has been found that the top-halves of the composite faces in the test phase were fixated longer than the bottom-halves, irrespective of whether the face-halves were aligned or misaligned. However, differently from de Heering et al. (2008), in the current study the Aligned and Misaligned conditions affected the amount of visual exploration of the novel and the familiar composite faces and number of fixations directed toward the top and the bottom composite face part. Third, differently from the study by Williams and Henderson (2007), the use of the composite paradigm allowed us to split faces into only two critical areas of interest (top face part and bottom face part) rather than in multiple areas related to each face feature (left eye, right eye, nose, mouth, chin, forehead, etc...). This might have produced a more adequate measure of holistic, rather than feature-based, face processing strategies.

Conclusion

The main outcome of the present study is that for the first time a clear demonstration was provided that young infants are capable of processing a face holistically, as an undifferentiated unit in which face parts and their relations are glued together (Experiment 13). The present work extends previous findings that reported a measure of the composite effect at 3 years of age (Macchi Cassia et al., 2009) and of the part-whole effect at 4 years of age (Pellicano & Rhodes, 2003). Also, the present results extend previous findings obtained by Cohen and colleagues, demonstrating that infants are not only capable of detecting correlations between outer and inner face features (Cashon & Cohen, 2001, 2003), but also between the sole inner features of a face.

Importantly, this study employed a version of the composite paradigm suitable for infants that permits to compare directly the holistic face processing performance in infants, older children and adults. Indeed, this paradigm was shown to be a potential measure of the composite face effect also in adults (Experiment 15), demonstrating that eye movements (duration and number of fixations) may be sensitive to holistic face processing during the entire life span. The use of the same task throughout development, from early infancy to adulthood, allows researchers to highlight both differences and similarities in the visual behavior across age groups. First, results clearly show that the facial features that attract both adults' and infants' ocular fixations are almost the same, in that at both ages a clear tendency to explore the top rather than the bottom face part was found. Second, although both age groups visually recognized the familiar stimulus in the misaligned but not in the aligned condition, infants preferred looking at the face with the familiar top part while adults tended to look longer at the face with the novel top part. Thus, adults did not need to re-explore the stimulus that comprises the familiar top of the face and directly focused attention on the face stimulus with a novel top. Overall, evidence from the current study reveals that the tuning toward configural information appears very early in life, although gradual experienced-based developmental processes will progressively refine early configural abilities.

General Conclusion

One central issue in cognitive developmental science is to understand how cognition grows and change over time to reach an adult level of specialization. Determining the abilities with which infants come equipped into the world, their mechanisms for acquiring knowledge, and whether and how these abilities change as a function of development and experience is a challenging issue. Face processing is an interesting topic of research in that respect because faces form a special class of visual objects elaborated in adults by a specific anatomical and functional face system (e.g., Kanwisher, 2000; Farah et al., 1998). Since what determines this specialization and how this specialization emerges during development still remain unknown, the purpose of my PhD dissertation was to study cognitive specialization during early infancy through the investigation of the development of infants' abilities to process faces. In particular, my hypothesis was that the face processing specificity is not present at birth, but emerges gradually from the interaction between general constraints and attentional biases present in the first months of life and the critical visual input provided by the specie-specific environment (Nelson, 2001, 2003; Johnson, 1993).

In Study 1 *(Chapter 3)*, using both the visual preference and visual habituation techniques, a first series of experiments investigated the nature of face representation in newborns and in 3-month-old infants. According to recent evidence showing that infants' response to faces becomes more and more tuned to the face category over the first three-months of life (Turati et al., 2005), collected data demonstrated that 3-month-old infants, but not newborns, are sensitive to specific perceptual cues within a face, such as the correct position and orientation of the eyes (Experiments 1, 2 and 3). Furthermore, results obtained from Experiments 4, 5, 6 and 7 demonstrated that early facial representation is not human-specific, corroborating the hypothesis that newborns come into the world with a face representation that is sufficiently general as to bias newborns' visual attention toward multiple categories of faces (e.g., monkey faces vs. human faces), and that this face representation, due to the visual experience that infants do in the specie-specific environment, becomes more specific to human face during the first 3 months of life (Nelson, 2001; Pascalis & Kelly, 2009).

Due to the social relevance of the face stimulus and due to the ability of 3-month-old infants to form a specific representation of the human face, the aim of Study 2 *(Chapter 4)* was to investigate whether human face capture and maintain infants' attention in complex visual scenes. Specifically, using an eye-tracker system, adults' and 6- and 3-month-old infants' visual search behavior was compared in a modified visual search task of a target face among heterogeneous (e.g., various objects, Experiments 8, 9 and 10) and homogeneous distractors (e.g., inverted faces, Experiments 11, 12). Collected data demonstrated that a face among heterogeneous distractors captures and maintains adults' and 6-month-old infants' attention and that 3-month-old infants detect a target face only when embedded among inverted faces (e.g., homogeneous distractors), corroborating previous findings showing the face detection advantage in infants (Gliga et al., 2009).

Importantly, to detect a target face among other distractors, infants have to process a face as a Gestalt, where the whole is more than the sum of its constituent parts (Tanaka & Farah, 1993). This kind of face processing, called "holistic", was investigated in newborns, 3-month-old-infants, and adults through a modified version of the composite face paradigm (Young et al., 1987) and the recording of eye movements in Study 3 *(Chapter 5)*. The main outcome of the study was that the tuning toward holistic information appears very early in life, although gradual experience-based developmental processes will progressively refine early holistic processing abilities (Experiments 13, 14 and 15).

Taken together, the data obtained herein suggests that face specificity is not prewired, but rather arises from general perceptual processes that, during development, become progressively tuned to the human face, as a result of extensive experience with this stimulus category. Overall, the data presented in this thesis are in line with an experience-expectant perspective, that emphasizes the relevance of both general constraints of the human visuo-perceptual system and exposure to certain experiences shortly after birth to drive the system to become functionally specialized to process faces in the first month of life. The three studies presented here highlighted the role of the visual experience as a determinant factor for the specialization of the face processing system.

However, at present, little is known about the specific experiences that lead to expert face processing or how early perceptual experience contributes to the specialization of the neural structures underlying face processing (e.g., specifying exactly what kinds of experiences are necessary, when these experiences need to occur, and lastly, for how long they need to occur). This research will specifically require future research that simultaneously combine the study of structural and functional changes in the brain during development, employing both behavioral and neuropsychological tasks (e.g., NIRS and ERP).

Finally, as suggested in the first chapter, within a neoconstructivistic theoretical framework, developmental disorders can be understood through altered constraints that push the developmental trajectory off its normal track to reach a different endstate (Karmiloff-Smith, 1998; Thomas & Karmiloff-Smith, 2002). Thus, atypical development can, like typical development, be characterized as an adaptation to multiple interacting constraints, only that the constraints are different. These atypical constraints then lead to different outcomes through the same processes of representation construction (Westermann et al., 2007). In this vein, understanding the constraints that shape typical development trajectory is an important first step to investigate which and how different constraints shape atypical development.

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