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The Caregiver Bias in Face Processing: A Multi-Method Investigation in Infants and Children

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to whom made it harder,

for they made it worth my while.

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ABSTRACT

Faces are universally important for a variety of reasons, ranging from identifying individuals to conveying social information. There is now ample evidence that, during the first year of life, facial experience provided to each infant by their social environment shapes the development of face representation, which progressively tunes towards the facial characteristics of the individuals that are more salient to the infant.

Data from parental reports and naturalistic studies indicate that there are typically large discrepancies in the social attributes of faces to which infants are exposed during their first year of life, with the majority of facial experience being with individuals of the same race, gender and age as the primary caregiver. Moreover, researchers have argued that the developmental task of forming attachment relationship with caregiver boosts the discrimination of the primary caregiver from all others, making female own-race faces the most socially and emotionally relevant face category for infants. These discrepancies in the amount of interactions, along with enhanced motivation to attend to individuals with demographic characteristics of the primary caregiver have been linked to the emergence in infancy of a representational bias toward caregiver-like faces. Despite such face bias is well established in infancy, little is known about the face-processing behavior later in development, when changes in both the structure of social environment (e.g., exposure to other adults and peers at the daycare) and developmental task (e.g., learning self-mastery) could influence how children attend and process faces.

In this doctoral dissertation, I will present four studies conducted during my PhD, which were aimed to investigate how the face processing system is influenced by each individual's social experience and developmental tasks during infancy and early childhood.

Study 1 and Study 2 (Chapter 1) investigated the development of the age bias by exploring the effects of early-acquired facial experience on perceptual recognition and visual exploration strategies used to encode adult and child faces in infants and children. Study 1 explored recognition abilities and scanning patterns of adult and child faces in first-born 10-month-old infants. Study 2 investigated these same aspects in 5-year-old children with different amount of experience with child faces resulting from the absence versus presence of an older sibling in the household. This second study also explored the relation between temperamental traits and individual differences in face processing skills. Overall, results showed that experience acquired early in life with adults directs infants’ face-processing behavior towards a better processing of such face age. Instead, in childhood the exposure to different people along with age-specific developmental tasks even out the encoding of adult and child faces.

Studies 3 and 4 (Chapter 2) were aimed at extending evidence on visual scanning strategies and neural activity in encoding facial race and gender attributes in 3- to 6-year-old children. Study 3 explored with multi-method analyses of eye-tracking data how children process the race and the gender of faces, systematically investigating the interaction between those facial attributes. Study 4 investigated children’s neural categorization of race and gender attributes of faces by comparing steady-state visual-evoked potentials in response to female and male faces from both own- and other-race. The results of these studies extend the existing evidence on how race and gender attributes interplay for defining children’s face-processing behavior and yielded novel insights into neural mechanisms underlying the race and gender biases.

Overall, these studies support the hypothesis that face-processing abilities vary throughout development, reflecting the continuous reorganization of the face perception to changing environmental experiences and developmental tasks.

INTRODUCTION

Human faces have unique biological structures that convey a variety of complex social messages. As human beings, our brain evolved in order to derive all these signals from faces and to promote the ability to adapt to the social environment. Multiple lines of research suggest that, in adults, faces are a class of stimuli that receives high priority from attention (for a review, see Palermo & Rhodes, 2007). A long-standing debate was conducted for defining as to whether high specialized processing and behavioral responses are unique to faces as a stimulus category, or they may reflect a more general ability to develop expertise in differentiating among exemplars in a domain. That is, some authors adopted a maturational perspective by arguing that face-sensitive brain circuits are devoted specifically to face processing already from birth, due to the high biological relevance of this stimulus for members of the human species (Kanwisher, McDermott, & Chun, 1997). Most of the evidence supporting this view comes from neuropsychology and neurophysiology fields and reports that patients with damage in the occipito-temporal region of the right hemisphere selectively lose the ability to recognize faces (De Renzi, 1997). Moreover, large neural responses seem to be elicited by faces but not by scrambled faces, cars, or butterflies over discrete portions of the fusiform and infero-temporal gyri in epileptic patients with implanted subdural electrodes (Ojemann, Ojemann, & Lettich, 1992; Allison et al., 1994; Nobre, Allison, & McCarthy, 1994). The maturational perspective finds support also in studies that explored the cortical specialization in the normal human brain. Indeed, there is evidence that proves that regions of the fusiform gyrus are more active during face than object viewing (Sergent, Ohta, & McDonald, 1992) and during the viewing of faces than scrambled faces

(Puce, Allison, Asgari, Gore, & McCarthy, 1996; Clark et al., 1996). Kanwisher and collaborators (1997), using functional Magnetic Resonance Imaging (fMRI), showed a selective involvement of the fusiform gyrus when adult participants viewed faces but not when they were presented to objects, arguing that this area selectively responds to faces (Kanwisher, McDermott, & Chun, 1997). Taken together, these sources of evidence seem to support the existence of specialized neural "modules" for face perception in adult extra striate visual cortex, namely in the Face Fusiform Area (FFA).

On opposing side, the perceptual-learning perspective argues that the supposed 'face specific' cortical areas are recruited for expert-level discrimination of any complex visual patterns for which massive experience has been accumulated, whether they are faces or other classes of object (Diamond, & Carey, 1986; Gauthier, Skudlarski, Gore, & Anderson, 2000). According to this hypothesis, some neuroimaging studies with adults indicate that visual areas selective for recognition of faces can likewise be recruited for non-face objects, based on the subject's expertise with that category of stimuli. For example, Gauthier and colleagues (1999; 2000) suggested that, when compared to the cortical activity of novice participants, the FFA in expert adults (i.e., car and bird experts) was activated for faces as well as for the experienced objects (Gauthier, Skudlarski, Gore, & Anderson, 2000). Furthermore, even the acquisition of expertise with novel objects (greebles) led to increase the activation of face-selective regions in the FFA (Gauthier, Tarr, Anderson, Skudlarski, & Gore, 1999), suggesting that perceptual expertise could be one of the factors driving neural commitment to face processing. Overall, these observations remark the implicit assumption that non-face categories employ the same mechanisms and neural circuits that were supposed to be face-sensitive.

A developmental approach can help to disambiguate between those two opposite perspectives, describing developmental trajectories of face processing abilities from early stages and following changes through childhood and adulthood. In this respect, the Neuroconstructivism is the main theoretical framework, which gives valuable basis for explaining underlying mechanisms of neural structures in the brain as well as the construction of representations in developing brain, with the ultimate aim of defining developmental trajectories of cognitive changes. Accordingly, such approach postulates the existence of an experience-expectant mechanism of learning for which cognitive and neural development occur as a result of common experiences to which all humans are exposed in everyday environment. That is, ubiquitous stimuli invite a specific range of action in relation to the agent’s skills. Thus, changes during development are not fully defined from birth, but follow a probabilistic epigenesis (Gottlieb, 1992; 2007) during which developmental changes are constrained by multiple interactions between intrinsic and extrinsic factors. Indeed, from this perspective developmental trajectory occurs in the context of a number of constraints that span on multiple levels of analysis (e.g., from genes to social environment) and operate on development of the domain-specific structures typical of cognitive architecture of adults. Thus, innately specified constraints and the structure of input provided by the species-typical environment interplay in different ways to shape neural structures that support mental representations (Westermann et al., 2007). The Neuroconstructivist approach ensues the Piagetian constructivist notion that proactive interactions between individual and environment in which development occurs have the ultimate aim of optimal adaptation of human beings (Westermann, Thomas, & Karmiloff-Smith, 2010). A relevant example of this phenomenon is the loss during infancy of phonemic boundaries if the language to which babies are exposed does not utilize them (Werker, & Tees, 1984). Such behavioral change is also associated at the neural level to an initial rapid peak of synapses numbers, which is followed by the loss of a significant proportion of them (Greenough, Black, & Wallace, 1987). Similarly, a number of behavioral studies have shown that newborns' visual attention is spontaneously and preferentially attracted toward face-like configurations as well as familiar faces (Bushnell, Sai, & Mullin, 1989; Field, Cohen, Garcia, & Greenberg, 1984). Although newborns learn from faces using different strategies than older infants (Pascalis, de Schonen, Morton, Deruelle, & Fabre-Grenet, 1995), they do show to discriminate between different identities, suggesting the existence of a detailed prototypical representation of the human face (Goren, Sarty, & Wu, 1975). This phenomenon has been taken as one of the strongest evidence supporting the existence at birth of a biologically determined and experience-independent neural mechanism dedicated to face processing (Farah, 2000; Farah, Rabinowitz, Quinn, & Liu, 2000; Johnson & de Haan, 2001; Johnson & Morton, 1991). However, it is also clear that how infants learn about faces changes rapidly, thus the initial state is added by experience in order to assist the infant in making sense of the complex world of faces and of people. That is, shortly after birth babies are biased to faces, since they prefer to look at face-like over non-face-like stimuli (Macchi Cassia, Turati, & Simion, 2004) and visual exposure quickly exerts effects on newborns' performance, so that by 3 days in their postnatal life they prefer to look at their mother's face over other female faces (Bushnell, 2003). Hence, the perceptual system seems to rely on initial constraints that direct newborns attention towards a preferential processing of faces. Thereafter, this initial perceptive preference rapidly develops during the first months of life, so that the perceptual processing, by means of specific sensitivity to the influence of social environment, became progressively specialized. Such effect enables the development of a face prototype (Valentine & Ferrara, 1991) and leads to biases in discriminating the most experienced category of faces (Pascalis et al., 2005). Indeed, not only the species-specific environment, but also significant perceptual experiences in infants own particular environment provides the basis on which face perceptual abilities are tailored.

Perceptual Narrowing is a developmental process that explains how human brain uses environmental experiences to shape perceptual abilities. By 9-12 months of age, perceptual discrimination is tuned to environmentally relevant distinctions, whereas it declines in the ability to perceive some aspects to which infants are not often exposed (Cashon, & De Nicola, 2011; Maurer & Werker, 2014; Nelson, 2001; Scott, Pascalis, & Nelson, 2007). This process is reported to act across several areas of development, such as phonetic perception (Kuhl et al., 2006), face perception (Pascalis, de Haan, & Nelson, 2002; Pascalis et al., 2005), musical rhythms (Hannon & Trehub, 2005) and intersensory perception (Lewkowicz, & Ghazanfar, 2006). It is important to note that this approach does not suggest a developmental regression, but a progression toward greater efficiency at perceiving and processing salient rather than less-salient environmental inputs. The decline in the discriminatory skill is also evident in the brain as a function of the progressive pruning of exuberant synaptic connections, which can be considered the neural mechanism mediating enhanced discriminatory abilities across domains (Scott et al., 2007). Such attunement towards the most experienced inputs in infants' surrounding was originally reported for nonnative speech contrasts (Werker & Tees, 1984), and it recently has been suggested as a shared process for all forms of social communication (Pascalis et al., 2014). Indeed, many findings about the development of face processing skills supported the developmental pattern suggested by the Perceptual Narrowing, showing that the discrimination between faces is more broadly tuned at 6 months, but it becomes narrowly tuned around 9 months. This mechanism entails that the development of perceptual abilities does not follow a linear trajectory, indeed bidirectional influences between neural and cognitive system and environmental events produce optimal acquisition only during certain sensitive periods.

Assuming that development of cognitive functions has not categorical and definitive outcome, sensitive periods are defined as a maturational stage of an organism during which the nervous system is especially sensitive to certain environmental stimuli. Outside these sensitive periods, an influence of surrounding inputs may still active on exerting little effects on the development of processing abilities and on setting the characteristics of an individual. Thus, during the lifespan experiences shape the development of cognitive skills during multiple periods. The vast majority of data regarding experience effects on cognitive development come from studies of visual perception abilities, which prove that even during adulthood there is a residual plasticity of cognitive system (Maurer, 2017). For example, adults with residual visual deficits after treatment for bilateral congenital cataract showed improvements in acuity, spatial contrast sensitivity, temporal contrast sensitivity, sensitivity to global motion, and the processing of upright human faces after 4 weeks of intensive training with action video games (Jeon, Lewis, & Maurer, 2012). Similarly, facial experience acquired in social and working contexts has been suggested to influence face processing abilities during adulthood and old age in participants without visual or neural deficits. Although the advantage in processing own-age faces in young adults (i.e., own-age bias) is a robust and stable phenomenon (Macchi Cassia, 2011 for a review), there is evidence that in both younger and older adults, the amount of self-reported social exposure to own- and other-age individuals is related to the size of such advantage (Ebner & Johnson, 2009; He, Ebne, & Johnson, 2011). In addition, Kuefner and colleagues (2008; 2010) found that school teachers were as accurate at discriminating child faces as they were at discriminating adult faces when compared to non-experienced age-matched controls (Kuefner, Macchi Cassia, Picozzi, & Bricolo, 2008; Kuefner, Macchi Cassia, Vescovo, & Picozzi; 2010). Similarly, while young participants clearly demonstrated more accurate memory for young versus old faces, aged participants, who reported high degrees of daily contact with elderly persons, yielded more accurate memory for as well as differential processing of old compared to young faces (Wiese, Komes, & Schweinberger, 2013; Wiese, Schweinberger, & Hansen, 2008).

The role of experience on the progressive attunement for face discrimination is evident for several social attributes of faces (i.e. species, race, age and gender). Although the early preference for faces over other categories of stimuli is linked to the low-level visual proprieties of faces, which attract infants' visual attention (Johnson, Dziurawiec, Ellis, & Morton, 1991), the subsequent face preferences become more specific and driven by cortical mechanisms (Mondloch et al., 1999) thanks to postnatal experiences (Macchi Cassia, Kuefner, Westelund, & Nelson, 2006). Such that, more-frequently experienced categories of faces might be more attractive than less-frequently experienced categories (Heron-Delaney et al., 2011; Kelly et al., 2005; Quinn, Yahr, & Kuhn, 2002) and the social attributes extracted from experienced faces interact to drive infants' preferences and consequently outline their abilities on both recognition and discrimination (Heron-Delaney, Damon, & Quinn, 2016; Scherf & Scott, 2012).

The period between 6 and 9 months of age has been found to be particularly important in shaping face processing via experience. In particular, 6-month-old infants are reported to show equal discrimination of both human and nonhuman primates, whereas 9-month-old infants and adults showed a significant advantage for discriminating only human faces, consequently exhibiting the own-species bias (Pascalis, de Haan, & Nelson, 2002). A similar pattern was found for the cortical responses of the two face-sensitive perceptual

Event-Related Potential (ERP) components (e.g. N290 and P400; for review, see de Haan, Johnson, & Halit, 2003) in babies before and after the critical period of the narrowing. Twelve-month-old but not 3-month-old infants demonstrated perceptual tuning to frequently experienced face groups, showing a specific neural inversion effect[1] for human faces (Halit, De Haan, & Johnson, 2003). Even if the exact processes and mechanisms underlying perceptual narrowing are still unknown (for a review, see Flom, 2014), there is evidence about the influence of individual labelling of faces on the perception of unfamiliar faces. In a longitudinal training study, 6-month-old infants received 3 months of experience hearing individual labels paired with monkey faces pictures (Scott & Monesson, 2009, 2010). After this intensive individual-labeling experience, 9-month-olds maintained their ability to discriminate individual faces (Pascalis et al., 2005; Scott & Monesson, 2009) as well as they exhibited expert-like neural activity (Scott & Monesson, 2010).

Similar to species-bias, previous research indicated that 3-month-old Caucasian infants, exposed primarily to Caucasian faces, showed to equally recognize Caucasian and other-race faces (i.e., African, Middle Eastern, and Chinese), while at 9 months infants' recognition was restricted to own-race faces (Kelly et al., 2007). Moreover, an initial preference for own-race faces (Kelly et al., 2005) is linked to greater recognition performances only by the end of the first year of life and it is suggested to be sensitive to the most experienced race, regardless of participants’ ethnicity. Indeed, 3-month-old Asian infants exposed primarily to Asian faces demonstrated a preference to Asian faces than to Caucasian, African, or Pakistani faces (Kelly, Liu, et al., 2007), while at 9 months, because

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[1] The inversion effect is define as the impairment in perceptual recognition when stimuli are presented with the upside-down orientation (Valentine, 1988). It is considered a marker for expert perceptual processing and, in adult participants, it typically occurs for human faces or objects of expertise (Rossion, & Curran, 2010).

of more efficient processing of own- versus other-race face, infants shifted their attention to the novel stimuli, namely the other-race faces (Liu, Xiao, Xiao, et al., 2015). Perceptual Narrowing towards own-race faces was also supported by neural evidence on face-specific ERP responses in infancy. For instance, whereas 5-month-olds did not show differential electrophysiological activity to own- and other-race faces (Vogel, Monesson, & Scott, 2012), 9-month-olds exhibited a larger N290 (Balas, Westerlund, Hung, & Nelson, 2011) and larger P400 (Vogel et al., 2012) amplitude of responses for own- versus other-race faces. In addition, the experience with the dominant race in infants' environment seems to shape the strategy they use for exploring faces of different races. Indeed, the scan path among internal features of 6- to 9-month-old infants involves more transitions between the eyes of own-race faces than between the eyes of other-race faces, revealing a possible use of second-order relations, also known as experienced strategy, when viewing own- versus other-race faces (Xiao et al., 2013). Moreover, Gaither, Pauker, and Johnson (2012) investigated the issue of how infants' scanning patterns is related to their face discrimination abilities. Using the habituation procedure, they tested 3-month-olds' preference for a novel face from either own- or other-race categories. Despite infants did not show behavioral preference for the novel face, the degree of novelty preference in own-race face discrimination was found to be positively related with the visual transitions between the top (eye region) and bottom (mouth region) halves of own-race faces during habituation, while such correlation was not found for other-race face discrimination (Gaither et al., 2012). Not least, cross-race exposure has an important influence on drawing both preference/discrimination skill and scanning patterns used for exploring faces of different race. In this respect, Bar-Haim et al. (2006) found that the preference for the own-race face at 3 months is observed only in infants living in predominantly homogeneous own-race environments, whereas African Israeli infants who had similar experience with both African and White faces did not display any preference. In addition, the discrimination of own-race faces in biracial infants is associated with a reduction of transition between eye and mouth areas, showing an opposite scanning pattern than monoracial babies of the same age (Gaither et al., 2012). Together these findings suggest that the interaction between the participants' perceptual system and face category drives performance differences between same- and other-race face processing, and it directly depends on the amount of experience that infants acquire in their surroundings.

While much of the investigative effort has been directed to determine the effect of face species and face race attributes on the development of face processing abilities, few studies were devoted to the examination of how infants represent face gender. In a series of experiment, Quinn and collaborators (2002) verified the spontaneous preference for male and female faces in 3- to 4-month-old infants, finding that participants reared by female caregivers preferred to look at and show recognition advantages for female but not for male adult faces. On the other hand, participants reared by male caregivers tended to show spontaneous preference for male than female adult faces (Quinn et al., 2002). Hence, gender should be considered an additional area in which Perceptual Narrowing may operate. Since experience exerts a large influence on the trajectory of perceptual narrowing, understanding the perceptual inputs received by infants is the key to understand the perceptual abilities and patterns of narrowing displayed by infants. Through parent reports (Rennels, & Davis, 2008) and by means of a head-mounted camera (Sugden, Mohamed-Ali, & Moulson, 2014), it has been suggested that infants' natural daily exposure to different face types is mainly focused on faces of the same race, gender, and age as their primary caregiver. Indeed, during the first three months of life, infants spent 25% of their waking hours exposed to faces that were primarily female (70%), own-race (96%), and adult-age (81%) faces. Such predominant experience with attributes that reflect those of infants' primary caregiver, constrains their visual system leading to the emergence of the above-mentioned biases.

Within this scenario, face age is an additional area in which perceptual narrowing has been investigated. During the first months of life, infants are primarily exposed to adult-age faces (81% of all face exposure, reported by Sugden et al., 2014). Because of this asymmetry, a discrimination advantage for adult over infant faces has been found to emerge in infants between 3 and 9 months of age (Macchi Cassia, Bulf, Quadrelli, & Proietti, 2014). Similarly, discrimination of adult faces but not of child faces was observed in 3- and 9-month-old infants in the absence of any additional experience with children. The same developmental pattern has been recently observed in 9-month-old Asian infants, who showed to selectively discriminate adult faces and exhibited enhanced right hemodynamic responses to own-race adult compared to infant faces (Kobayashi, Macchi Cassia, Kanazawa, Yamaguchi, & Kakigi, 2018). Moreover, perceptual experience provided by everyday contact with an older sibling from birth affects infants' processing of child faces by 9 months, allowing them to generalize their discrimination skills to child faces (Proietti, Rigoldi, Croci, & Macchi Cassia, *submitted*). A series of studies on subsequent developmental stages have shown that, similar to adult participants, 3-year-old (Macchi Cassia, Kuefner, et al., 2009; Macchi Cassia, Pisacane, & Gava, 2012) and 6-year-old children (Macchi Cassia, Proietti, & Pisacane, 2013) manifest the processing advantage for adult faces compared to other-age faces, including those of peers (Macchi Cassia et al., 2012). Like for species, race, and gender, the discrimination advantage for adult faces in infancy was interpreted as resulting from a process of perceptual narrowing, by which face discrimination abilities narrow towards the faces that are more frequently represented in the infant's environment.

Altogether, this evidence seems to speak in favor of a “caregiver bias” so that, by the end of the first year of life, infants face processing abilities are tuned toward a better elaboration of human adult faces with race and gender of the primary caregiver. However, it seems difficult leading the search for a single underlying mechanism of developmental changes of all face-processing biases. First, because for some attributes early experiences appear to be critical for organizing face-processing biases (e.g., species and race biases), while for others early experiences are important, but they frequently vary as the age increases (e.g., age- and gender-related biases). Second, because both the specificity of timing and the quality of experience that is needed to shape face-processing skills appear to influence the developmental trajectories of the various face-processing biases. For example, perceptual narrowing may be particularly relevant to shaping some (e.g., species, race), but not all (e.g., age, gender) of the biases within a limited age range in infancy. That is, discontinuities in processing face attributes from infancy, through childhood and into adulthood are qualified by transitions between continuous and discontinuous aspects of the developmental trajectory. Such changes are largely influenced by transitions in specific developmental tasks that ultimately reflect the adaptation to both ontogenetic periods and sociocultural expectations (Scherf, & Scott, 2012). These age-appropriate developmental tasks are derived from the social, emotional, contextual aspects of an individual’s environment and the solution to these problems defines in the end the characteristics of the perceptual system across ages (Picci & Scherf, 2016).

The studies presented in the following chapters aim to investigate how perceptual experiences with caregiver facial attributes shape face processing abilities in both infants and children, and whether the perceptual system of preschool-aged children changes its sensitivity to different social attributes of faces (i.e., race and gender) based on age-appropriate developmental tasks. By means of multimethod approach, studies here presented will explore the effects of early experience on shaping discrimination and recognition performances, visual scanning patterns and neural underpinning of faces biases throughout development. Specifically, it will be discussed how massive experience with adult faces tunes perceptual discrimination and modulates the gaze pattern on exploring adult and child faces in infants at the end of the first year of life (Study 1), and how multiple experiences, especially those with peers and siblings, influence the age-bias in preschoolers (Study 2). In two other studies, it will be explored the modulation of both race and gender attributes over the gaze exploration (Study 3) and the neural underpinning (Study 4) of face discrimination in children from 3 to 6 years.

Chapter 1 will examine the age-bias at different stages of the development, focusing on the discrimination and recognition of adult and child faces in 10-month-old infants and 5-year-old children, respectively. Previous investigation of the effects of early experience with adult faces in infancy reported that the perceptual tuning toward adult faces occurs between 3 and 9 months of age, which is the same time window during which perceptual narrowing for species and race is known to occur. Perceptual attunement towards highly prevalent stimuli in the environment is also matched with a decline in infants’ responsiveness to less relevant, non-native or infrequent stimuli. Likewise, by the end of the first year of life infants with massive experience with adult faces exhibit selective discrimination abilities for adult faces when compared to non-adult faces (Macchi Cassia et al., 2014; Proietti et al., *submitted*). The goal of Study 1 was twofold. First, the selective novelty preference for adult faces in first-born infants of 10 months was examined by using an infant controlled visual habituation procedure. Second, it was compared the visual pattern strategy implemented in the exploration of adult and child faces and it was explored the relation of those patterns to infants' discrimination performances. Study 2 was aimed to extend evidence of the age-bias in childhood by comparing perceptual recognition, assessed with a two-alternative forced-choice (2-AFC) match-to-sample task, and gaze strategies used for learning adult and child faces in 5-year-old children. In childhood, findings on the age-bias are mixed. Some evidence reported that school-aged children show superior recognition for faces within two years of their chronological age compared to younger and older faces (Hills & Lewis, 2011), and that the exploration of other-age faces is qualitatively different to the viewing of own-age faces (Hills, & Wills, 2016). On the other hand, a specific perceptual bias for adult-age faces was found in 3- to 4-year-old children without an older sibling, while this effect seemed to be extended to child-age faces in children with an older sibling (Macchi Cassia et al., 2012). By tracking the gaze movements of 5-year-old children with and without older siblings, it was investigated participants' recognition performances and strategies used in learning adult and child faces with upright and inverted orientation. The aim was to verify how heretofore amount of experience with faces of different ages influences children's recognition skills. Moreover, it was explored the relation between task performances and the principal measures of participant temperament defined by a parent-report questionnaire (Child Behavior Questionnaire – CBQ, Rothbart)

Chapter 2 will focus on the exploration of two other social attributes, namely face race and face gender, in shaping processing abilities for faces in preschool-aged children. Previous studies with infants suggested a hierarchy of face processing in which some social attributes receive priority over others. In particular, both Asian and Caucasian 3-month-old infants are reported to prefer female over male faces of the own-race, but not of the other-race (Quinn et al., 2008; Liu, Xiao, Quinn, et al., 2015). Although, the role of different social attributes on faces recognition advantage for adult faces is not fully understood in infancy, there is even less evidence on their influence on face processing system during childhood. Study 3 specifically aimed to compare the children’s face scanning of female and male, own- and other-race faces with upright and inverted orientation, in order to verify if specific strategies are used for those faces that have the characteristics of the primary caregiver. Moreover, using a multi-method approach for analyzing the eye-tracker data, it was investigated if race and gender are explored by children in parallel or in hierarchal way, in which one of the two attributes is prioritized over the other. Study 4 extended the investigation of Study 3 by providing the first examination of neural categorization of race and gender attributes by measuring the steady state Visual-Evoked Potentials (ssVEPs, for a review see Norcia, Appelbaum, Ales, Cottereau, & Rossion, 2015) in 3- to 5-year-old children. The issue of the categorization of social attributes during childhood was addressed by means of a fast periodic visual stimulation (FPVS) approach, verifying how the amount of experience with female faces of the same race of the primary caregiver affects the children’s cortical activity.

In the General Discussion I will combine the evidence provided by Studies 1 to 4 to draw an overall picture of how perceptual experience provided by the social environment at different times in development affects face processing abilities. I will underline how different behavioral and neural procedures and techniques can provide information about developmental changes in face processing and allow defining how the face processing system adapts to reflect both changes in environmental inputs and each individual-specific developmental task.

CHAPTER 1

The impact of early social experience on visual exploration and perceptual recognition of adult and child faces in infants and children

There is ample evidence showing that experience provided by infant's social environment greatly contributes to the development of face-processing abilities. Within the first year of life, face discrimination and recognition abilities become more selective as a function of experience with distinct face categories defined by species (Pascalis et al., 2002), race (Bar-Haim, Ziz, Lamy, & Hodes, 2006; Kelly et al., 2007), gender (Quinn et al., 2002), and age (Macchi Cassia, 2011). Notably, around 9-12 months of age infants' perceptual system is tuned toward faces displaying the same race, gender and age of the primary caregiver. Such tuning process has been interpreted as caused by the natural asymmetries in the amount of experience that infants accumulated with different face types (Rennel, & Davis, 2008; Sugden et al., 2014). Moreover, it has been reported that visual training with unfamiliar face categories (other-species faces: Pascalis et al., 2005; Scott, & Monesson, 2009; other-race faces: Anzures et al., 2012; Heron-Delaney et al., 2011) holds open the perceptual window for less experienced faces in natural environment. This evidence together suggests that perceptual narrowing reflects each infant's individual experience with faces during the first months of life.

The face age is one of several attributes that is rapidly extracted from faces by adults and children (Rhodes, 2009), and that affects how faces are both encoded (e.g., Kuefner, Macchi Cassia, Picozzi, & Bricolo, 2008; Macchi Cassia, Kuefner, Picozzi, & Vescovo, 2009) and remembered (e.g., Anastasi & Rhodes, 2005; Wright & Stroud, 2002). Therefore, age attribute gives rise to biases in different aspects of face processing in a similar way as other facial information does (i.e., race, gender, emotional expression). Consistent with previous findings about perceptual narrowing for faces of the most experienced species (Pascalis et al., 2002) and race (Kelly et al., 2007, 2009), infant at 9 months show selective discrimination abilities to faces of the most experienced age group, namely adults (Macchi Cassia et al., 2014). Thus, the bias toward adult faces seems to emerge in infants' face representational space within the same time frame during which other biases in infants' face processing have been shown to emerge (Cashon & DeNicola, 2011; Nelson, 2001; Scott et al., 2007).

In this respect, using an infant-controlled habituation procedure Macchi Cassia and colleagues (2014) compared 3- and 9-month-old infants' discrimination of adult and non-adult faces (i.e., infant faces). Results showed that 3-month-old infants exhibited above chance discrimination of adult and infant faces, whereas 9-month-olds showed reliable discrimination of adult faces but chance-level discrimination of infant faces. Similarly, Proietti and colleagues (*submitted*) showed that, in absence of sibling experience, 9-month-old infants showed reduced ability to discriminate among child faces, whereas the discrimination of those faces was still evident at 3 months (Experiment 2, Proietti et al., *submitted*). Such bias toward adult faces has been recently observed also in studies that examined the neural underpinnings of face age processing. Indeed, by the end of the first year of life, Asian infants showed enhanced right-hemisphere activation in response to own-race adult faces compared to infant faces (Kobayashi et al., 2018). Likewise, infant face-sensitive ERP components showed sensitivity to adult but not to child faces in Caucasian 9-month-old infants with limited experience with children (Conte, Proietti, *submitted*).

Although the adult face advantage is reported to typify infants' face-processing abilities, recent studies have provided evidence that natural exposure to a sibling's face since birth is capable to modulate infants' face-processing behavior. That is, 9-month-old infants showed to equally well discriminate among adult and child faces (Proietti et al., *submitted*) and exhibited specific neural responses when compared to fist-born matched-age infants (Conte, Proietti, *submitted*). Taken together, these results point out the role of early natural experience acquired in the context of social interactions in preserving the plasticity of perceptual processes and neural networks involved in face processing. Further, such studies underline how infants' perceptual system adapts to preferentially process day-to-day encountered face types.

All in all, previous research makes clear that the processing of different categories of faces changes systematically during development. Beginning with a more general ability to discriminate all kinds of faces, infants' processing abilities progressively narrow towards a more specific processing and discrimination of those classes of faces that have been most common in the infant's environment (Le Grand, Mondloch, Maurer, & Brent, 2001). Thus, with age and experience, infants and then children representation of face information becomes more holistic and configural (Carey & Diamond, 1994; Maurer, Mondloch, & Lewis, 2007; Mondloch, Pathman, Maurer, Le Grand, & de Schonen, 2007; Tanaka & Farah, 1993). In spite of this, recent evidence from studies using head cameras suggests that the cumulative hours of face exposure does not follow a linear increase during the first year of life, but it increases at a much slower rate than the number of infants' waking hours. This means that very young infants' waking hours are more densely filled with faces than are older infants, whose waking hours are more often filled with other kinds of visual entities (e.g., hands, toys, objects). Moreover, the face experiences are more frequent front-loaded earlier than later in infants' visual experience. Thus, the representation of the prototypical facial pattern is recurrent during the first months of life, while it seems to decrease late in development (Fausey, Jayaraman, & Smith, 2016; Jayaraman, Fausey, & Smith, 2015). Such variability in the amount of experience with faces could be considered one of the factors that produces developmental changes in face-processing behavior.

Recent evidence also suggests that the developmental course of face-processing behavior could be accounted by the influences of both the amount of facial experience and the age-appropriate social developmental tasks. That is, in infancy the need to form an attachment relationship with a caregiver involves seeking proximity and drives infants' perceptual system to discriminate the primary caregivers from all the other people. Such social developmental task makes adult female faces the most socially and emotionally relevant of all faces in young infants' world, and therefore influences the strength and magnitude of face recognition biases (Scherf & Scott, 2012).

The role of early experience with faces in shaping face processing biases has been explored also in studies conducted with older children (de Heering et al., 2010; Sangrigoli & De Schonen, 2004). With respect to the encoding of face age attribute, studies that explored preschoolers' processing abilities aimed to verify whether experience with multiple face ages (e.g., exposure to sibling's face) or changes in the amount of experience with different ages (e.g., due to the daycare attendance and growing interactions with peers) allow perceptual system to extend discrimination ability to faces of different ages.

Hereof, in two different studies, Macchi Cassia and colleagues (Macchi Cassia, Kuefner et al., 2009; Macchi Cassia et al., 2012) tested 3-year-old children with and without a younger or an older sibling for their ability to discriminate among adult and infant or child faces, respectively. Results showed that children with a younger sibling were equally skilled at discriminating adult and infant faces, and exhibited an inversion effect of comparable magnitude for both face types (Macchi Cassia, Kuefner et al., 2009, Experiment 1). Likewise, the discrimination ability of 3-year-olds with an older sibling compared with that of first-born children, showed comparable and a generalized inversion effect for adult and child faces (Macchi Cassia et al., 2012). Similarly, at 6 years, children with a younger sibling seemed to be equally skilled at differentiating among adult and infant faces, and showed a generalized inversion effect for the two ages, irrespective of when exposure to the sibling face began (Macchi Cassia, Proietti, Pisacane, 2013). Even though it has been suggested that social experience of young children is more biased toward caregivers and other adult individuals than peers (Macchi Cassia, 2011; Scherf & Scott, 2012), there is evidence that few additional years of experience with child faces allow participants to better recognize own-age faces. Indeed, 7- to 9-year-old children demonstrated an efficient recognition and specific visual scanning of own-age faces (Hills, & Lewis, 2011; Hills, & Willis, 2016). It seems reasonable that quantitative and qualitative variations of face age experience during preschool age exert an effect on processing abilities of face age attribute, so that children's face representation adapts to reflect the individual's specific living conditions and social experiences. Moreover, the social developmental task of childhood drives children on learning self-mastery while they are still depending on primary caregiver. This leads children to develop additional significant relationships with other individuals (e.g., teachers and peers), and heads their representational space for faces to self-organize in order to reflect the perceptual characteristics of other individuals (Picci & Scherf, 2016; Scherf & Scott, 2012).

Study 1 and Study 2 add evidence on the development of age bias by investigating the visual exploration strategies of adult and child faces in both infants and preschoolers. Specifically, Study 1 investigated 10-month-old infants' ability to learn and discriminate adult and child faces as well as infants' scanning of faces. Indeed, it was examined the infants' looking behavior, recorded by means of an eye-tracker, during free scanning of adult and child face ages, with emphasis on exploration pattern of the whole face as well as gaze movements towards major internal features (i.e., eyes, nose, and mouth). Moreover, it was examined the relations between visual strategies used for encoding faces and subsequent discrimination of adult and child faces. Study 2 investigated the impact of early experience on the age bias in children, exploring how frequent exposures to and interactions with sibling affect scanning strategies and recognition abilities for adult and child faces in 5-year-old children. In order to gain a more comprehensive picture of the aspects that could modulate children’s face-processing behavior, it was investigated the influence of both environmental variations (i.e., the amount of experience with faces) and individual differences of temperamental traits on encoding and learning adult and child faces. Thus, the aim of Study 2 was threefold: (1) to compare the recognition of own-age faces and adult faces in first-born children and in children who were exposed to child faces since birth; (2) to investigate the visual exploration of stimuli; (3) to explore the relation between child’s temperamental traits and visual scanning behaviors.

Study 1[‡]

Looking behavior and perceptual recognition for adult and non-adult faces in 10-month-old infants

Aims

The aim of the current study was to compare discrimination accuracy and visual exploration strategies used by infants during the encoding of adult and child faces. Infants were tested at 10 months, that is immediately after the end of the time-window in which perceptual narrowing has been reported to occur (for a review see Maurer & Werker, 2014). The specific aim of the current study was twofold: (1) to investigate visual scanning strategies used by 10-month-old infants for learning adult and child faces, and (2) to examine how infants' scanning behavior relates to the adult and child discrimination. To address these questions, first-born 10-month-old infants completed an eye tracking study comprising a between- subject, infant-controlled habituation paradigm where infants viewed adult or child faces. It was predicted that infants would discriminate adult faces but not child faces, and they would use specific scanning strategy for exploring the most commonly experienced face age.

[‡] This study was carried out in collaboration with Prof. Macchi Cassia and Prof. Hermann Bulf, at the University of Milano-Bicocca. Data analyses were conducted in collaboration with Dr. Valentina Proietti, Post-Doctoral Associate at Nipissing University, North Bay, Ontario.
Results were presented at the Annual Meeting of the British Psychology Society-Developmental Section, Nottingham, January 2016 and at the Workshop on Early experience and sensitive periods in development, Erice, September 2016.

Method

Participants

Forty-four first-born infants between 9- and 12-months (23 males; M_{age} = 309 days; SD_{age} = 21 days; $range_{age}$ 275 - 360 days) were randomly assigned to one of two groups depending on the age of the face to which they were habituated. Twenty-three additional infants were excluded due to fussiness (13), technical problem (2), bad calibration data (4), or because they did not reach the habituation criterion (4). All infants included in the analyses were Caucasian, full-term born and had no neurological or visual problems. Participants were recruited via a written invitation that was sent to parents based on birth record provided by neighboring cities. All parents gave their written consent and filled out a questionnaire with general demographic inquiries and contact questions aimed at assessing the amount of experience that infants had acquired with female and male adult individuals and specific enquires aimed at assessing if, in the past 9 months, their infants have had contact with children aged between 2 and 6 years. The questionnaire confirmed that, on average, infants in the sample spent 75% of their waking time with female adult individuals. Specifically, all infants except 3 spent at least 60% (M = 78%, range = 60% – 90%) of their waking hours with a female adult caregiver, while 3 infants had equal exposure (50%) to male and female caregivers. Moreover, all infants had no more than 8 hours of experience per week (M= 1.5 h/week, range= 0-8 h/week) with children aged between 2 and 6 years. The protocol was carried out in accordance with the ethical standards of the Declaration of Helsinki (BMJ 1991; 302: 1194) and approved by the Ethics Committee of the University of Milano-Bicocca.

Stimuli

Stimuli consisted of digitized, high-quality colored images of 4 young adult female faces (20-23 years old), and 4 child faces (3-6 years old), all of Caucasian origin and displaying a front neutral expression with open eyes. Gender was kept constant for adult faces because participants included in the sample had more exposure to female than male faces, and previous studies have shown that by 3 months of age infants develop a processing advantage for faces of the same gender as their primary caregiver (Quinn et al., 2002; Ramsey-Rennels & Langlois, 2006). No efforts were made to keep gender constant for child faces because biometric and morphometric studies suggest that stable inter-individual patterns of sexual dimorphism in facial morphology are not yet apparent during early childhood (Bulygina, Mitteroecker, & Aiello, 2006; Farkas, 1988). Faces were paired based on subjective criteria of perceptual similarity. Using the software Adobe Photoshop, faces were cropped using an oval shape in order to block out the hairline and the external features (i.e. ears and neck) that could be used as an identifying feature, and were pasted on a grey background (Figure 1.1). To reflect the natural differences in the size and shape of real adult and child faces, adult face stimuli were slightly taller and thinner than child face stimuli. In fact, adult faces subtended a vertical visual angle of 8.83° and a horizontal angle of 5.72°, and child faces subtended visual angles of 7.94° and 5.72° when viewed from approximately 60 cm. When presented side by side on the computer screen during test trials, the two stimuli were 10.15° apart.

Figure 1.1 Representative stimuli of adult and child faces used in Study 1

Apparatus

Infants were tested in a dedicated darkened and sound attenuated cabin. They were placed in an infant seat at approximately 60 cm from a 24-inch computer screen where the stimuli were presented. Eye movements were recorded with an Applied Science and Laboratories (ASL) Eye-Trac 6 eye-tracker with a sampling rate of 120 Hz. The infrared camera that automatically detected the pupil and corneal reflection of an infrared light source was located at the bottom of the computer screen on which the stimuli appeared; the system recorded X and Y coordinates of the eye position for event codes indicating both the start and end of each trial, and the stimulus presented. Stimuli presentation and data collection were performed using the software E-Prime 2. Moreover, the whole experiment was recorded through a video camera, hidden over the screen, which fed into a TV monitor and a digital video recorder. The session was coded online by one of the experimenters, who was outside the testing cabin and blind to the stimuli presented to the infants. A second experimenter seated outside the testing cabin was involved in managing and controlling the eye tracker signal for the entire experimental session.

Procedure

Infants were tested in a visual habituation task with an infant-controlled procedure. The testing session started with a calibration phase during which the infant’s point of gaze was calibrated with colorful flashing geometrical figures that appeared one at time over nine locations (the four corners, the center and four locations along the screen edges half-way from the corners) across the screen. To catch the infants' attention each calibration target was associated to a sound. The experimenter judged a fixation at each calibration target as correct if the cross indicating the location of the gaze overlapped with the position of the calibration target being presented. Calibration’s accuracy was checked and repeated if necessary for a maximum of three times.

The experimental session began with a short animation displayed on a black background to direct infants’ attention toward the center of the screen. As soon as the infant fixated the screen and both the pupil and corneal reflection were stable, an experimenter turned off the animation and activated the stimulus, so that the habituation phase began. Face stimuli appeared centrally on the screen while the experimenter recorded infant’s looking time by holding the mouse's button whenever the infant fixated on the stimulus. Each habituation trial lasted until the infant looked away from the stimulus for more than 2 seconds, at which point the stimulus was automatically turned off and the attention getter appeared again in the center of the screen to re-attach the infant's attention before the subsequent trial. The infant was judged to have been habituated when, from the fourth trial on, the sum of participant’s looking time on three consecutive trials was 50% or less than the total of the first three trials (Slater, Morison, & Rose, 1985), with a maximum limit of 14 trials. Once this habituation criterion was reached and before showing the test trials, was presented a blank screen with a red dot flashing in the three positions of horizontal middle line of the screen, in order to check for potential calibration drifts. Then, a new attention getter was turned on and, as soon as the infant's gaze was in the middle of the screen, the test phase began. Infants were presented with two test trials with the familiar face paired with a novel face; each trial ended following the same criterion used for the habituation trials (2 s-look away). Left-right position of the stimuli on the screen was counterbalanced across participants on the first and reversed on the second test trial (Figure 1.2). Looking times and scanning patterns were recorded by the eye tracker.

A second observer coded frame by frame the digitized video of the infants' eye movements during test trials, yielding to an inter-observer agreement (Pearson correlation), as computed on total fixation times on the novel and familiar face across the two test trials, of $r = .95$. Both the experimenter and the second observer were blind to the left/right position of the familiar and novel faces on the screen. The preprocessing of eye-tracking data was performed using ASL Result Plus software, while all the statistical analyses were performed using SPSS Statistics 24.

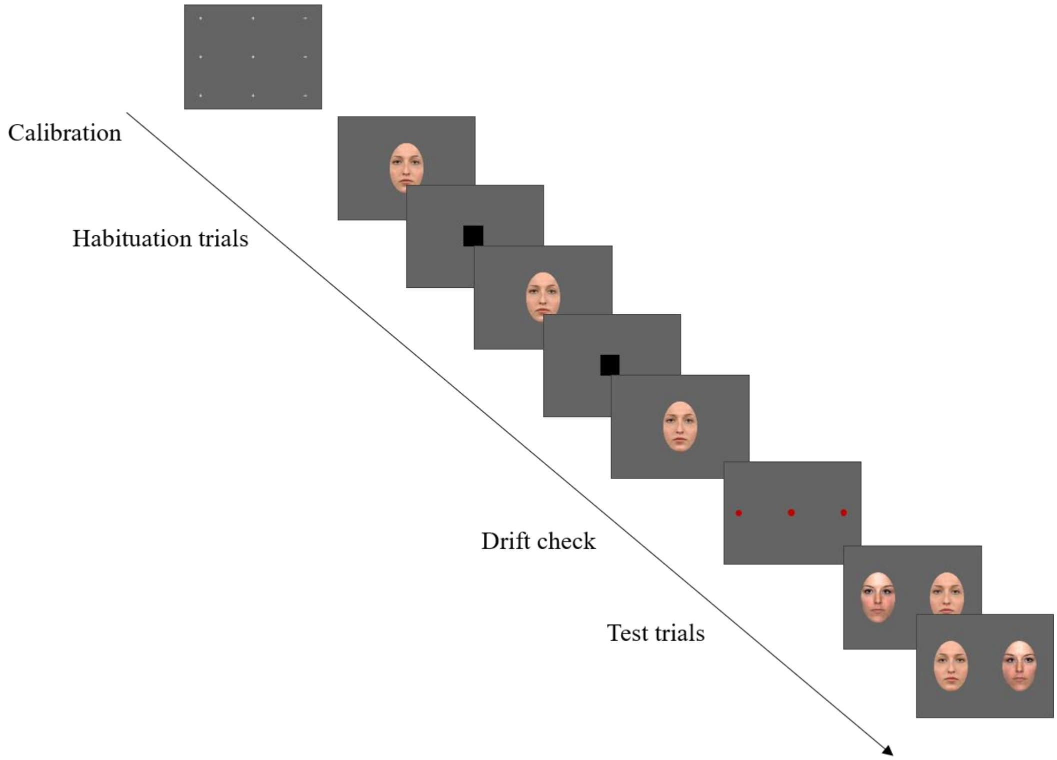

Figure 1.2 Representation (not drawn to scale) of the procedure in Study 1.

AOI definition and eye movement analyses

Participants' eye movement scanning behavior was analyzed for the habituation phase in order to test the prediction that looking behavior would differ for adult and child faces. Four areas of interest (AOIs) were defined for each face of the two age groups: the whole face, the eyes (right and left combined), the nose, and the mouth (see Figure 1.3). The three internal AOIs were equal in size and, together, covered 24% of the total area of the face (each AOI covered 8% of the face). Thus, the proportion of the face captured by the AOIs was held constant for adult and for child faces. Also, AOIs of internal facial features were slightly bigger than the corresponding feature, to allow for the sampling variations in eye tracking precision, and they were located to be non-overlapped each other.

Figure 1.3 Example of the AOIs that were centered on the face (yellow ovals), the eyes (red rectangles), the nose (green rectangles), and the mouth (blue rectangles).

Three measures were derived from eye movement data: the proportion of looking time on each AOI, the number of visits per second on each AOI, and the scan path amplitude. The first variable was created to provide a measure of the relative amount of sampling of each facial feature, while the second was created to index the dynamicity of visual processing across all AOIs. Proportional looking times provide a measure of the relative amount of sampling of each facial feature, and were calculated for each trial by dividing the total fixation time on each AOI (i.e., whole face, eyes, nose, and mouth) by total fixation time on the whole face (or on the screen for the whole face AOI). The total number of visits received by each AOI provides an index of the dynamicity of visual processing across the face, and was calculated by dividing the total number of visits (the number of times the gaze entered a specific AOI in a given trial) received by each AOI by total fixation time on the whole face.

The scan path amplitudes were calculated to provide a measure of the distance covered by fixation shifts within each trial (Ellis, Xiao, Naiqi, Lee, & Oakes, 2017; Goldberg, & Kotval, 1999), and were obtained by summing the distances between consecutive fixations performed within the whole face AOI in a trial. Given the difference in size between adult and child faces, proportional scan path amplitudes were created dividing each amplitude by the area of respective face. Moreover, because of the infant controlled nature of the present procedure, the scan path amplitude values were corrected by the total looking time on the whole face that each participant made in a trial. Adjusted values were averaged to obtain the mean distance covered by fixation shifts on both adult and child faces.

Results

Looking times

Habituation Phase. Habituation times (total looking time across habituation trials) were analyzed in a 2 X 2 analysis of variance (ANOVA) with trial (first three vs. last three habituation trials) as within-subjects factor and face age (adult vs. child) as between-subjects factor. Results revealed a significant decline in mean looking time from the first three (M = 172.06 s) to the last three habituation trials (57.93 s), $F(1,42) = 61.16$; $p < .001$, $p\eta^2 = .59$. No results involving the age of the stimuli were found (*ps* > .304). Total habituation time and number of trials to habituate were compared between infants tested with adult and child faces by means of two separate independent-sample t-tests. Results showed that, regardless of face age, infants required similar time ($t(42) = .29$; $p = .770$, $d = .09$) and number of trials ($t(42) = -.72$; $p = .474$, $d = .22$) to habituate.

Test Phase. To facilitate the comparison of looking times during test trials across the two groups, a novelty preference score was computed for each participant by dividing looking time toward the novel face by total looking duration toward both the novel and familiar face across both trials of the test phase and multiplying this ratio by 100. A group mean novelty score that is significantly different from the chance level of 50% reflects discrimination, whereas a score that is not different from 50% indicates a lack of discrimination; also, a novelty score above 50% indicates a preference for the novel stimulus, whereas a novelty score below 50% indicates a preference for the familiar stimulus. Novelty preference scores for adult and child faces were compared through an independent *t*-test, which attained statistical significance, $t(42) = 2.02$; $p = .050$, $d = .61$, indicating that infants spent a larger percentage of time looking at the novel stimulus when they were tested with adult faces ($M = 56.84\%$) compared to child faces ($M = 52.23\%$). One-sample t-tests (two-tailed) showed that the percentage of time spent looking at the novel stimulus was significantly above the chance level of 50% for infants tested with adult faces, $t(21) = 3.70$; $p =.001$, $d = 1.58$, but not for infant tested with child faces, $t(21) = 1.68$; $p = .11$, $d = .72$ (Figure 1.4). Two-tailed binomial tests revealed that the novelty preference scores were above 50% for 17 out of the 22 infants tested with adult faces (17 vs. 5, $p = .02$), and for 14 out of the 22 infants tested with child faces (14 vs. 8, $p = .29$).

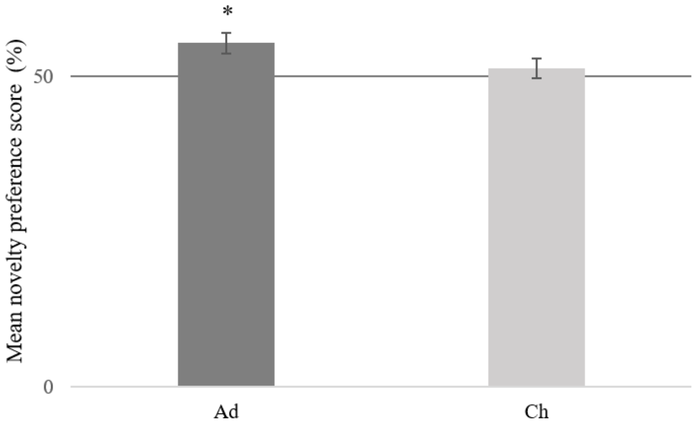

Figure 1.4. Mean novelty preferences (in percentage) for adult and child faces in test trials. Error bars represent the standard error of the means (* *p* < .05).

Scanning behavior during the Habituation Phase

Although total habituation looking times recorded through online coding (*M* = 918.90 s) were longer than total looking times on the whole face AOI recorded during habituation trials (*M* = 777.70 s), *t*(43) = -13.99; *p* < .001, *d* = .29, the two looking time measures were significantly correlated, *r* = .77, *p* < .001. Moreover, a repeated-measures ANOVA with face age (adult vs. child faces) as the between-subjects factor and trial (first three vs. last three habituation trials) as the within-subjects factor confirmed that total looking time on the face AOI during first three trials (*M* = 121.20 s) was significantly longer than the looking time of last three habituation trials (*M* = 33.90 s), *F*(1,42) = 40.17, *p* < .001, $p\eta^2$ = .49.

It should be noted that in order to obtain comparable subset of data for the two portion of the habituation phase, infants' scanning behavior during habituation trials was analyzed by comparing the first three to all the remaining habituation trials. In fact, the last three habituation trials were associated to a great loss of eye-tracking signal, resulting in a number of data points much smaller (19.85% of the total signal) than those obtained for the first three trials (57.33% of the signal) as well as for all the remaining trials (42.67% of the signal). The presence of a significant overall decrease in looking time from the first three habituation trials to all the remaining trials (*M* = 45.20 s) was confirmed by a 2 (face age: adult vs. child) x 2 (trial: fist three vs. remaining trials) repeated measures ANOVA, that showed the main effect of trial, *F*(1,42) = 27.10, $p < .001$, $p\eta^2 = .39$, in the absence of any effect involving the factor face age (p > .265).

To compare infants' scanning behavior during habituation to adult and child faces, the proportion of looking time and the number of visits per second on each AOI were entered in two repeated-measures ANOVAs with habituation trial (first three vs. remaining habituation trials) and AOI (eyes vs. nose vs. mouth) as within-subjects factors and face age (adult vs. child) as the between-subjects factor. A similar 2 (trial) x 2 (face age) ANOVA was implemented for analyzing the scan path amplitudes.

Proportion of total looking time. Independent t-tests revealed that participant spent the same amount of looking time on adult (*M* = .93) and child faces (*M* = .92), *t*(42) = .572; *p* = .570, *d* =1.02. The 2 (trial: first three vs. remaining habituation trials) X 3 (AOI: eyes vs. nose vs. mouth) X 2 (face age: adult vs. child faces) repeated measures ANOVA showed a main effect of trial, *F* (1,42) = 4.31; *p* = .044, $p\eta^2 = .093$, confirming longer viewing time at the beginning (*M* = .175) rather than during the final trials (*M* = .151) of habituation phase. Furthermore, a main effect of AOI was found, *F*(2,84) = 17.60; $p < .001$, $p\eta^2 = .32$, qualified by significant interaction with face age, *F*(2,84) = 3.22; $p < .045$, $p\eta^2 = .08$. Bonferroni-corrected, multiple-comparison tests revealed for child faces a smaller proportion of looking time on the mouth region (*M* = .035) compared to both the nose region (*M* = .146), *p* = .009, and the eye region (*M* = .328) $p < .001$. Also, nose area was explored for less proportion of time than the eyes area, $p = .009$, while between group comparisons showed that the mouth of adult faces ($M = .102$) was explored for longer time than the same area of the child faces, $p = .030$ (see Figure 1.5a).

Number of visits per second. Comparisons between the number of visits made on adult and child faces showed that child stimuli ($M = .78$) were overall explored making more visits than adult stimuli ($M = .56$), $t(42) = -2.75$; $p = .009$, $d = 1.12$. Moreover, the 2 (trial: first three vs. remaining habituation trials) X 3 (AOI: eyes vs. nose vs. mouth) X 2 (face age: adult vs. child faces) repeated measures ANOVA revealed that the main effect of AOI, $F(2,84) = 19.63$; $p < .001$, $p\eta^2 = .319$ was qualified by a significant interaction with the factor face age, $F(2,84) = 3.93$; $p = .023$, $p\eta^2 = .09$. Bonferroni-corrected comparisons revealed a similar pattern obtained for the looking time measure, indeed the mouth region ($M = .086$) of child faces was less sampled than both the nose region ($M = .299$), p = .007, and the eye region ($M = .592$) $p < 0.001$, and child nose was less sampled than child eyes, $p = .007$. Interestingly, between group comparisons showed that participants made less visits while encoding the mouth of child faces ($M = .086$) compared to adult faces ($M = .231$), while more visits for the eye region were made for child ($M = .592$) compared to adult faces ($M = .424$), $p = .039$ (see Figure 1.5b).

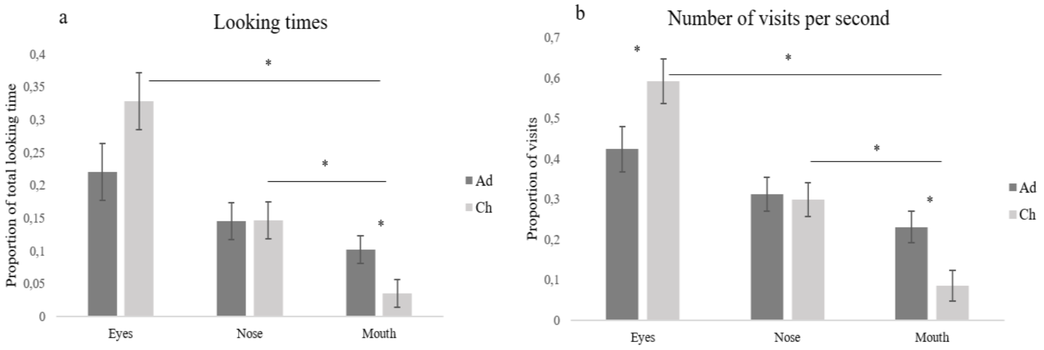

Figure 1.5. Proportion of looking time (a) and number of visits per second (b) recorded on all habituation trials plotted as a function of AOIs (eyes, nose, and mouth) for adult and child faces. Error bars represent the standard error of the means. (* $p < .05$).

Scan path amplitude. Analyses on scan path amplitude examined how far infants traveled as they shifted fixation from one location to another on the face. Such measure reflects different aspects of infants' eye movements than both looking time and number of visits per second, and therefore may provide insight into differences in processing that are not covered by how infants distribute their looking to regions of interest. Regardless of comparable amount of looking time of adult and child faces (see above), comparison between scan path amplitudes revealed that infants tested with adult faces ($M = .05$) had shorter scan path amplitude than did infants tested with child faces ($M = .07$), as revealed by main effect of face age, $F(1,42) = 8.21$; $p = .006$, $p\eta^2 = .16$. Thus, infants' scan path lengths varied as a function of face age, indicating that participants efficiently processed adult faces, since their scanning strategy seemed to maximally encode the facial information through focusing fixations on a small area of adult faces.

Relations between discrimination performance at Test and scanning behavior during Habituation.

To explore how visual scanning patterns at the beginning and the end of the habituation phase related to the ability to discriminate faces during test trials, the novelty preference score was correlated with the measures of gaze movement (i.e., proportion of looking time, number of visits per second and scan path amplitudes) on the critical areas (eyes and mouth) that differentiated the face age explorations. Unexpectedly, none of the correlations involving infants' behavior on looking at adult faces were significant. However, for child faces a positive relation between the novelty preference score and the number of visits made at the end of the habituation trials was found, $r = .593$; $p = .004$ (Figure 1.6). This result suggests that facility in child face discrimination stems from a dynamic visual exploration of those faces at the end of habituation trials.

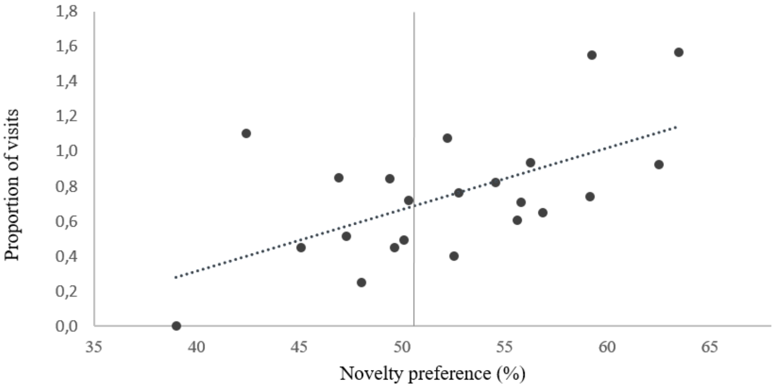

Figure 1.6. Scatter plot of the correlation between novelty preference score and number of visits during the second part of the habituation phase for infants tested with child faces.

Discussion

This study provides novel evidence on the impact of face age on infants' exploring behavior during a perceptual recognition/discrimination task. Specifically, the study here presented replicates earlier demonstrations of perceptual tuning toward adult faces, which emerges in infants' face representational space during the same time window in which other face processing biases have been shown to emerge (Cashon & DeNicola, 2011; Nelson, 2001; Scott et al., 2007). As found in previous studies aimed to explore the age bias in infants at the end of the first year of life (Macchi Cassia et al., 2014; Proietti et al., *submitted*), in the absence of sibling experience infants showed reliable discrimination of adult faces, but chance-level discrimination of non-adult faces (e.g., baby faces and child faces). Similarly, findings of the present study suggested that, when tested with an infant-controlled habituation task, 10-month-old infants exhibited discrimination of female adult faces, while no discrimination occurred for child faces. These results confirmed that when infants spend the majority of their waking time with their adult caregivers, their perceptual system tunes towards adult faces, leading to efficient discrimination between different exemplars from this face category. Indeed, participants in the current study were presented with female adult faces only, and most of them had a female caregiver and spent their waking time mostly with females (see participant section). In light of existing evidence that infants' gender preference is modulated by gender of the primary caregiver (Quinn et al., 2002), I would expect that the results of the current study would generalize to male adult faces if participants reared by a male caregiver would be tested.

Additionally, results from Study 1 extended evidence on infants' visual scanning strategies of adult and child faces and shed light on the role of perceptual experience in shaping the exploration of faces of different ages. Even though participants showed to overall less explore the mouth when compared to other internal features, and to make more frequent and lasting scanning of the eyes than the nose area, those differences involved mainly the scanning of child faces. Moreover, it was found that critical differences between the explorations of the two face ages concerned the eyes and the mouth. Indeed, data suggested that the eyes of child faces were more sampled than the eyes of adult faces, while infants directed their gaze and spent more time looking at the mouth of adult stimuli.

These results are partly at odd with findings of studies that verified scanning strategies involved in infants' processing of own- and other-race faces (Liu et al., 2015; Wheeler et al., 2011; Xiao et al., 2013). It is generally reported that, with increased age, infants show an advantage in scanning the upper-region of own-race faces, whereas the gaze for other-race faces is typically directs toward the lower-region (Liu et al., 2015; Xiao et al., 2013). It is also reported a decrease on both fixation shifts and viewing time of the mouth of the own-race when compared to the other-race faces (Wheeler et al., 2011; Xiao et al., 2013), which corresponds to an increase of the fixations toward the upper portion of own-race stimuli. Instead, results of Study 1 suggested that participants directed their attention toward the mouth of the most experienced face age and to the eyes of the less experienced face age.

This result fits well with the idea suggested by Scherf and Scott (2012) of the influence of age-appropriate developmental task on leading face processing abilities, which is ultimately linked to the role of early experience on shaping behaviors through the course of development. Hence, many studies reported an increase in performance for the native-language contrast between 6 and 12 months of age, and a decline in nonnative perception over the same time period (Best, & McRoberts, 2003; Kuhl et al., 2006; Werker, & Tees, 1984). This developmental pattern suggests that this period is characterized by significant changes in babies’ language acquisition, and it is concurrently associated to an increase in the vocal inputs that they receive from parents (Baldwin & Moses, 1996; Rollins, 2003). Even though for this study static images were used, it is likely that the infants’ perceptual system guides gaze movement toward the exploration of the mouth of an adult face, because such area is particularly influent for their current goal of acquiring language skills. As suggested by Lewkowicz and colleagues (2012), the need to refine speech categories could drive infant attention to the mouth (Lewkowicz & Hansen-Tift, 2012), thereby facilitating the development of holistic face processing.

Results of Study 1 indicate that asymmetrical amount of visual experiences with adult and child faces produces significant effects on infants’ discrimination performance as well as distinct scanning patterns of adult and non-adult faces. Nevertheless, the results do not allow to assert if the specific exploration of adult faces is related to participants’ discrimination ability of those faces, given that nonsignificant correlations between scanning patterns and novelty preference were found for adult face stimuli.

A previous study with adults (Proietti et al., 2015) revealed that gaze patterns for own-age faces (i.e., adult faces) involved a more dynamic sampling of the internal features compared to other-age faces. Analyses on number of visits per second in the current experiment revealed that infants used a more dynamic strategy when exploring non-adult compared to adult faces. Thus, it seems that in infancy the exploration of less encountered faces, namely child faces, requires more gaze shifts between internal features, with a strong preference for the eyes area. This strategy was also related to behavioral discrimination of child faces. That is, results of correlation analyses revealed that the few babies that showed a preference for the novel face used a dynamic strategy for exploring child faces during the final section of the habituation phase, which may reflect the acquisition of a functional strategy for discriminating faces.

By also examining infants' scan path amplitudes, additional conclusions were drawn on the role of early experience in shaping infants' scanning strategies of adult and child faces. Analysis of this measure revealed evidence of the use of mature strategies to scan adult faces that were explored with shorter amplitudes compared to child faces. This difference is consistent with adult work indicating that shorter scan path amplitudes reflect more sophisticated processing (Heisz & Shore, 2008; Hsiao, 2010), and with evidence from infant studies showing differences on quality of scanning for own- versus other-race faces at 8 months (Ellis et al., 2017). Specifically, Ellis and colleagues (2017) found that 8-month-old infants had significantly longer scan amplitudes on other-race faces compared to own-race faces, suggesting a more efficient processing of the more experienced face race (Ellis et al., 2017). Whereas the proportion of infants' looking time and number of visits towards specific areas of interest tells us how participants distribute their looking to different features, scan path amplitude reflects the distance traveled by the gaze between fixations. Thus, this measure tells us about differences in how much "territory" infants traveled as they scanned faces and gives additional evidence of the quality of face processing.

Taken together, the results from Study 1 confirm that massive exposure to adult faces during the first year of life shape infants' face-processing behavior toward a selective discrimination of adult faces. These results also suggest that the infants' perceptual system adapts to reflect the predominant age morphologies of those faces that are common and socially relevant in the infant's environment. The results cannot directly reveal whether qualitative characteristics (e.g., the quality of interactions or the development of attachment bond with the caregiver) of infants' daily experience exert influence on scanning strategies that they adopt in learning familiar versus unfamiliar faces. In spite of this, data from the present study revealed that infants do develop specific face-scanning strategies for adult faces that allow them to maximize the discrimination of such relevant category of faces. Further studies should assess whether infants' face-processing behavior is modulated by the characteristics of the relation with the caregiver and/or other qualitative aspects of social interactions.

Study 2[§]

Looking behavior and perceptual recognition for adult and child faces in 5-year-old children

Aims

The aim of Study 2 was to investigate the role of both early experiences with faces of different ages and temperamental traits on the processing of adult and child faces in 5-year-old children. In particular, previous researches showed that the processing of different categories of faces changes systematically during development. Thus, with age and experience, infants' and then children's representation of face information becomes tuned towards the classes of faces that have been most common in everyday environment (Kelly et al., 2007; Macchi Cassia et al., 2014; Pascalis, de Haan, & Nelson, 2002; Quinn et al., 2002). At the same time, individual differences in looking behavior are reported to relate with temperamental traits in infancy (Rose, Futterweit, & Jankowski, 1999) and in later childhood (Papageorgiou, Farroni, Johnson, Smith, & Ronald, 2015). Hence, variations in children's exploration of faces may be related to aspects of individuals' personality, like temperamental traits.

Given that, the study investigated the effect of early sibling experience on children's face-processing behavior, and specifically on perceptual recognition accuracy and visual scanning strategies for adult and peer faces. Previous findings showed a recognition advantage for adult faces in 3-year-old children without an older sibling (Macchi Cassia et

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[§] This study was carried out in collaboration with Prof. Macchi Cassia, at the University of Milano-Bicocca (UNIMIB). Data collection and analyses were conducted in collaboration with Dr. Elena Nava, Assistant Professor at the Department of Psychology, UNIMIB.

al., 2012), while school-aged children between 7- and 9-years of age are reported to better recognize peer faces when compared to faces belonging to both younger and older age groups (Hills & Lewis, 2011). The current study aimed to fill the gap in the literature by testing perceptual recognition and visual scanning strategies for adult and child faces in 5-year-old children. Moreover, earlier evidence shows that infant temperament influences performance in cognitive tasks (Rothbart, Posner, & Hershey, 2006), and that individual differences in infants' attention are predictive of behavioral traits later in childhood. That is, the ability to hold fixations for a longer period of time in infancy was reported as predictive of better effortful control, and less surgency and hyperactivity-inattention in later childhood (Papageorgiou et al., 2014). Thus, we investigated the association between individual differences in face-processing behavior and children's temperamental Surgency and Effortful Control.

Method

Participants

Participants were 21 5-year-old children without an older sibling (11 males, mean age = 4.7 years, range = 4.4 – 5.2) and 21 5-year-olds without one or more older siblings (11 males, mean age = 4.8 years, range = 4.4 – 5.3). An additional 14 children were excluded from the sample due to failure to complete the task (2), technical problem (3), inclusion criteria for analyses (2) or bad eye-tracking data (7). All children were recruited through a university database containing the contact information of parents who brought their children to the lab in their first year of life and agreed to be contacted again for later studies. At the time of testing all children were attending kindergarten, which they all started to attend after 3 years of age. They spent 6 to 10 hours per day (*M* = 7.71 hours) at preschool, and the average number of hours spent at preschool was similar for the two groups (no-sibling group:

M = 7.7 h; sibling group: *M* = 7.7 h). Within the sibling group, 3 children had two older siblings. The mean age of the youngest among the older siblings at the time of the participants' birth was 4.5 years (range = 2;9 – 6;0). All children were from middle-class Caucasian families, had no neurological nor cognitive issues, and had normal vision, as reported from parents. At the end of the testing session parents completed a short questionnaire with general demographic enquires, and contact questions aimed at assessing the amount of experience that children had acquired with female and male adult individuals and with siblings (i.e., children in the 3- to 6-years age range). The questionnaire confirmed that all children in the sample had the majority of their facial experience with female adult faces, as on average, 63% of their weekly exposure time to adult individuals was with female individuals. Moreover, the amount of experience accumulated with peers' faces outside school hours was similar for children in the sibling and no-sibling group, as one average, children in the two groups spent, respectively, 7.5 hours and 7.8 hours per week with children of relatives, friends or acquaintances. All procedures used in the study were in accordance with the Declaration of Helsinki and approved by the Ethics Committee of the University of Milano-Bicocca. Parents signed a written informed consent before the child was tested, and children provided their verbal consent.

Stimuli

Stimuli were created from digitized, high-quality images of 24 adult female faces (20 – 30 years old) and 24 child faces (3 – 6 years old), all of Caucasian origin. All faces were unfamiliar to the participants and displayed a full-front neutral expression with open eyes. Similar to Study 1, gender was kept constant for adult faces because participants included in the sample had more exposure to female than male faces, and previous studies have shown that by 3 months of age infants develop a processing advantage for faces of the same gender as their primary caregiver (Quinn et al., 2002; Ramsey-Rennels & Langlois, 2006). No efforts were made to keep gender constant for child faces because biometric and morphometric studies suggest that stable inter-individual patterns of sexual dimorphism in facial morphology are not yet apparent during early childhood (Bulygina et al., 2006; Farkas, 1988). Face images were manipulated in the same way as in Study 1: they were cropped in a standard oval and pasted on a gray background using the software Adobe Photoshop (Figure 2.1). Faces within each age category were cropped to obtain same size. To reflect the natural differences in the size and shape of real adult and child faces, adult faces were slightly taller and thinner than child face stimuli: they subtended a vertical visual angle of 9.33° and a horizontal angle of 5.87°, and child faces subtended visual angles of 7.57° x 5.87° when viewed from approximately 60 cm. An attempt was made to pair faces based on subjective criteria of luminance and overall similarity to generate 12 pairs for each face age. An additional 4 face images (2 for each face age) were used as stimuli in the practice trials. Inverted stimuli were created by rotating each face by 180°, so that each target face and test pair was shown twice, once upright and once inverted. When presented side by side on the computer screen during test trials, the two faces were 6.81° apart.

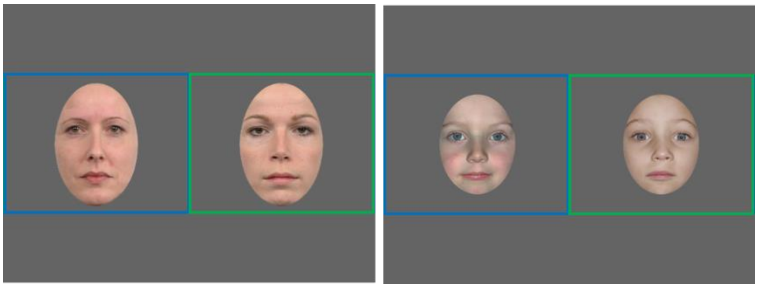

Figure 2.1 Examples of the adult and child faces presented to the children tested in Study 2. Participants responded by pressing the key associated to the color (blue or green) of the frame containing the familiar target face.

Apparatus

Participants were tested individually in a dedicated darkened and sound attenuated room. They sat on a child high chair in front of a 19-inches Samsung SyncMaster 1200 NF computer screen (resolution of 1024 x 768 pixels), on which the stimuli were presented, and their head location was fixed using a chin rest arranged about 60 cm apart from the eye-tracker camera. Eye movements were recorded using an infrared camera, Applied Science and Laboratories (ASL) model 504 Eye Tracker 6 system EYE-TRAC™ PC that was located at the bottom of the computer screen. Gaze direction was measured with x and y coordinates and sampled at a frequency of 50 Hz. Eye movements that were stable for more than 100 ms within a 1° of visual angle were classified as a fixation. Stimulus presentation and data collection were performed using the software E-Prime 2.

Procedure

Participants were tested individually in a single session of the maximum duration of 60 minutes; the parent was allowed to watch during testing, but was asked not to interfere and to sit in a corner of the room. Each child completed a delayed two-alternative, forced-choice matching-to-sample task. They were told that one face would appear on the screen and that they would be asked to recognize that face between two faces appearing after the initial presentation. On each trial, a target face appeared in the center of the screen for 3 sec, followed by a blank interstimulus interval (1500 msec) and then two probe stimuli, the target face and a novel face, that appeared side by side until the participant responded. Children were instructed to provide their responses by pressing a computer key, and the experimenter determined the start of the next trial by pressing the mouse. To help children select the correct key, colored frames were added to the probe displays. The colors of the frames corresponded to the color of the keys used to collect the response (blue on the left, green on the right). The target face and the two probes appeared in the same orientation. The left or right position of the target and novel faces was counterbalanced across trials.

Trials from each face age and orientation were presented in blocks, and participants completed one block of 12 trials for each condition (48 total trials). Upright and inverted trials were administered in two sessions separated by a short break. Face age was alternated between blocks, with the age of the faces in the first block counterbalanced across participants. All children familiarized with the task by completing four practice trials displaying cartoon faces. At the beginning of each session participants' eyes were calibrated to the eye-tracker. Calibration was achieved by asking the child to follow colorful flashing geometrical figures that moved to nine points on the screen (see Study 1). Calibration was successful for all participants at the first or second attempt. After calibration, participants completed 4 practice trials (2 for each face age condition). Responses on practice trials were followed by a feedback display consisting of either a thumb-up emoticon for correct responses or a thumb-down emoticon for incorrect responses. Response accuracy on experimental trials was recorded as the dependent variable.

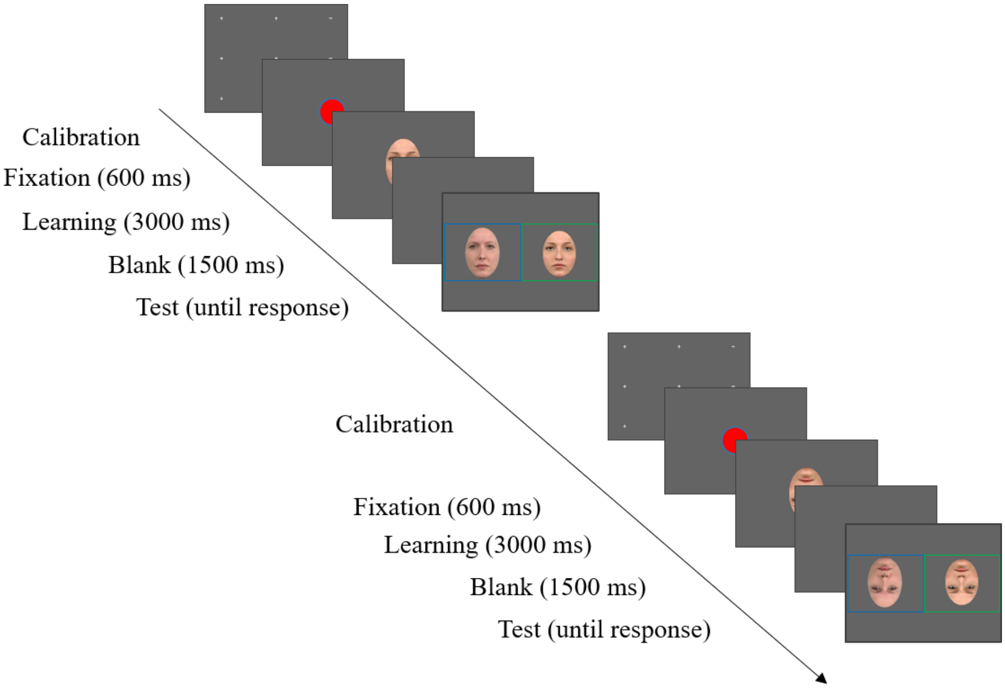

Figure 2.2 Representation (not drawn to scale) of the procedure in Study 2.

Child Temperament

Evidence has shown that infant temperament influences performance in various types of cognitive tasks (Rothbart, Posner, & Hershey, 2006). Moreover, recent studies have reported that behavior and temperament in preschoolers are influenced by factors already present at birth and individual differences in visual attention in infancy (Papageorgiou, Farroni, Johnson, Smith, & Ronald, 2015; Papageorgiou et al., 2014). As with most constructs shaped by developmental processes, the behavioral manifestation of temperamental traits changes over time, shifting from motoric displays of affects in infancy to withdrawn and subdued behavior in middle childhood. On the other hand, previous research indicates that there is continuity of attentional style from infancy to childhood (Rose, Feldman, Jankowski, & Van Rossem, 2012) and that individual differences in infant attention are predictive of behavioral traits later in childhood (Papageorgiou et al., 2014). Given that, the current study explored the relationship between participant's temperament and children's processing and attentional behavior to faces of different ages. To address this question, the visual scanning behavior was considered as a measure of child's ability to regulate and control attention to faces. Indeed, it has been proposed that the looking time duration could be a stable measure of individual differences in attention across both short and long test-retest intervals (Colombo, Mitchell, Coldren & Freeseman, 1991) and across different tasks (Castelhano & Henderson, 2008; Rayner, Williams, Cave & Well, 2007).

Data on children's temperament were collected using the Italian version of the Childhood Behavior Questionnaire (CBQ-sf translated by Giada Matricardi; Putnam, & Rothbart, 2006). The CBQ-sf is validated for children aged 3 to 7 years, and requires for the parent to report the frequency of particular behaviors on a seven-point scale ranging from 1 (Never) to 7 (Always). For the purposes of this study, two main temperamental dimensions were considered: Surgency and Effortful Control. Surgency is analogous to the personality trait of Extraversion and defined by high scores on approach, vocal reactivity, smiling and laughter, and high activity level. Effortful Control is analogous to Conscientiousness, and it is defined by positive loadings from inhibitory control, attentional focusing, low intensity pleasure (non-risk taking pleasure), and perceptual sensitivity.

AOI definition and eye movement analyses

Participants' eye movement scanning behavior was analyzed for the learning phase in order to investigate whether looking behavior would differ for adult and child faces as a function of sibling experience. The same set of areas of interest (AOIs) used in Study 1 were used for adult and child faces: the whole face, the eyes (right and left combined), the nose, and the mouth (Figure 2.2). As in Study 1, the proportion of the face captured by the AOIs was held constant for adult and for child faces. Two measures were derived from eye movement data for each participant: the proportion of looking time on each AOI and the number of visits per unit time (second) across all AOIs. For the whole face AOI the proportion of looking time was calculated for each trial by dividing the total fixation time on the whole face by total fixation time on the screen. To compare viewing times on the familiar and novel probes during the recognition phase, two AOIs were drawn considering the whole face: familiar face AOI, novel face AOI. The proportion of looking time for familiar and novel probes was computed by dividing looking time toward each probe by total looking time toward the novel and familiar probes.

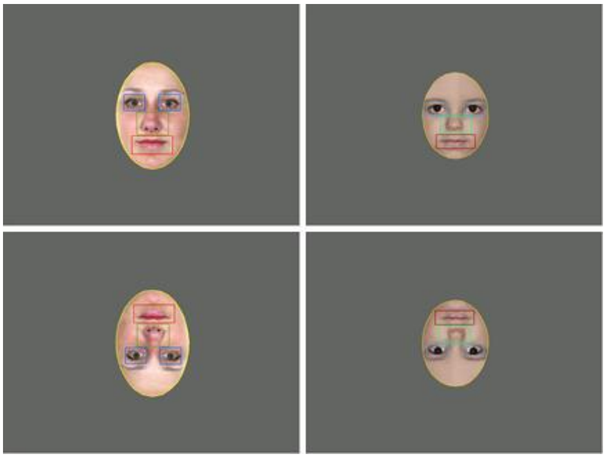

Figure 2.2 AOI sets used in Study 2. AOIs were centered on the face (yellow ovals), the eyes (blue rectangles), the nose (green rectangles), and the mouth (red rectangles).

Results

Recognition accuracy

To capture children’s ability to perceptually recognize familiar faces, all the trials in which participants were not paying attention to the screen during Learning phase were excluded from the analyses. Moreover, in the subsequent analyses were included only participants who had at least 7 good trials in each condition (2 participants excluded). Mean response accuracy (expressed in percentage) for each condition was calculated for each participant. One-sample *t*-tests confirmed that for both the sibling and no-sibling groups, accuracy rates were significantly above chance in all conditions (all *p*s < .001). To compare recognition performance of children in the two groups, it was conducted a preliminary Analysis of Variance (ANOVA) with group (sibling vs. no sibling) as the between-participants factor, face age (adult vs. child) and orientation (upright vs. inverted) as within-participants factors, and face-block order (child face first vs. adult face first) and orientation-block order (upright face first vs. inverted face first) as additional factors. Results did not reveal any main effect or interaction involving the factor block order. Therefore, data were collapsed across these factors in the subsequent 2 (Sibling Group) X 2 (Face Age) X 2 (Orientation) ANOVA. The analysis revealed a main effect of orientation, $F(1,40) = 7.82$; $p = .008$, $p\eta^2 = .16$, indicating that children in both groups were more accurate at recognizing upright faces (M = 78%) compared to inverted faces (M = 70%). The interaction between face age and orientation was nonsignificant, $F(1,40) = 2.96$; $p = .093$, $p\eta^2 = .07$. Although the magnitude of the inversion effect calculated by subtracting accuracy for inverted faces from that for upright faces (inversion score), was slightly larger for adult faces ($M = .11$) than for child faces ($M = .05$), the comparison did not reach significance, $t(41) = 1.53$; $p = .13$, $d = .24$ (Figure 2.4). No other main effects or interactions reached significance.

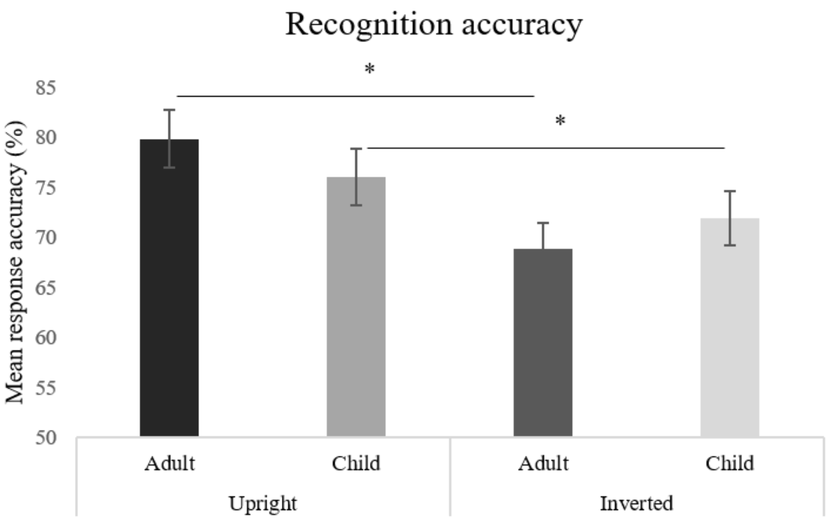

Figure 2.4. Mean response accuracy (expressed in percentage) for upright and inverted adult and child faces. (* $p < .05$).

Eye movement scanning behavior during the Learning phase

To test whether children' scanning behavior of adult and child faces during learning was impacted by sibling experience, the proportion of looking time and the number of visits per second on each AOI were entered in two repeated-measures ANOVAs with sibling group (sibling vs. no-sibling) as the between-subjects factor, and face age (adult vs. child), orientation (upright vs. inverted), and AOI (eyes vs. nose vs. mouth) as within-subjects factors.

Proportion of total looking time. A 2 (sibling group) x 2 (face age) x 2 (orientation) repeated measures ANOVA on the proportion of looking times on the whole face AOI revealed no main effects nor interactions (all *p*s > .12), indicating that all participants spent the same amount of time exploring all face categories, irrespective of face age and orientation.

To explore whether the distribution of children's looking times across the three internal AOIs (Figure 2.5a) differed for adult and child faces as a function of sibling experience it was conducted a 2 (sibling group) x 2 (face age) x 2 (orientation) x 3 (AOI) repeated-measures ANOVA. Results did not reveal any main effect or interaction involving the factor sibling group (all *p*s > .248). The ANOVA showed significant main effects of face age, $F(1,40) = 9.94$; $p = .003$, $p\eta^2 = .19$, orientation, $F(1,40) = 9.94$; $p = .003$, $p\eta^2 = .16$, and AOI, $F(2,80) = 11.97$; $p < .001$, $p\eta^2 = .23$. Children explored longer the internal AOIs when viewing adult faces compared to child face as well as inverted faces compared to upright faces; moreover, they spent more time looking at the eyes and nose AOIs compared to the mouth. These three main effects were all qualified by a significant three-way interaction, $F(2,80) = 6.71$; $p = .002$, $p\eta^2 = .14$, indicating that the distribution of children's looking times across the internal AOIs in the two stimulus orientation conditions differed for adult and child faces.

To further explore this interaction, separate 2 x 3 ANOVAs were performed on looking time measures for each orientation condition. For the upright condition there were significant main effects of face age, $F(1,40) = 4.56$; $p = .039$, $p\eta^2 = .10$, and AOI, $F(2,82) = 9.87$; $p < .001$, $p\eta^2 = .19$, as well a marginal Face Age x AOI interaction, $F(2,82) = 2.96$; $p = .058$, $p\eta^2 = .07$. Bonferroni-corrected, multiple-comparison tests revealed an overall smaller percentage of viewing time on the mouth region compared to both the nose region and the eye region for both face ages, *p*s < .006, with no difference in viewing time between the eye and the nose regions (*p*s > .282). The percentage of time that participants spent viewing the eye region was higher for adult faces compared to child faces, $p = .002$, whereas there was no significant difference between the two face ages on viewing time on the nose, $p = .699$, and mouth, $p = .320$.

The ANOVA for the inverted orientation condition revealed a similar pattern of results by showing the presence of significant main effects of face age, $F(1,41) = 9.83$; $p = .003$, $p\eta^2 = .19$, and AOI, $F\ (2,82) = 5.23$; $p = .007$, $p\eta^2 = .11$, as well as a significant Face

Age x AOI interaction, *F*(2,82) = 4.27; $p = .017$, $p\eta^2 = .09$. However, unlike upright faces, differences in viewing time between the internal AOIs were observed only for adult faces, with the mouth region being fixated for a shorter time compared to the nose, p < .001, (but not the eyes, $p = .239$). Moreover, unlike the upright orientation condition, in the inverted condition the differences between the two face ages was in viewing time on the nose, $p = .001$, rather than on the eyes.

Number of visits per second. The 2 (sibling group) x 2 (face age) x 2 (orientation) x 3 (AOI) repeated-measures ANOVA showed that the main effect of AOI, *F*(2,80) = 12.72; $p < .001$, $p\eta^2 = .24$, was qualified by a significant three-way interaction between face age, orientation and AOI factors, *F*(2,80) = 3.24; $p = .044$, $p\eta^2 = .08$. To further explore the interaction, separate 2 X 3 ANOVAs, one for each stimulus orientation, were performed on the number of visits per second. There were no significant main effect or interactions involving the factor sibling group (all *p*s > .263).

Results of upright faces revealed that the mouth AOI (*M* = .21) was less sampled than both eyes (*M* = .41) and nose (*M* = .56), *F*(2,82) = 6.50; $p = .002$, $p\eta^2 = .14$. In contrast, the sampling of adult inverted faces (*M* = .46) was greater when compared to child faces (*M* = .39), as suggested by main effect of face age, *F*(1,41) = 6.08; $p = .018$, $p\eta^2 = .13$. Moreover, a less frequent sampling of the mouth (*M* = .30) than nose area (*M* = .56) was made across face ages, as revealed by main effect of AOI, *F*(2,82) = 10.88; $p < .001$, $p\eta^2 = .21$. Both these main effects were qualified by a face age X AOI interaction, *F*(2,82) = 4.99; $p = .0109$, $p\eta^2 = .11$, that showed that for both adult and child inverted faces the mouth (adult faces: *M* = .29; child faces: *M* = .31) was less sampled than the nose (adult faces: *M* = .62; child faces: *M* = .49), *p*s < .001. Interestingly, the two face ages differed for the sampling of nose ($p = .014$) and eyes ($p = .010$), which were more sampled when children explored adult (eyes: *M*

= .47; nose: *M* = .62) than child faces (eyes: *M* = .38; nose: *M* = .49). Figure 2.5 depicts the distribution of the proportional looking scores (panel a) and the number of visits per second (panel b) on the eyes, nose, and mouth of upright and inverted faces during Learning phase.

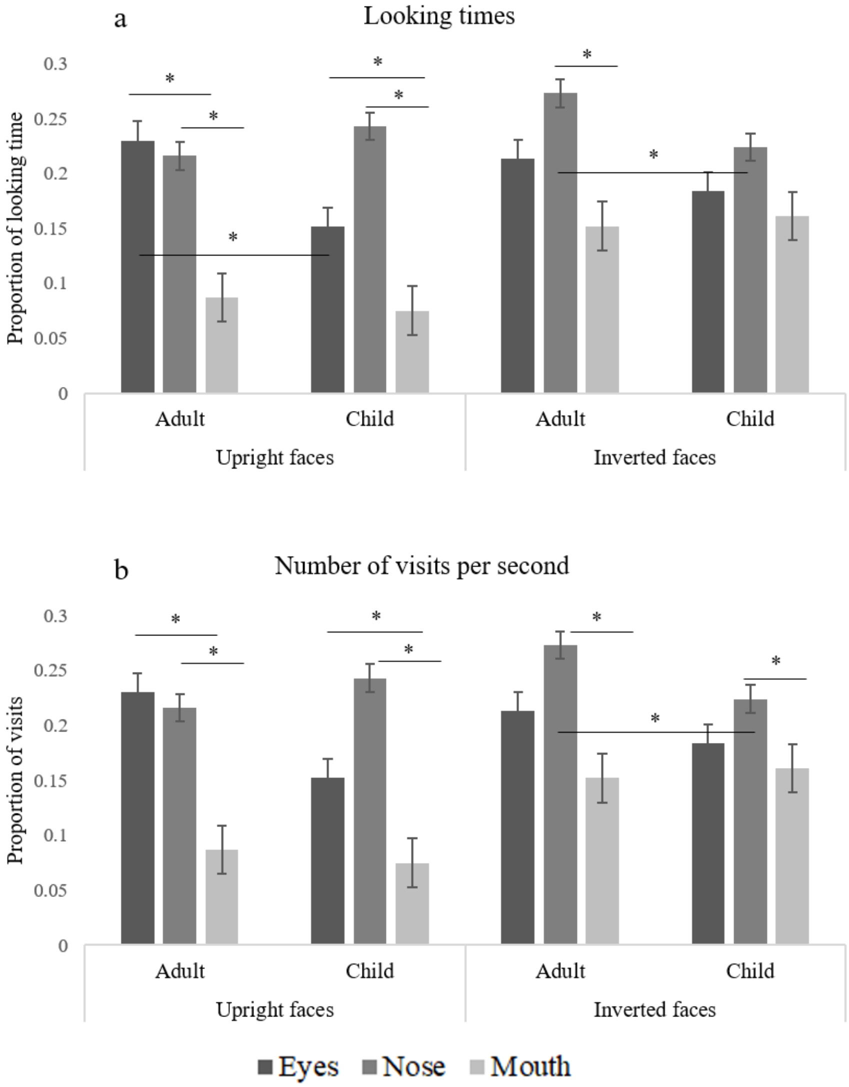

Figure 2.5. Distribution of proportional looking time (a) and number of visits per second (b) on the eyes, nose, and mouth regions of adult and child faces in the upright and inverted orientation. (**p*<.05).

Eye movement scanning behavior during the Recognition phase

To compare viewing times on the familiar and novel probes during the recognition phase it was performed a 2 (sibling group) x 2 (face age) x 2 (orientation) x 2 (probe type) repeated-measures ANOVA, which revealed a main effect of probe type, *F*(1,40) = 13.61; $p = .001$, $p\eta^2 = .25$, indicating that, irrespective of face age and orientation, familiar probes (*M* = .86) were explored longer than novel probes (*M* = .71). This effect was qualified by a spurious Probe Type x Face Age x Sibling Group interaction, *F*(1,40) = 3.99; $p = .053$, $p\eta^2 = .091$, for which follow-up comparisons failed to reveal any significant effect, *p*s > .106. No main effects or other interactions involving the factor sibling group attained statistical significance (all *p*s > .244).

Relations between scanning behavior and child temperament

The CBQ questionnaire was not filled in by all parents, thus the correlation analyses on children's temperamental traits were performed for only a subset of the sample (*N* = 32) composed of 15 children without siblings and 17 children with siblings.

Looking time behavior on upright faces presented during both Learning and Recognition phases were correlated to temperamental scales (i.e., Surgency and Effortful Control) of the short form of the Childhood Behavior Questionnaire parent report (CBQ-sf; Putnam and Rothbart, 2006). Preliminary analyses on the temperamental dimensions revealed that participants with and without siblings did not differ for the Surgency, *t*(30) = .99; $p = .331$, $d = .35$, nor Effortful Control *t*(30) = - .84; $p = .406$, $d = .34$. Therefore, temperamental values from these two groups were collapsed for all subsequent analyses.

For what concern children's visual scanning for upright faces during the Learning phase, the duration of looking times of both adult and child faces showed a negative relation with Surgency dimension (adult: $r = -.43$, $p = .014$; child: $r = -.43$, $p = .013$) and a positive relation with Effortful Control dimension (adult: $r = .43$, $p = .014$; child: $r = .36$, $p = .042$). The latter dimension positively related to the number of visits per second of adult faces, $r = .37$; $p = .036$, while Surgency values were positively related to the number of visits made on child faces, $r = .35$; $p = .047$. No significant correlations were found between temperamental traits and the familiarity scores of face exploration during the recognition phase, *p*s > .121.

Discussion

The present investigation focused on the age bias (Macchi Cassia, 2011) in face recognition, with special emphasis on the information gathering that preschool-aged children exhibit while learning adult and child faces, and on the effects that sibling experience may have in modulating visual scanning strategies. Previous evidence reported a recognition advantage for adult faces in 3-year-old children without an older sibling (Macchi Cassia et al., 2012). Such finding suggests that the massive exposure to adult faces, which lead to a better processing and discrimination of adult faces in infancy (Conte, Proietti, et al., *submitted*; Macchi Cassia et al., 2014; Proietti et al. *submitted*; Heron-Delaney et al., 2016; Kobayashi et al., 2018), keep tuning face representational space to human adult faces in childhood. However, face-processing behavior seems to rapidly change with age, due to increased experience and interactions with peers. Indeed, Hills and Lewis (2011) showed that school-aged children between 7- and 9-years of age are better in recognizing faces of their own-age (8-year-old faces) when compared to faces belonging to both younger and older age groups. Even though authors did not control for the presence of younger/older siblings nor for participants' amount of experience with other children, it is likely that, compared to earlier developmental stages, children's perceptual exposure to and interactions with peers are either equal or even more than the time that they spend with adults.

Furthermore, sibling experience has been shown to affect the extent to which children showed greater expertise at processing adult versus non-adult faces. Several studies with children of different ages (i.e. 3- and 6-year-olds) reported that perceptual learning engendered by sibling experience – with both older and younger siblings - affected their recognition performance, so they exhibited comparable magnitude of inversion effect for both adult and non-adult face ages (Macchi Cassia et al., 2012; Macchi Cassia et al., 2013).

In light of the significant role of experience with multiple face ages in shaping the age bias for both infants (Proietti et al., *submitted*) and children (Macchi Cassia et al., 2012; Macchi Cassia et al., 2013; Proietti et al., 2013), Study 2 focused on comparing recognition and face encoding in children with and without an older sibling. Several studies have investigated the face processing strategies in adults and children, considering an array of methodologies based on inversion, part-whole, and composite face effects (Diamond & Carey, 1986; Maurer, Grand, & Mondloch, 2002; Pellicano, Rhodes, & Peters, 2006; Tanaka, Kiefer, & Bukach, 2004). However, eye-movements may provide a different index of a functional face learning (Althoff & Cohen, 1999) and additional information about allocation of visual attention (Findlay & Gilchrist, 2003; Yarbus, 1965). Nevertheless, few studies to date has documented children’s face-processing behavior using eye-tracking recordings. The present study, therefore, sought to determine if 5-year-old children exhibit different recognition performance as well as visual exploration strategies when viewing adult and child faces. Literature findings suggest that individual differences in infants’ attention are related to infant temperament and associated to participant temperamental traits in childhood (Papageorgiou et al., 2015; Rose, Frutterweit, & Jankowski, 1999). It was, therefore, explored the relation between preschoolers’ visual scanning strategies and their temperamental traits, by the use of the parent-report CBQ-sf, in order to verify if different temperamental dimensions could influence the quality of exploration of faces in the recognition task.

Results of Study 2 revealed that 5-year-old children were equally proficient at recognizing adult and child faces, regardless of their sibling experience. The comparable magnitude of inversion effects for adult and child faces in children with and without older siblings is only apparently in contrast with previous studies that compared the recognition skills in children with and without siblings. By means of specific inquiries about face-to-face contact with other children, both same-age (3-6 years) and younger (0-2 years), parents reported that all children spend most of their day attending daycare, and seemed to have extra amount of interactions with peers. It is reasonable to assume that the increased amount of interactions with peers steers children’s face space towards a better processing of child faces, but at the same time, such experience was not enough for showing an own-age bias, as reported in older children.

Both participants with and without older sibling showed a similar recognition pattern found in previous study with younger children with older siblings (Macchi cassia et al., 2014). That is, regardless of early experience with siblings, 5-year-old children did show to be equally good at discriminating adult and child faces, exhibiting similar recognition abilities to 3-year-olds who accumulated experience with older sibling since birth (Macchi Cassia et al., 2012). Together, these results highlight the role of multiple face-age experiences in building face representation and face-processing biases. Notably, although the comparison did not reach significance, the magnitude of the inversion effect was greater for adult than child faces, showing that the extensive and continuous exposure to adult faces still exerts an influence at subtle level. Moreover, it seems that by the end of preschool age, children undergo a period of reorganization and qualitative change in their processing abilities of face age attribute.

Given the results of recognition performance, eye movement can be a useful measure to verify whether qualitative changes of face processing occur in preschoolers. Indeed, it has been suggested that the way the faces are categorized affects the way in which stimuli are scanned. Evidence from adult studies revealed that the main difference in exploring own- and other-race faces concerned the fixations made to the nose that is more sampled in other-race faces than own-ethnicity faces (Caldara, Zhou, & Miellet, 2010; Goldinger, He, & Papesh, 2009). It has also been established that young and older adults scan own-age face more than other-age faces (Ebner, He, & Johnson, 2011; He, Ebner, & Johnson, 2011), and that, in young adult participants, long exploration of the nose area is positively related to successful subsequent recognition (Firestone, Turk-Browne, & Ryan, 2007). Moreover, Proietti and collaborators (2015) explored with an old/new task the infant-novice adults' scanning behavior of adult and baby faces. Results revealed that the own-age bias in recognition was attended by differential scanning patterns and consequently differential encoding strategies, for own- compared to other-age-faces. Specifically, adults used a more dynamic strategy for and longer looking at the eye region of own-age faces. Both these strategies were positively correlated to subsequent discriminability of own-age faces, while the inspection of the mouth of both face ages did not provide diagnostic information to identity recognition.

Results of the present study indicated that, regardless of sibling experience, preschool-aged children used different strategy for scanning adult and child faces. Overall, adult faces were explored longer than child faces; furthermore, children used a more dynamic strategy for encoding adult over child stimuli when face were presented in the inverted orientation. The exploration of the internal features seemed to show both similarities and differences between the scanning of adult and child faces. Indeed, it was evident that the mouth area has not been considered a diagnostic feature in any category of faces, thus was less looked and sampled on both face ages and orientations. On the other hand, eyes seemed to be a critical area on which the exploration strategies of adult and child faces differed. The eyes of adult faces explored for longer time compared to those of child faces when faces were presented in the canonical upright orientation, suggesting the diagnostic value of the eyes for encoding adult faces. Furthermore, the nose of adult faces was explored for longer time and more frequently than the same area of child faces only when stimuli were presented with inverted orientation. Such strategy was not related to face recognition, and it is also at odd with evidence about the exploration of own- and other-race faces (Hu, Wang, Fu, Quinn, & Lee, 2014). However, it is likely that children used a nose-centered strategy for the orientation-specific coding of relations between internal features of adult faces (Firestone et al., 2007; Moscovitch, & Winocur, 1997).

To the best of my knowledge, only the study conducted by Hills and Willis (2016) investigated the recognition and the exploration strategies of faces of different ages in childhood. Investigating face recognition as well as eye-tracking and pupillometry differences in coding own- and other-age faces (two years younger and two years older than the participants' age), authors replicated that school-aged children recognized own-age upright faces more accurately than other-age upright faces (Hills, & Lewis, 2011). Moreover, results indicated that children spent more time, made more fixations and explore own-age faces with less cognitive effort, as suggested by their grater pupil constriction. However, no differences were found about the encoding of internal features of the own- and other-age faces (Hills, & Willis, 2016).

In contrast, results of the current study suggested that preschoolers scanned adult and child faces in a different manner. Despite both face ages were less explored in the mouth area, the eyes of adult but not of child faces seemed to be considered as a diagnostic feature that children actively searched for when stimuli were displayed upside-down. Moreover, when viewing inverted faces, children spent more time and more dynamically sampled the nose area of adult compared to child faces. This difference potentially suggests the use of a holistic, thereby mature, strategy in encoding adult faces with unfamiliar orientation, since it has been established that central fixations are sufficient to create a holistic representation of a face (Hsiao & Cottrell, 2008). Although findings of Study 2 seem to be at odd with what found in the study by Hills and Willis (2016), there are at least two methodological differences that may explain the conflicting results. First, Hillis and Willis (2016) compared visual scanning strategies of older children (all attended the primary school) considering age-matched stimuli as the own-age category and faces of children of another school year as the other-age category. It is likely that the dissimilar conformation of adult and child faces boosted differential scanning strategies of facial dimension between the two face ages used in the current experiment. Second, stimuli in Hills and Willis's (2016) study were displayed with a randomized order, while I opted for blocking the presentation for both face age and orientation. The sequential presentation of faces of the same age and orientation reasonably allowed children to exhibit a consistent exploration strategy that thereby stressed the scanning differences on facial dimensions.

Lastly, it was found that qualitative differences in visual encoding of faces were related to participant temperamental traits. Interestingly, it was found that high levels of extraversion (i.e., Surgency dimension) were correlated to shorter viewing of faces and to a more dynamic exploration of child faces. These results suggest that high levels of activity and impulsivity, and relative lack of unease in new social situations, are related to a rushed scanning of adult and child faces and a more active gaze behavior for child faces. A complementary patter of result was found for the Effortful Control dimension, so that children exhibiting a conscientious behavior and a voluntary and willful regulation of attention tended to spend more time in exploring faces and made more gaze movement when exploring adult faces. To date, few studies have analyzed the role of temperamental traits on cognitive abilities during developmental age, and most of them were aimed to test the degree to which individual differences in infants' visual attention is predictive of individual variation in behavior and temperament in childhood (Papageorgiou et al., 2014; Papageorgiou, et al., 2015). Results of the present study underline the link between participants' temperament and mechanisms that are used to process social stimuli, such as faces, suggesting the importance to control for individual traits when testing face recognition in children.

Returning to the central question of developmental changes in age bias, current results suggest that 5-year-old children are equally well at recognizing adult and child faces, suggesting that the face processing system developed to reflect the changes in children's environmental experiences with faces as well their current developmental task. That is, varying experiences and interactions with people other than the primary caregiver (e.g., teachers and peers) along with children's social developmental task of acquiring self-mastery and forming significant relations with peers make significant changes in children's face-processing behavior, which is also evident in the modulation of visual scanning strategies used to recognize faces of different ages.

GENERAL DISCUSSION

Results of the studies presented in this first chapter extend available evidence on the role of ongoing experience on the changes in face processing ability across developmental populations. Differences in frequency and length of interactions with certain types of faces, as well as in infants' attention towards certain individuals during the first year, have been linked to the early development of race (Kelly et al., 2009) and gender biases (Ramsey-Rennels & Langlois, 2006). A similar link has been hypothesized for age bias (Macchi Cassia et al., 2014; Proietti et al. *submitted*), therefore, extensive experience accumulated with adult faces throughout development has dramatic effects on the tuning of the perceptual processes used for face recognition. Such process may result in both superior discrimination and enhanced configural processing of adult compared to non-adult faces.

Findings of Study 1 and 2 draw important conclusions regarding the effect of early and later experiences with faces on perceptual processing abilities of infants and children. Specifically, face representational system appears to continuously adapt, in order to reflect ongoing experience with faces. Hence, selective exposure to adult caregivers leads to the narrowing of the face system towards adult faces, whereas a broader array of exposure, including more interactions with peers, reduces such narrowing later in childhood. Infants, who for the first 9 months of life had massive contact with adult individuals through extensive experience with adult caregivers, show the typical developmental trend of perceptual tuning towards adult faces, while reduced discrimination ability for non-adult faces (Study 1). Later in development, changes in face-processing behavior result in non-selective recognition abilities in preschoolers, who, by making experiences with both adult and peer faces, do not show the adult recognition advantage (Study 2). Notably, in contrast to findings of younger children (Macchi Cassia et al., 2012), between 4 and 5 years of age children's early experience with sibling does not exert significant effect, suggesting that additional interactions with peers level off recognition abilities of children with and without an older sibling.

Both studies presented in the first chapter provide novel evidence about the influence of ongoing experience on visual scanning strategies involved in viewing adult and child faces. In fact, the differences on discrimination and recognition performances are combined with specific scanning patterns of adult and child faces. The adult discrimination advantage showed by first-born 9-month-old infants is accompanied by the use of more sophisticated strategies, namely short scan path amplitudes, in exploring those faces. Furthermore, the scanning of adult faces stands out from that of child faces for the greater looking and sampling of the mouth area, which in the end could be related to infants' sensitivity to language inputs. Thus, it seems that extensive experiences with talking adults lead infants' perceptual system to move the attention to a selective facial dimension of adult faces, which is overlooked in child faces. Moreover, eyes are the most scanned area of both adult and child faces, even though children's eyes seem to exclusively attract attention when infants are exposed to those faces.

Human eyes seem be of particular importance at least for Caucasian infants, since the increased fixation on the eyes occurs at the same time as advanced recognition ability for own-race faces (Wheeler et al., 2011; Xiao, Quinn, Pascalis, & Lee, 2014). The presence of human eyes in monkey faces also facilitates the discrimination of other-species faces in 9-month-olds, but it is reported as not sufficient for aiding the discrimination of 12-month-olds (Damon et al., 2016). Thus, even if human eyes are important for face recognition in Caucasian infants, in order to provide a useful information they might be related to the other facial features and embed into a correct face template. The almost exclusive preference for children's eyes is likely due to high level of attractiveness of this area that is enlarged in children compared to adult faces. In spite of the importance of eyes as a key facial feature, present results prove that in infancy using a scanning strategy that limits the exploration to the eyes is not sufficient to discriminate child faces.

The general preference of infants for exploring the eye area (Wheeler et al., 2011) is confirmed and extended to the nose in older children. Critically, later in development the mouth area of both adult and child faces loses importance in favor of a larger processing of the top-half part of faces, namely the eyes and the nose. The exploration of those two features diversify visual scanning strategies used for adult and child faces. In particular, a nose-centered strategy seems to be used for processing adult faces when stimuli are presented upside-down, and it could reflect an attempt of catching configurational information from spatial relations among the facial features.

In conclusion, the advantage in processing adult faces in infancy, which is evident in both selective novelty preference and specific scanning strategies for those faces, is not clearly evident in children. Such difference could due to children's extensive experience with adult and child faces through contact with adult caregivers and with peers and to children's developmental task of forming relationship with people beyond the primary caregiver (Picci & Scherf, 2016). In spite of a nonselective face age recognition, a certain degree of specificity on perceptual ability for adult faces is still evident on eye movements and on scanning strategies made for that category of faces.

CHAPTER 2[**]

How race and gender attributes of faces modulate visual scanning strategies and electrophysiological responses in children

In this chapter I will discuss available evidence on race and gender face processing biases in children, and two studies that were aimed at investing how children's visual exploration strategies (Study 3) and neural categorization abilities (Study 4) are modulated by racial and gender facial attributes.

Almost all available research on race and gender biases in face processing has focused on infant and adult populations, while less is known about the trajectory of responsiveness to those social attributes of faces in childhood. A number of studies suggest that both race and gender influence children's social preferences. In other words, children connote others using race and gender attributes, and express social preferences as well draw inferences based on a preferential element of each category (for a review, see Kinzler, Shutts, & Correll, 2010). Although children are capable of attending to race and gender category distinctions, evidence reported that such distinctions follow different developmental trajectories. For instance, gender has been shown to be a robust and early guide to children's playmate choices and reasoning about others (for a review, see Ruble, Martin, & Berenbaum, 2006). By comparison, race is certainly salient to older children, but it is not as important early in development. That is, although children show social preferences for same-gender

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[**] Studies reported in Chapter 2 were carried out in collaboration with Prof. Lisa Scott and Dr. Ryan Barry-Anwar, respectively Associate Professor and Post-Doctoral Associate at the University of Florida, at the Brain, Cognitive and Development (BCD) Lab at the University of Florida.

peers by 2–3 years of age (LaFreniere, Strayer, & Gauthier, 1984), race-based attitudes may not emerge until closer to 4 or 5 years of age (Aboud, 2003).

Recent literature evidence highlights the relations between perceptual processing and social preferences, sustaining the perceptual–social linkage hypothesis (Lee, Quinn, & Heyman, 2017; Lee, Quinn, & Pascalis, 2017). That is, the early asymmetry in exposure to own- versus other-race faces has both perceptual consequences on face recognition/categorization and social consequences in terms of racial bias. Specifically, infants respond positively to own-race than other-race individuals, because they are typically exposed to own-race people who interact with them positively. Similarly, the propensity of infants to be wary of strangers along with the perceptual differences between familiar own-race faces and unfamiliar other-race faces, lead infants to respond negatively to unfamiliar other-race individuals (Turner & Reynolds, 2010). The causal linkage between perceptual and social processing is supported by studies with children, which also revealed that teaching children to recognize the faces of one other race significantly reduced their racial bias with long-lasting effect (Quian et al., 2017; Xiao et al., 2015).

Extant researches suggest that face representation adapts to represent the most predominant face race in the environment, which is reflective of children's specific living conditions and social experience. As a result, by 3 years of age, children build a specific prototype for native race and manifest an adult-like race bias. Sangrigoli and De Schonen (2004) demonstrated that from 3- to 5-years Caucasian children improved their performance in discriminating between own-race faces and showed to use expert face processing strategies for these faces compared with other-race faces. Moreover, it has been demonstrated that the development of face representations is strictly related to the length of exposure to faces of different races. Indeed, it is reported that changes in the proportional size of racial groups occurring as a consequence of cross-cultural adoption during early (de Heering, de Liedekerke, Deboni, & Rossion, 2010) or late (Sangrigoli, Pallier, Argenti, Ventureyra, & de Schonen, 2005) childhood can mitigate or reverse the size of the own-race bias.

Although investigators generally agree that the face representations remain plastic enough to be modified or to incorporate faces from another race in early childhood, research on the impact of facial gender diversity on early face processing skills is confined to infancy. At an early stage of life, infants have relatively rich interaction with female caregivers, which contributes to forming a more robust representation of female faces relative to that of male faces. Indeed, it is estimated by parental reports that infants during the first year of life spend approximately 70% of their time with females, inclusive of a 50% contribution from a female caregiver and an approximate 20% contribution from other females (Rennels and Davis, 2008). Such bulk of experience with female faces has been corroborated by data obtained with a head mounted camera during the first 3 months of life (Sugden et al., 2014).

Given that, it is clear why infants’ face representation is influenced by the gender of the primary caregiver already by 3–4 months of age. Quinn and collaborators (2002) presented infants with male versus female face pairings and reported that the participants primarily raised by female caregivers preferred the female faces, while infants raised mostly by male caregivers showed a reliable preference for male faces (Quinn, Yahr, Kuhn, Slater, & Pascalis, 2002). A more recent study found that a similar gender preference was not evident in newborns, and that the female face preference was limited to own-race faces at 3 months of age (Quinn et al., 2008). Despite by 7 months of age infants primarily raised by female caregivers were equally capable to differentiate among male and female faces, they did show enhanced neural sensitivity to female faces, as indexed by larger N290 response to female than male faces (Righi, Westerlund, Congdon, Troller-Renfree, & Nelson, 2014). Taken together, this evidence suggests that face gender experience contributes to determine how infants respond to female versus male faces. However, there is lack of evidence on how face gender modulates face-processing abilities in childhood.

Though research has shown that children’s recognition abilities are modulated by the race of the faces to be recognized, no study has examined the interactive effects of racial and gender facial traits on children’s face processing abilities. Infant studies suggest that the role of race and gender experience in driving infants’ attention to faces changes across the first year of life. In fact, at 3-4 months of age the preference for female faces is limited to own-race stimuli, as gender modulates Caucasian infants’ looking times in a visual preference task when Caucasian but not Asian faces are presented (Liu et al., 2015; Quinn et al., 2008; Tham, Bremner, & Hay, 2015). Instead, Kelly and collaborators (2007) showed that the preference of 3-month-old Caucasian infants for same-race over other-race faces occurs for both male and female faces. Recent evidence from visual-paired comparison tasks reveals that the own-race discrimination advantage in 3-4-month-olds Caucasian infants is confined to female faces alone, whereas it is generalized across gender at 8-9 months (Tham et al., 2015).

Overall, this evidence suggests that during the first year of life there is a shift from a female-based own-race recognition advantage to a general own-race recognition advantage, in keeping with a social experience-based account of the own-race bias. Therefore, it seems that by the end of the first year of life infants prioritize race information over gender information when processing faces. This would be consistent with a hierarchical processing model in which race information is superordinate to and processed before gender information (O’Toole, Peterson, & Deffenbacher, 1996).

Furthermore, recent evidence also suggests that the developmental course of face attribute preferences seems to be influenced by both the diversity of children’s facial experience, and their age-appropriate developmental tasks (Scherf, & Scott, 2012). For instance, Heron-Delaney and colleagues (Heron-Delaney, Damon, Quinn, & Pascalis, 2017) showed that 3-4-year-old children prefer adult over child faces, whereas older children (i.e., 5-6 years) prefer child over adult faces, and this pattern of preferential responses was observed only for own-race faces as it was absent for other-race faces. Such results suggest that growing experience with peers influences age preferences, although race information is always prioritized in face encoding.

In light of this evidence, the aim of Study 3 and Study 4 was to investigate whether and how face race and gender cues interact to affect visual scanning strategies (Study 3) and neural categorization (Study 4) in children within the 3- to 5-years age range. Specifically, it was extended the investigation on the role of face gender attribute, the effect of which is well establish in infancy, in modulating the face-processing behavior in childhood. Moreover, it was investigated whether and how racial and gender facial attributes interplay each other in defining how children encode faces. Therefore, it was explored if gender information modulates the effect of race cues or if the race of faces supersedes gender information in directing the encoding of faces. If the perceptual tuning towards caregiver-like faces occurred in infancy keep modulating the face-processing behavior in children, I predict a specific encoding of female own-race faces when compared to all the other face types. On the other hand, consistent with the hierarchical processing model of face attributes, in which race information is superordinate to gender information (O’Toole et al., 1996), an enhanced processing for own-race faces regardless of gender might be observed.

To explore the visual encoding of race and gender attributes, in Study 3 children’s eye movements and pupil dilation have been recorded during free viewing exploration of male and female faces of different races. If children’s processing behavior is influenced by the massive experience with the caregiver, children would exhibit specific scanning strategies and pupil responses for female own-race faces; alternatively, the cumulative experience with people beyond the primary caregiver could tune children's scanning behavior towards a specific exploration of and a specific pupil reaction to own-race faces across genders. The multi-method analyses used to analyze eye-tracking data provided a useful approach for better understanding how face race and face gender interact in modulating children's face scanning patterns. Specifically, the traditional AOI approach focused on the duration and the number of gaze shifts, was performed using specific AOI sets drawn around the principal internal features (i.e., eyes, nose and mouth) of the faces. Such approach provides a default mode of analysis for most eye-tracking studies, as it suggests which of the internal facial feature is used by children as diagnostic during the facial encoding. A second approach to eye-tracking data analysis is the one that focuses on pupil changes occurring during stimulus presentation. The pupillometry analysis is based on the assumption that the eyes'pupils dilatate during autonomic arousal (Beatty & Lucero-Wagoner, 2000; Granholm & Steinhauer, 2004; Samuels & Szabadi, 2008) and mental activity (Beatty, 1982; Granholm & Steinhauer, 2004; Loewenfeld & Lowenstein, 1993; Sirois & Brisson, 2014) by means of the modulation of the norepinephrine (NE) projections to the Locus Coeruleus (LC). LC-NE activity leads to pupil dilation because the LC has direct inhibitory projections to the parasympathetic Edinger-Westphal nucleus, where the pupil's constricting fibers originate. By inhibiting the Edinger-Westphal nucleus and the pupil's constricting muscle, LC activity therefore indirectly dilates the pupil (Beatty & Lucero-Wagoner, 2000; Loewenfeld & Lowenstein, 1993; Samuels & Szabadi, 2008). LC activity also increases activity in the sympathetic system (Samuels & Szabadi, 2008), including sympathetic fibers that innervate the pupil, resulting in additional pupil dilation. Thus, pupil dilation can be used as a measure of a person’s mental effort when working on a task (Eckstein, Guerra-Carrillo, Singley, & Bunge, 2016) and it is also reported to be associate with attentional engagement and information processing (Hess, 1975; Hess & Polt, 1964). Importantly, changes in pupillary responses are used as a metric for measuring the effort put in during the encoding of faces (Goldinger, Papesh, & He, 2009). In Study 3, pupillometry was used to compare pupil changes during the encoding of racial and gender attributes of the stimuli.

The last data analysis approach used in Study 3 involved the computation of similarity scores of scan paths across the whole face, which provided a measure of how efficiently facial information was collected through eye movements. Such approach is based on the bioinformatic method utilized to analyze biological sequences (either DNA or protein sequences), and was used to quantitatively score the similarity among eye movement sequences. Eye movement data collected through any eye-tracker can be used to create a sequence of eye movements onto which the Needleman–Wunsch algorithm (Needleman & Wunsch,1970) is applied to quantify the similarity between scan paths. Thus, according to Kato and Konishi (2013), the similarity score of scan paths provides a measure of how efficiently information is collected during the encoding of faces. As children’ scan paths simplify to the most efficient path, it is reasonable to assume that their scan paths become more likely to resemble each other.

Study 4 explored the neural correlates of race and gender categorization by measuring the steady-state visual evoked potentials (ssVEPs) while 3- to 6-year-old children completed a fast-periodic visual stimulation (FPVS) oddball task. It was hypothesized that children’s selective experience with own-race faces would result in a categorization advantage for own race faces. That is, only the neural response for own-race stimuli presented in the oddball position of the sequence would synchronize with the oddball frequency of 1.2

Hz. On the other hand, children’s cumulative experience with face gender attributes would result either in a specific categorization of females (i.e., 1.2 Hz response for female faces regardless of race), if the early experience with the caregiver still exerts influence on neural face processing, or in similar neural responses for male and female faces, if the increased tendency to orient to male faces eliminates the female gender preference. Lastly, it was explored the relation between children’s neural response and gaze movements made for encoding racial and gender facial attributes of those participants who accomplished both Study 3 and Study 4. It should be noted that data collection for both Study 3 and Study 4 is still ongoing, thus the results should be considered as preliminary. Moreover, in order to increase the power of the study, which is currently reduced due to the limited sample size, participant’s age was not included in statistical analyses, although evaluating the effect of the age is within the aims of both Study 3 and Study 4.

Study 3

Children's visual scanning patterns and pupil dilations during the encoding of male and female faces of different races

Aims

Study 3 aimed to explore how children encode race and gender attributes of faces by using a multi-methods approach to analyze their eye-tracking data. By comparing visual scanning strategies of own- and other-race, female and male faces, it was investigated the possible interconnection between the encoding of racial and gender facial attributes in 3- to 6-year-old children. Given the dearth of work on the face-processing behavior in childhood, especially about the gender bias, my hypotheses are tentative. If the disparity in processing the gender categories, which is evident in the preference for female faces (Quinn et al., 2002), persists beyond infancy, the encoding of face gender information would guide the processing of gender attributes of faces. Thus, children should exhibit specific scanning strategies for female faces of their own-race. Alternatively, specific scanning patterns for own-race faces general across gender would be consistent with a hierarchical processing model in which race information supersedes the processing of gender information (O'Toole, Peterson, & Deffenbacher, 1996).

Method

Participants

Participants included in the analyses consisted of 23 3- to 6-yearold children (13 males, M_{age} = 4 years 3 months, range = 3;0 – 6;7). All children were recruited from schools and day-care centers in the local area, were from middle-class Caucasian families and had no neurological issues and normal vision. All parents gave their written consent and filled out a questionnaire with general demographic inquiries and contact questions aimed at assessing the amount of experience that children had acquired with female and male adult individuals. All parents reported that the children were mainly exposed to their mother (70%) and to other adult females (64%; i.e., teachers, babysitters, or family friends). Moreover, through the same questionnaire it was assessed that all participants had no regular exposure to Asian individuals (i.e., parents did not have close family or friends of other ethnicities with whom their children had frequent contact). All children except one attended the daycare center and had regular exposure to Caucasian children (72%). An additional 2 children were excluded due to fussiness (N = 1), or technical issue (N = 1). Parents of participants were paid $10 and children received a small toy for their participation. The University of Florida Institutional Review Board approved all methods and procedures used in the study.

Stimuli

Visual stimuli were created from digitalize, high-quality images depicting four Caucasian and Asian female or male faces, one per category. Caucasian faces were selected from the NimStim database, while Asian face were from the CUHK Face Sketch Database. All faces were unfamiliar to participants and displayed a full-front neutral expression with open eyes. Gray scale face images were equated for luminance level, cropped in a standard oval to discourage reliance on salient external features and pasted on a black square, using the software Adobe Photoshop. All faces were presented in the center of the screen with a grey background and subtended a horizontal visual angle of 17.5° and a vertical angle of 25° when viewed from a viewing distance of 60 cm. Inverted stimuli were created by a 180° rotation of each face (Figure 3.1)

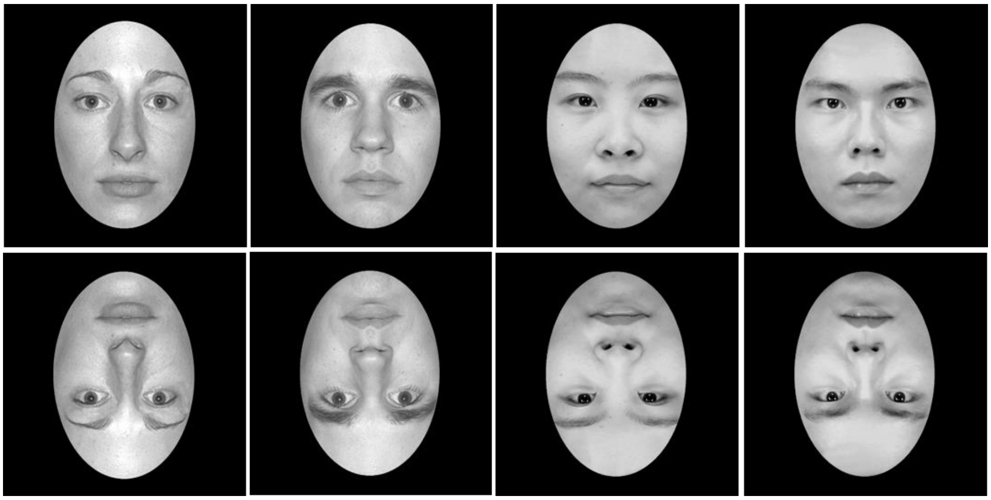


Figure 3.1. Upright and inverted Caucasian and Asian, male and female faces used in Study 3.

Apparatus

Participants were tested individually in a dedicated semi-darkened and sound attenuated room. They sat on a child high chair in front of a 17.5-inch flat-screen monitor (resolution 1280 x 1024) where the stimuli were presented with a viewing distance of 60 cm. Eye movements were recorded using an infrared camera, SR Research EyeLink 1000 Plus Remote eye-tracker, that was located at the bottom of the computer screen. The eye-tracking camera recorded the reflection of an infrared light source on the cornea relative to the pupil at a frequency of 500 Hz. Fixations, defined as a period of at least 100 ms in a dispersion region of 1 degree of visual angle, and pupil areas were continuously tracked from one eye throughout the experiment.

Procedure

Each participant was tested on a single occasion with the parent behind him/her during the whole testing session. Two experimenters attended the experimental session; one of them was involved in managing and controlling the eye tracker signal, while the other experimenter fostered participants' attention to the task. Due to the high sensitivity of pupil size to light conditions, trials in which participants moved their gaze outside the black square around faces were marked down and excluded from the pupillometry analyses (see Data Analyses section). Calibration was achieved by asking the child to follow looming and colorful calibration targets that appeared at three different locations on the screen. A fixation at a calibration target was judged as correct if the spatial pattern of recorded gaze location corresponded with the pattern of calibration targets being presented. The calibration procedure was successful for all participants at the first or second attempt.

A within-participants design was used, so that each child was exposed to eight trial types corresponding to the eight experimental conditions: race (own, other), gender (female, male), and orientation (upright, inverted). Before each trial, a black and white star was randomly displayed on the right or on the left side of the screen, next to the position were the face would subsequently appear, in order to align the child's gaze to the screen. After a blank of 500 msec a face appeared in the center of the screen for 2 sec, followed by a brief sketch displaying a cartoon character (see Figure 3.2). Participants were asked to perform a "catching Dory" game, in which they had to press the space bar on a keyboard only when they viewed Dory. Face stimuli were presented in a semi-random order, avoiding the presentation of the same face identity two times in a row. Trial presentation continued until a minimum of 20 trials were administered, and ended when the participant became too fussy or bored to attend. Participants viewed an average of 44 trials (range = 20-55).

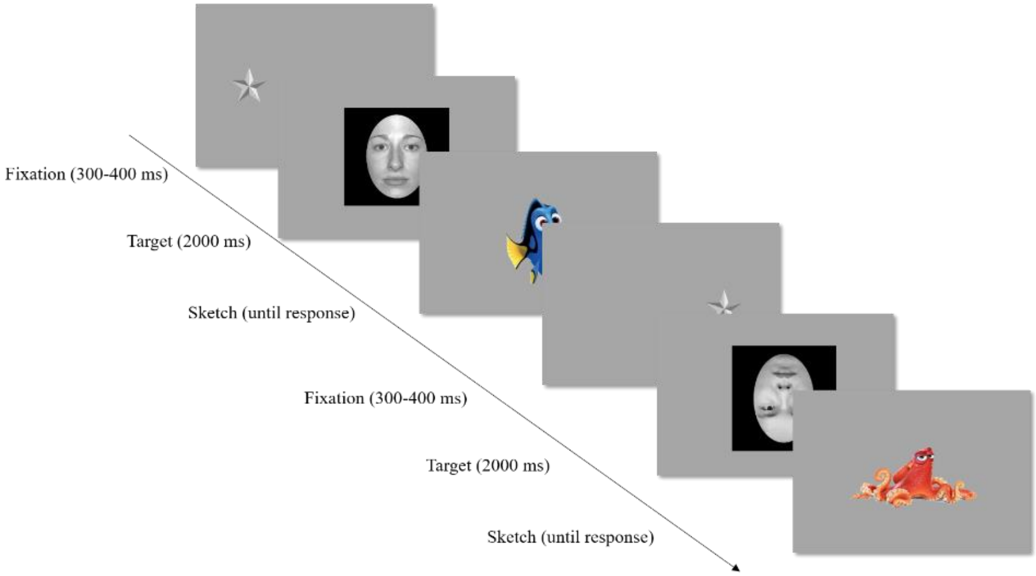


Figure 3.2. Representation (not drawn to scale) of the procedure in Study 3.

Eye movement analyses

Using a multi-method approach to analyze eye-tracking data, three different sets of measures were derived, respectively, from eye movement data, pupil size variations, and similarity scores of scan paths across the whole face.

To analyze participants' eye movement scanning behavior, four areas of interest (AOIs) were defined for each face: the whole face, the eyes (left and right separately drawn but combined), the nose, and the mouth. The three internal AOIs were equal in size and each covered 8% of the total area of the face (together they covered 24% of the face) (Figure 3.3). Three measures were derived from eye movement data: the proportion of total looking time on each AOI, the number of fixations per unit time (second) on each AOI, and the proportional number of transitions between internal AOIs. As in Study 1 and 2, proportional looking times were calculated for each trial by dividing the total fixation time on each internal AOI (i.e., eyes, nose, and mouth) by total fixation time on the whole face. Number of fixations per second was calculated by dividing the total number of fixations recorded within each internal AOI in a given trial by total fixation time on the whole face. The proportional number of transitions between internal AOIs provides a measure of the extent to which viewers are assessing the relations among the facial features, and was calculated by dividing the total number of shifts between internal features (i.e., eye-to-eye, eye-to-nose, eye-to-mouth, or nose-to-mouth) by total fixation time on the whole face.

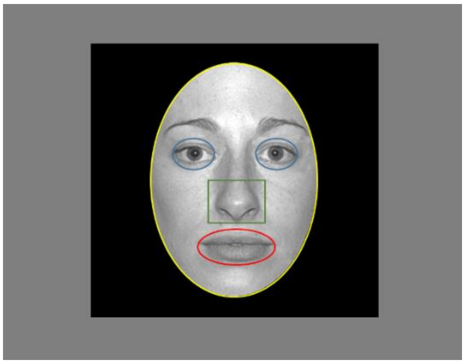


Figure 3.3. Example of the AOIs that were centered on the face (yellow), the eyes (blue), the nose (green), and the mouth (red). Proportional AOIs were created for all face categories.

Pupil size variations were derived through the FieldTrip toolbox using the same method described in Urai et al. (2017), which allows examination of each individual pupil trace and the subsequent removal of those traces that contain artifacts. Missing data and blinks, as detected by the EyeLink software, were padded by 150 msec; additional blinks were found using peak detection on the velocity of the pupil signal. All missing data and blinks were linearly interpolated. It was estimated the effect of blinks and saccades on the pupil size through deconvolution, and these responses were removed from the data using linear regression according to the procedure detailed in Knapen et al. (2016). The residual pupil time series were bandpass filtered using a 0.01–10 Hz second-order Butterworth filter, and resampled to 100 Hz. The recordings were segmented in epochs based on the 2000 msec trial length, and each trial was baseline-corrected by subtracting the mean pupil area 250 msec before the onset of the first experimental stimulus. The pupil area variation was extracted for each stimulus category and, after removing trials in which participants did not pay attention to the screen, the variation in pupil area was averaged based on race, gender and orientation of the stimuli.

Similarity scores of scan paths across the whole face were derived through ScanMatch MATLAB Toolbox (Cristino, Mathot, Theeuwes, & Gilchrist, 2010), which allowed to extract the spatial and temporal sequences of visual fixations performed during each single trial. ScanMatch transforms both spatial and temporal information of a fixation sequence into a sequence of letters that represent the location, duration and order of the fixations. To this end, the temporal sampling rate was set to 100 msec. A grid was added offline to each face image to identify 21 X 17 spatial bins (each bin 60 X 60 pixels), and fixations located within each bin were coded by two letters (Figure 3.4). The letter sequences of two sets of eye movements were then compared to each other and a similarity score was calculated based on the Needleman–Wunsch algorithm that is commonly used to compare DNA sequences. A similarity score close to 1 indicates that the two sequences of eye movements are highly similar in terms of their spatial and temporal order. Two different similarity scores were derived from participants’ gaze shifts during exploration of different face types: within-subjects similarity scores and between-subjects similarity scores. Within-subjects similarity scores of scan paths were derived for each experimental condition by computing for each participant an average similarity score across all trials within the same condition. Between-subjects similarity scores of scan paths were derived by computing an average similarity score among all the participant combinations for each experimental condition.

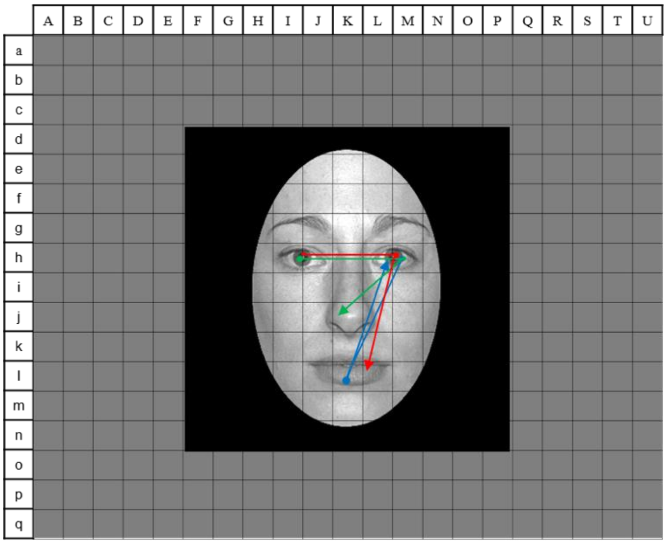


Figure 3.4. The grid added offline to each face image to define the spatial bins used to perform the ScanMatch analysis to derive similarities scores of scan paths. Colored arrows simulate gaze movements performed by three participants. Red and green paths would result in a higher similarity score compared to red and blue paths.

Results

To test whether children's visual exploration strategies were differentially impacted by face race and gender as a function of stimulus orientation, repeated-measures ANOVAs with face race (own-race vs. other-race), face gender (male vs. female), AOI (eyes, nose, mouth) and orientation (upright vs. inverted) as within-subject factors was performed for all the eye-tracking measures above described. The factor AOI was omitted from the ANOVAs on proportional numbers of transitions between internal AOIs, pupil size variations, and similarity scores of scan paths. For all dependent variables, preliminary analyses revealed no significant effect of participants' gender, and data were collapsed across this factor in all subsequent analyses. Although evaluating the effect of participants' age is within the aims of the current study, in order to increase the power of the results, which are currently reduced to the limited sample size, participant's age was not included as a factor in statistical analyses.

Proportion of total looking time on internal AOIs. The 2 (race) x 2 (gender) x 2 (orientation) x 3 (AOI) repeated-measures ANOVA on proportional looking times revealed a main effect, $F(2,44) = 33.25$, $p < .001$, $p\eta^2 = .60$, and two different 2-way interactions involving the factor AOI (AOI x orientation, $F(2,44) = 23.98$, $p < .001$, $p\eta^2 = .52$, AOI x gender, $F(2,44) = 4.42$, $p = .018$, $p\eta^2 = .17$). Bonferroni-corrected post hoc comparisons were performed to further explore how the looking time on each internal feature varied as a function of stimuli orientation and face gender attribute (Figure 3.5). Results revealed that the eyes region was fixated longer in upright faces ($M = .71$) than in inverted faces ($M = .39$), $p < .001$, while the opposite pattern was found for the mouth region, which was fixated longer for inverted faces ($M = .32$) than for upright faces ($M = .15$), $p < .001$. Moreover, when viewing faces with canonical upright orientation children longer explored the eyes region ($M = .71$) compared with both the nose ($M = .23$) and mouth regions ($M = .15$), *p*s < .001. Such preference for the exploration of the upper half of the stimuli was found for both female (eyes: $M = .50$; nose: $M = 25$; mouth: $M = .14$) and male faces (eyes: $M = .60$; nose: $M = 26$; mouth: $M = .22$), *p*s < .001.

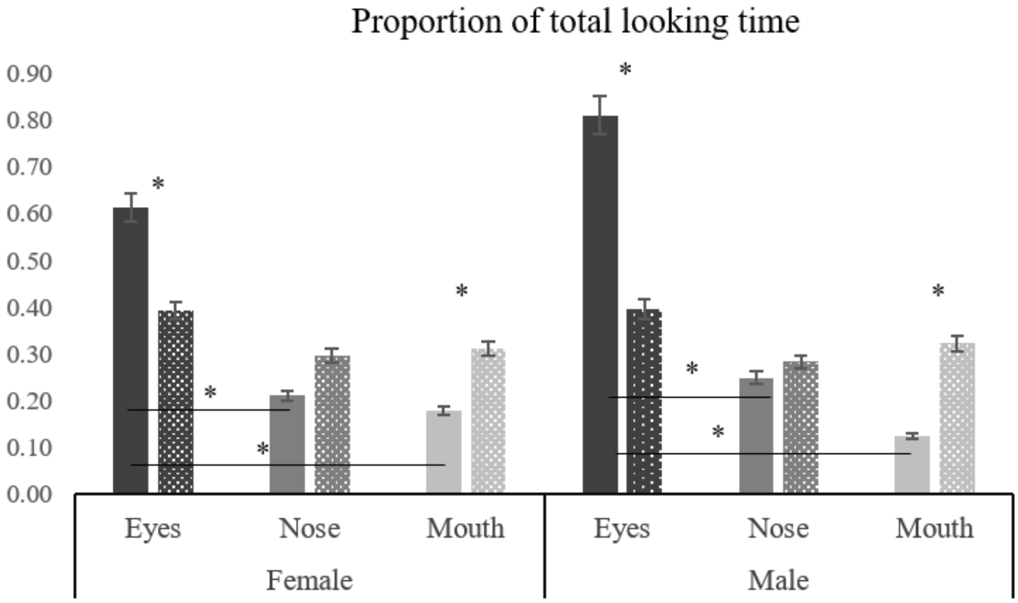


Figure 3.5. Proportion of total looking time on each internal AOI plotted as a function of face gender and orientation. Solid bars represent upright faces, while dotted bars represent inverted faces (* $p < .05$).

Number of fixations per second. The 2 (race) x 2 (gender) x 2 (orientation) x 3 (AOI) repeated-measures ANOVA revealed main effects of race, $F(1,22) = 18.29$, $p < .001$, $p\eta^2 = .44$, gender, $F(1,22) = 5.48$, $p = .028$, $p\eta^2 = .19$, and orientation, $F(1,22) = 87.41$, $p < .001$, $p\eta^2 = .79$. Those effects were qualified by significant interactions between gender, AOI, and orientation, $F(2,44) = 5.00$; $p = .011$, $p\eta^2 = .18$, and between race, gender, and AOI, $F(2,44) = 5.36$; $p = .008$, $p\eta^2 = .19$ (Figure 3.6). Bonferroni-corrected post hoc comparisons revealed that for both face genders more number of fixations per second were made on the eyes of upright than inverted stimuli, *p*s < .001, whereas the nose and the mouth were more sampled in inverted compared to upright faces, *p*s <.001. Additionally, the nose region was sampled more often for upright (own-race and other-race) female faces than for upright (own- and other-race) male faces, p = .002. Moreover, children sampled the mouth region in female own-race faces more often (M = .39) than in male own-race faces (M = .27), p = .001.

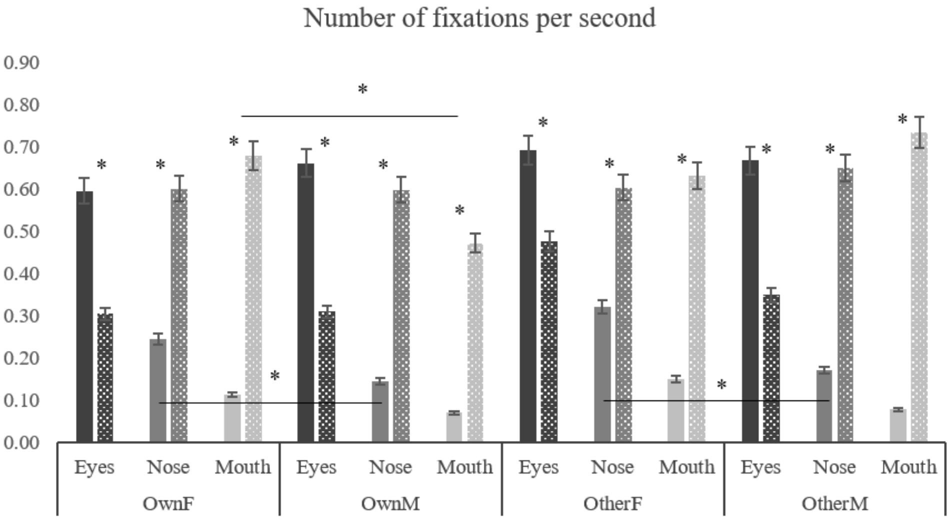


Figure 3.6. Number of fixations per second on each internal AOI plotted as a function of face race, face gender and orientation. Solid bars represent upright faces, while dotted bars represent inverted faces (* p < .05). OwnF: own-race female faces; OwnM: own-race male faces; OtherF: other-race female faces; OtherM: other-race male faces.

Proportional number of transitions across internal AOIs. The x 2 (race) x 2 (gender) x 2 (orientation) ANOVA revealed a main effect of orientation, $F(1,22) = 9.67$, $p = .005$, $p\eta^2$ =.31, indicating that children made more transitions across internal AOIs of inverted faces (M = 1.59) compared to upright faces (M = .76). There were also significant main effects of race, $F(1,22) = 5.06$, $p = .044$, $p\eta^2$ =.19, and gender, $F(1,22) = 4.62$, $p = .043$, $p\eta^2$ =.17, which were qualified by a marginal race x gender interaction, $F(1,22) = 4.28$, $p = .051$, $p\eta^2$ =.16. Bonferroni-corrected comparisons revealed that children made more transitions between the internal features when viewing own-race female faces (M = 1.33) compared to own-race male faces (M = .70), p = .001 (see Figure 3.7).

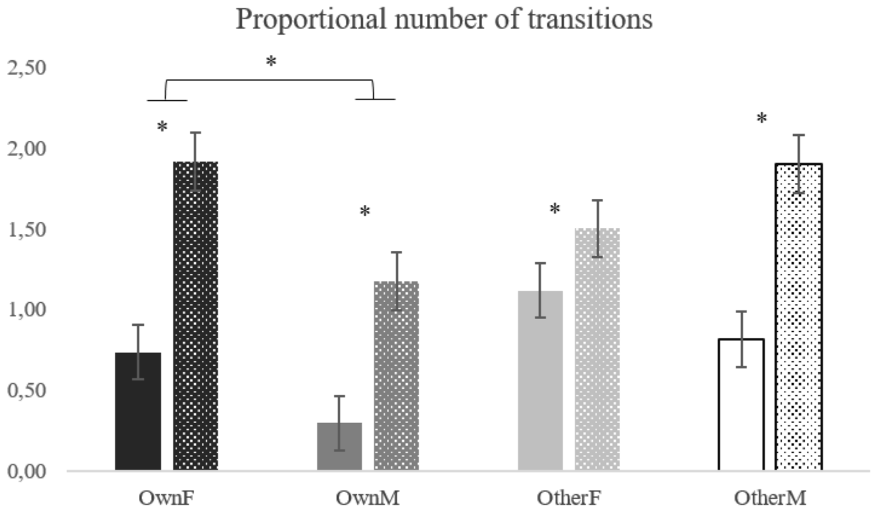


Figure 3.7. The proportional number of transitions across the internal AOIs plotted as a function of face race, face gender and orientation. Solid bars represent upright faces, while dotted bars represent inverted faces (* $p < .05$). OwnF: own-race female faces; OwnM: own-race male faces; OtherF: other-race female faces; OtherM: other-race male faces.

Pupil size variations. One participant was removed for the pupil size analyses because no good trials remained for the upright own-race male condition after online coding of participants' attention to the screen. In order to determine the presence of a stimulus-specific pupil response, the average change in pupil area was derived within the 1000-1950 msec time-window after stimulus onset with respect to the baseline for each participant. Similarly to Conway and collaborators (2008), the time interval between the onset and offset of the pupil response was determined by visual inspection of pupil traces performed by two different researchers independently (see Figure 3.8). The average changes in pupil area were entered in a 2 (race) x 2 (gender) x 2 (orientation) repeated-measures ANOVA. Although the Race x Gender x Orientation interaction did not reach statistical significance, $F(1,21) = 3.38$, $p = .080$, $p\eta^2 = .14$, hypothesis-driven planned comparisons were performed to explore the effects of race and gender attributes on pupil variations for both stimulus orientations.

Bonferroni-corrected multiple-comparisons revealed that, in the upright orientation only, own-race female faces elicited greater pupil dilatation than own-race male faces, *p* = .020, whereas not face race nor face gender impacted on pupil size in the inverted condition, *p*s > .131 .

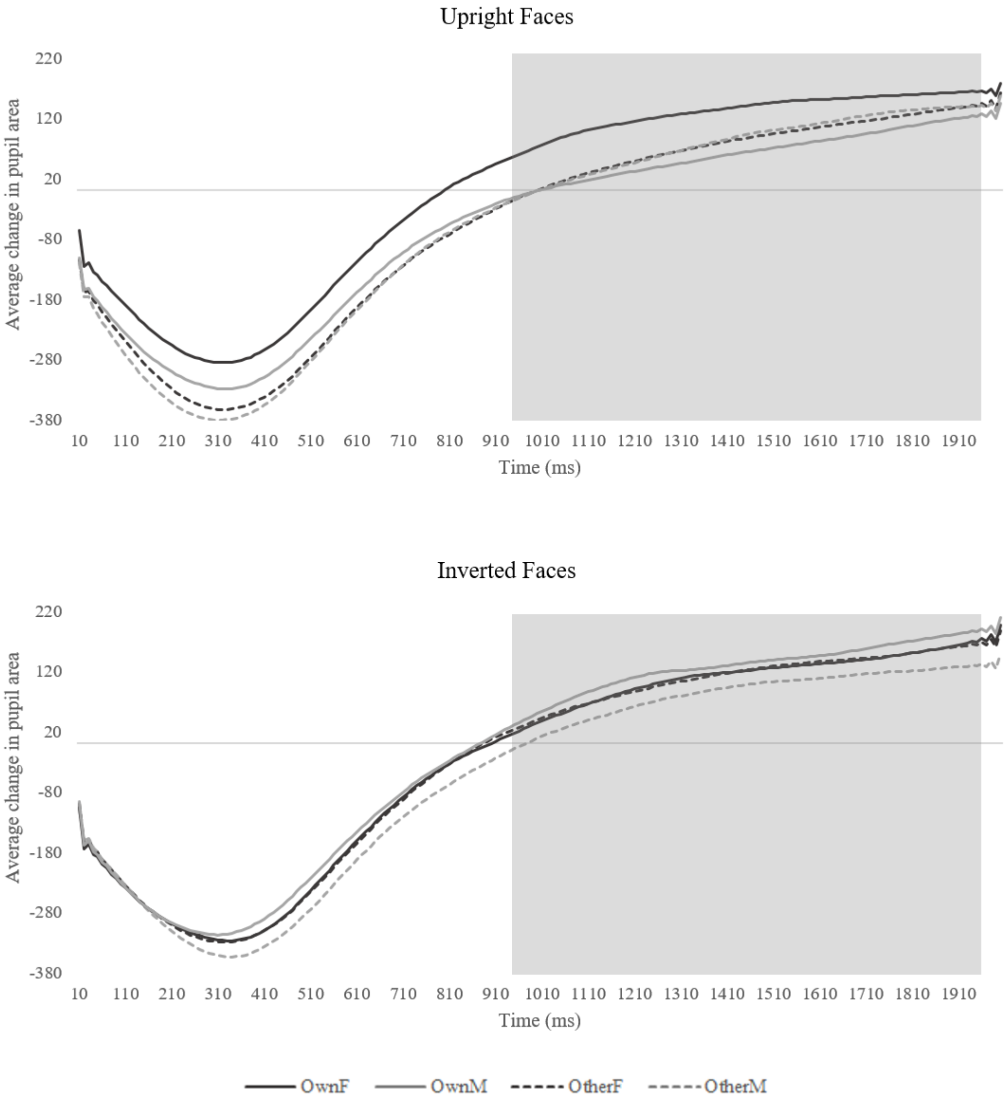


Figure 3.8. Pupil size variations recorded within the 1000-1950 ms time-window after stimulus onset for upright (top) and inverted (bottom) faces. OwnF: own-race female faces; OwnM: own-race male faces; OtherF: other-race female faces; OtherM: other-race male faces.

Similarity scores of scan paths. To compare the consistency of scan paths produced by each single participant as they explored different face types, the within-subjects similarity scores of scan paths were entered into a 2 (race) x 2 (gender) x 2 (orientation) repeated-measures ANOVA. The analysis revealed a significant main effect of orientation, $F(1,22) = 8.74$, $p = .007$, $p\eta^2 = .28$, indicating that participants were significantly more consistent in their scanning pattern while exploring upright faces ($M = .670$) than inverted faces ($M = .630$), irrespectively of face race and gender.

To compare the consistency of scan paths produced by all participants while viewing different face types the between-subjects similarity scores of scan paths were entered into a 2 (race) x 2 (gender) x 2 (orientation) repeated-measures ANOVA (Figure 3.9). The analysis revealed a significant main effect of orientation, $F(1,252) = 127.33$, $p < .001$, $p\eta^2 = .34$, due to scan paths being more consistent across participants for upright faces ($M = .637$) than for inverted faces ($M = .600$). There was also a main effect of race, $F(1,252) = 21.08$, $p < .001$, $p\eta^2 = .08$, which was qualified by a significant race x gender interaction, $F(1,252) = 13.44$, $p < .001$, $p\eta^2 = .05$. Bonferroni-corrected comparisons revealed larger similarities between participants’ scan paths for other-race male faces ($M = .632$) than for both other-race female faces ($M = .619$), $p < .001$ and own-race male faces ($M = .609$), $p < .001$, irrespective of stimulus orientation.

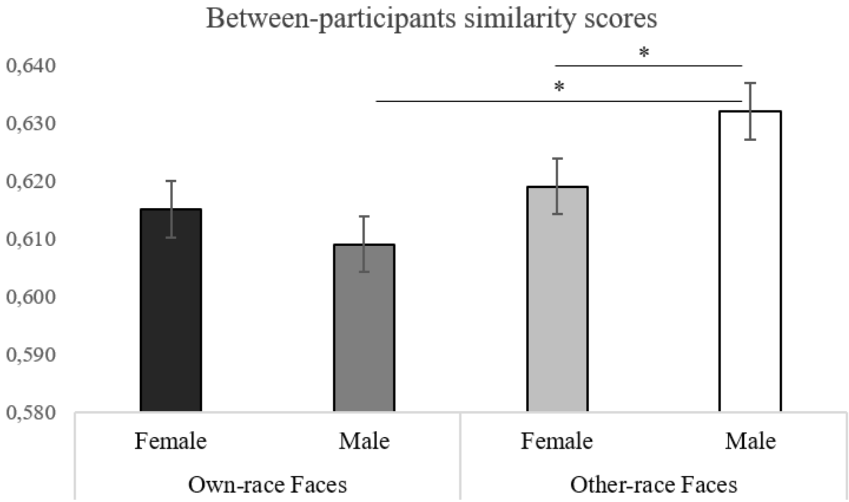


Figure 3.9. Mean between-participants similarity scores of scan paths for female and male own-race and other-race faces (* *p* < .05).

Discussion

Study 3 extended existing demonstrations with infants of the perceptual processing of race and gender attributes of faces by examined children's visual scanning of female and male of own- and other-race faces. It was explored whether the processing advantage for faces with the characteristics of the primary caregiver (female faces of own-race) direct the encoding of racial and gender facial attributes in 3- to 6-year-old children. That is, the current study sought to determine if the face race and the face gender attributes were processed at the same hierarchical level or if race information supersedes the encoding of gender information.

Eye-tracking findings indicated that the looking time in exploring internal features of stimuli was modulated by the orientation in which stimuli were presented. Consistent with adult studies (Blais, Jack, Scheepers, Fiset, & Caldara, 2008) children longer explored the eyes region compared to both nose and mouth of all faces. However, such scanning preference was modulated by stimulus orientation, so that the eyes were explored for a long time when faces were presented in canonical upright rather than in inverted orientation. Instead, longer looking time were performed for exploring the mouth region of inverted than upright faces. In line with prior reports of upper region processing advantages in infants (Macchi Cassia, Turati, & Simion, 2004; Quinn, & Tanaka, 2009), a fixation time advantage for the upper half of the face was here evident in children.

Concerning the number of fixations per second, participants showed to use a central point of fixation (which is aligned with the nose) for upright faces of female but not male gender. This finding fits well with evidence of visual scanning strategies used for exploring own-race faces by Asian adult and infant participants (Blais, Jack, Scheepers, Fiset, & Caldara, 2008; Liu et al., 2011), but it seems at odd with the triangular pattern of fixations, which is well-established in studies with Caucasian adults (for a review, see Caldara 2017). In spite of this, such pattern of exploration could suggest that children used a configural, therefore mature, strategy for exploring the most experienced gender (i.e., female faces). That is, the use of a central-region strategy could help children in encoding perceptual distances between internal features of female faces, thereby it could be considered as an optimal strategy for global processing of faces. Moreover, the sampling of the mouth distinguished the exploration of female and male own-race faces, suggesting that the mouth may be a cue to gender discrimination in own-race faces. Similarly, children showed greater proportional number of transition across internal features on female own-race faces compared to male own-race faces. Hence, children seemed to make more shifts between internal features for encoding female own-race faces, likely suggesting an attempt at binding the relations among internal features of the most experienced category of faces. Such exploration strategy could be considered a mature approach for deeply encoding the global structure of a face (Firestone et al., 2007) and could ultimately reflect the massive experience with female faces of own-race.

Altogether, findings on the visual exploration of internal AOIs showed that children adopt different visual scanning strategies for processing female and male as well as own- and other-race faces. It is known that Western Caucasian adults explore faces using a triangular scanning pattern over the eyes and the mouth (Blais et al., 2008; Caldara, 2017). Moreover, studies with infants reported developmental changes in scanning internal features of own- and other-race faces. Indeed, with increased age of participants, own-race faces seem to be explored looking longer at the eyes and less at the mouth (Wheeler et al., 2011). In spite of this, the data on children’s scanning patterns suggest that the mouth could be a diagnostic area that differentiated the sampling of female and male own-race faces. Additionally, results in the present study indicate that a strategy centered on the nose is implemented for holistically explore female but not male faces. Overall, it seems that children use specific visual scanning patterns for female faces of own-race, therefore suggesting that their representational space for faces is organized to reflect the perceptual characteristics of their primary caregiver.

Analyses on the pupil size variation indicated that, when presented in their canonical upright orientation, own-race female faces were processed in a more effortful and deep manner than male individuals. Thus, the expert coding afforded to female own-race faces was coupled with pupil dilatation, which indicates that more cognitive resources were used to process own-race faces (Beatty, 1982; Granholm, Asarnow, Sarkin, & Dykes, 1996; see for a review Sirois, & Brisson, 2014). These results are inconsistent with those obtained with adult participants by Goldinger et al. (2009) and Conway et al. (2008), who reported greater pupil constriction during presentation of own-race faces compared to other-race faces

(Goldinger et al., 2009) and upright human faces compared to inverted faces and monkey faces (Conwey et al., 2008). On the other hand, the finding of greater dilation for female own-race faces is in line with earlier demonstrations of greater pupil dilation for upright own-age faces compared to other-age faces in children (Hills, & Willis, 2017). These findings suggest that pupil size variations in response to facial traits may reflect different mechanisms in children and adults. Future work may further explore the developmental trajectory of race and gender biases by directly comparing pupil responses to female and male, own- and other-race faces in children and adults. However, it should be noted that hypothesis-driven planned comparisons were performed to explore the interaction between race, gender and orientation factors, although it was nonsignificant. Thus, conclusions of the effect of face race and face gender on pupil variations should be carefully addressed.

Lastly, analyses on the similarity of participants' scan paths revealed that, when comparing within-subjects similarity scores, children used a more consistent strategy for upright compared to inverted faces. These findings may suggest a sensitivity for encoding faces that are presented with canonical upright orientation. Instead, the face category made a significant difference when similarity scores were compared between participants, so both the face race and face gender attributes and orientation seemed to modulate the between-subjects similarity of scanning patterns. That is, scan paths were more similar from one participant to another (between-subjects similarity scores) for upright compared to inverted faces, and when children viewed less experienced category of faces, namely male faces of other-race. Even though such finding was unexpected, it is reasonable to infer that the experience gathered with the caregiver-like attributes of faces allow participants to build up individualized strategies for exploring the category of faces that they have more often encountered (i.e., female faces of own-race). Otherwise, children could use a more general, therefore more similar each other, strategy when they scanned less experienced faces.

These results suggest that during preschool age children's processing strategies undergo a period of reorganization that could be accounted for the interplay between children's expanded face experience, and age-related developmental tasks (Scherf, & Scott, 2012). That is, data of Study 3 revealed that children use specific visual scanning strategies for encoding female own-race faces, underlining the effect of the experience with caregiver-like faces gathered since early infancy. At the same time, children exhibit similar exploration patterns for male faces of other race, which could presumably reflect their interest in the perceptual characteristics of other people other than the primary caregiver. When considered alongside previous research on the interaction between face race and face gender within the first year of life (Tham et al., 2015), data on gaze movements of the present study seem to suggest that children exhibit preferential visual scanning strategies for the same category of faces for which young infants show a preferential face-processing behavior, namely female own-race faces. Although at the end of the first year of life infants show recognition advantage for own-race faces regardless of gender, it is reasonable to assume that early experience combined with further interactions with female faces (e.g., teachers) contributed to consolidate children's perceptual strategies in exploring caregiver-like faces. Investigation of developmental trajectories in encoding face race and face gender attributes as well as analyses of the relative contribution of quantity and quality of interactions with people in shaping face-processing behavior were beyond the scope of Study 3, but should be an important question for future work.

Study 4

Children's neural categorization of race and gender facial attributes as revealed by steady-state visual evoked potentials

Aims

Study 4 aimed to investigate the categorization of face race and gender attributes in 3- to 6-year-old children by means of a Fast Periodic Visual Stimulation (FPVS) paradigm, which provides electroencephalographic (EEG) responses known as steady state Visual Evoked Potentials (ssVEPs). Fast periodic visual stimulation is based on the assumption that a periodically presented stimulus elicit a periodic EEG response, namely ssVEP, only if this periodicity is detected by the brain (for a review see Norcia et al., 2015). This method has recently reported to provide an objective measure of face discrimination (Rossion, & Boremanse, 2011) and categorization by presenting two stimulus categories at different frequency rates (de Heering & Rossion, 2015; Peykarjou, Hoehl, Pauen, & Rossion, 2017). An advantage of this technique when compared to classic Event-Related Potential (ERP) measures is that ssVEPs are relatively immune to artifacts and yield a high signal-to-noise ratio, such that few minutes of stimulation are required to obtain a robust effect.

Perceptual categorization of faces has been documented with neural and behavioral measures in adults, thus human faces activate specialized regions along the ventral visual pathway with a right hemispheric advantage (Haxby, Hoffman, & Gobbini, 2000; Rossion & Caharel, 2011). Recently, categorization of human faces from many non-face visual objects has been demonstrated in adults with a FPVS task (Rossion, Torfs, Jacques, & Liu-Shuang, 2015). Similarly, human faces elicited a strong right-lateralized occipito-temporal categorization response when compared to both objects and phase-scramble faces in 4–6-month-old infants (de Heering & Rossion, 2015). Moreover, recent researches investigated infants' neural underpinning of species bias using FPVS and an oddball task design. Results of these studies revealed that the ssVEPs responses of 9-month-old infants were sensitive to individual-level differences within ape faces (Ryan Barry-Anwar, Hadley, Conte, Keil, & Scott, 2017) and to the categorization of unfamiliar (i.e., ape faces) presented among human faces (Peykarjou et al., 2017).

To extend evidence of neural processing of different categories of faces (i.e., own- versus other-race, female vs male face) in preschoolers, children's categorization of face race and face gender attributes was investigated by comparing ssVEP responses to own- and other-race faces as well as female and male faces. Using an oddball task design, it was measured the neural activity elicited by base and oddball stimuli, differing on one dimension of interest (i.e., race or gender), that were presented at two different periodicities within the same sequence. Hence, if children are able to categorize oddball from base category of faces, two periodicities would be detected, namely the base response (6 Hz) and the oddball response (1.2 Hz). In contrast, if children do not categorize the dimension of interest, it will be detected only one periodic response at 6 Hz (base response). Given the on-going nature of the study, in order to increase the power of the study, which is currently reduced due to the limited sample size, the effect of participant age was omitted in the analyses, although the evaluation of the effect of the age is within the aims of Study 4.

Method

Participants

Participants were the same 19 children who took part in Study 3. Three children were excluded from the analyses because they did not complete the task (N = 1) or did not contribute enough usable trials per condition (see below, N = 2). The final sample consisted of 15 3- to 6-year-old children (9 males, mean age = 4 years 3 months; range = 3;2 – 5;5). All children were from middle-class Caucasian families and had no history of neurological or visual impairments. All parents reported that the children spent the majority of their time with their mother (70%) and other adult females (66%; i.e., teachers, babysitters, or family friends). All children except one attended the daycare center and had regular exposure to Caucasian children (70%). Parents of participants were paid $10 and children received a small toy for their participation. The University of Florida Institutional Review Board approved all methods and procedures used in the study.

Stimuli

Visual stimuli consisted of 20 digitalized high-quality gray-scale images depicting Caucasian and Asian female or male faces, 5 per category. Caucasian faces were selected from NimStim and Radboud Faces databases, while Asian face were from CUHK Face Sketch database and a custom database. All faces showed external features (i.e., hair, ears and neck), were unfamiliar to participants and displayed a full-front neutral expression with open eyes. Through the use of Adobe Photoshop software all face images were equated for luminance and contrast levels and pasted on a white background. Within each category, faces were subsequently varied in luminance (from a 40% decrease to a 40% increase from the original image) and size (from 95% to 105% of the original image size). Both luminance and size varied randomly during presentation, to ensure that any oddball responses were primarily due to changes in face attributes, and not low-level stimulus features (Dzhelyova & Rossion, 2014). The mean (± SD) height × width of the facial image was 1161.75 (± 16.49) x 805 (± 29.65) pixels, corresponding roughly to 28.74° x 20.13° at a viewing distance of 60 cm.

Apparatus and Procedure

Participants were tested individually in a dedicated darkened and sound attenuated room. Each parent was in the same testing room although out of the infant's sight, and was instructed to remain silent during the whole testing session. Participants sat on a child high chair in front of a VIEWpixx display (resolution 1920 x 1200) where the stimuli were presented at a viewing distance of 60 cm. EEG was acquired using a 128-electrode HydroCel Geodesic Sensor Net (Electrical Geodesic Inc., Eugene, OR), amplified using a DC-coupled 128-channel high input impedance amplifier (Net Amps 300 TM, Electrical Geodesics Inc., Eugene, OR). Amplified signals were low-pass filtered online at 100 Hz and sampled at 1000 Hz. Impedances were checked prior to the beginning of recording and considered acceptable if lower than 50 kΩ. All electrodes were referenced online to the vertex (Cz). Eye movements were monitored via a webcam attached to the computer screen. The FPVS task was structured as an oddball task, and to engage children on paying attention to faces, they were asked to perform the same "catching Dory" game used in Study 3. Stimulus sequences were presented using the Psychtoolbox version 3.0.13 for Windows in Matlab version 2016b 9.1.0.441655 (MathWorks Inc.) at a rate of 6 Hz (6 images/s). To align the child's gaze to the screen, each sequence started with a centrally presented animation; as soon as the infant fixated the animation, the experimenter manually launched the sequence. Each sequence was composed of four identities from one face category (i.e., the standard) followed, every fifth stimulus, by a novel identity that differed from the standard in race only or gender only information (i.e., the oddball) (i.e., AAAABAAAAC). All faces were randomly selected from their respective category, and varied in size and luminance in order to reduce neural responses to low-level stimulus features. Given this design, the oddball stimulus was presented at the frequency of 1.2 Hz (6 Hz/5), and could be directly identified in the EEG spectrum as the signature of infants' face categorization response. Each trial lasted 10 s, and included 10 sequences composed of the same pair of face attributes (e.g., Caucasian male and female faces) in which each attribute was presented as both the standard and the oddball; therefore, each trial included 12 oddball faces. A total of 32 trials were presented (8 for each face attributes pair) and the whole testing session lasted approximately 6 to 10 minutes (Figure 4.1).

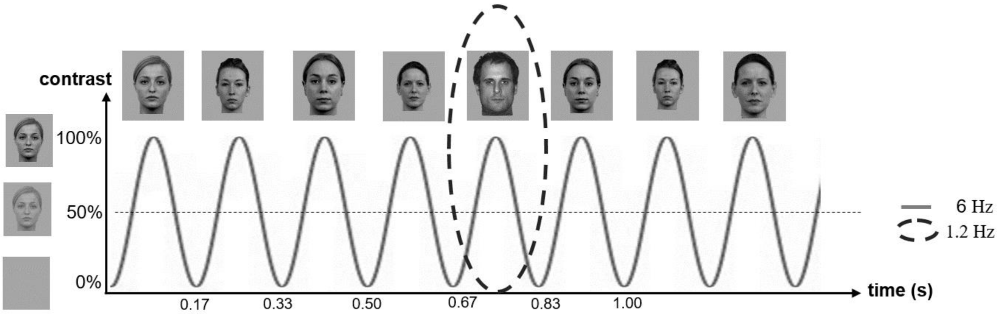


Figure 4.1. Example of a stimulus sequence of the FPVS oddball task. Faces were presented centrally on the screen at a rate of 6 stimuli per second (base rate: 6 Hz). Every fifth face (circled) was a stimulus that varied in race or gender information (oddball rate: 6Hz/5 = 1.2 Hz). Faces varied in size and luminance in order to reduce neural responses to low-level stimulus properties. The contrast/opacity of the image rapidly increased and decreased at each presentation such that the maximal contrast was reached at approximately 0.08 seconds.

EEG pre-processing and analyses

Custom scripts using EEGlab 13.6 and MATLAB 2016 were used for all processing steps. A bandpass filter was applied to EEG data. It was used a high-pass cut-off of 0.02 Hz, 3rd order Butterworth filter with a slope of 18 dB/octet and a low-pass cut-off of 30 Hz, 6th order Butterworth filter with a slope of 36 dB/octet. Filtered data were segmented from 100 ms before the start to the end of each 10s sequence. Before cleaning data from artifacts, the outermost band of electrodes (17, 43, 48, 49, 56, 63, 68, 73, 81, 88, 94, 99, 107, 113, 119, 120, 125, 126, 127, and 128) was removed from analyses due to the presence of noise.

For each trial, bad channels were identified based on the values of median absolute voltage, standard deviation of voltage, and the maximum difference in voltage at each channel. These three metrics were summed to create a quality metric index, and all channels 2.5 standard deviations or greater than the median quality metric index were removed. On the remaining channels, the electrodes 3.5 standard deviations or greater than the updated median quality metric index were identified and removed. Bad channels were replaced using the average voltage from up to six of the nearest channels. If any of the closest channels were previously marked as bad, fewer than six channels were used for the interpolation. No more than 10% of channels were interpolated for a given trial. The average reference was then computed and applied to all channels. Trials in which the participant did not fixate the screen for at least half of the trial length were removed, while remaining trials were visually inspected for artifacts or noise and removed if off scale was greater than 50% of each 10 second trial. If less than half of a trial had artifacts or noise, such bad portions were removed by replacing the values with zeros. This allowed for a manual artifact removal without creating trials of variable length. 5.5% of all trials (30 out of 544 total) were excluded because noisy signal was greater than 50% of the trial length, while 32% of all trials (175 out of 544 total) included manually removed artifacts.

In order to allow frequency-domain analyses, the 100 ms before the start of each trial was removed so that segments contained an integer number of 1.2 Hz cycles. A windowed Fast Fourier Transform (FFT) was then applied to each trial individually at a frequency resolution of 0.10 Hz (= 1/10s). Once transformed to the frequency domain, signal to noise ratios (SNR) were computed for each individual trial. The SNR was calculated as the ratio of the amplitude at each frequency of interest to the average of the 12 surrounding frequency bins (6 on each side, excluding the immediately adjacent bin on either side). If the child did not have an SNR of at least 1.5 Hz for the base frequency over medial occipital group of electrodes (70, 75, and 83), that trial was removed. Participant was included for analysis if he/she had at least one good trial of the same pair of face attributes. Based on previous studies (de Heering & Rossion, 2015; Liu-Shuang et al., 2014) and visual inspection of the topographical distribution of neural response, three Regions Of Interest (ROIs) were identified across posterior scalp regions (left occipital channels: 65, 66, 69, 70; medial occipital channels: 71, 74, 75, 76, 82; right occipital channels: 83, 84, 89, 90), and seven additional ROIs, three across parietal regions (left parietal channels: 50, 51, 58, 59; medial parietal channels: 62, 67, 72, 77; right parietal channels: 83, 84, 89, 90)and four across centrotemporal regions (left temporal channels: 41, 45, 46, 47; right temporal channels: 98, 102, 103, 108; left central channels: 30, 36, 37, 42; right central channels: 87, 93, 104, 105), were also included (see Figure 4.2a). For each subject, average SNRs for the two frequencies of interest were derived for each face category within each ROI.All participants contributed an average of 13.65 (*SD* = 6.63; range 6-27 trials) out of 32 trials.

Results

In order to verify the effects of race and gender on neural categorization responses, the average base response over the occipital ROI and the oddball responses over all the examined ROIs for each of the two pairs of face attributes were compared to the signal equal to the noise level (SNR = 1) through one-tailed one-sample *t*-tests, one for each ROI.

EEG response at the base stimulation frequency (6 Hz)

Results of the 6 Hz response over occipital regions revealed that a clear standard response was evident for all conditions, *t* (14) > 2.68, *p* < .018, *d* = 1.43. The maximal 6 Hz responses was recorded at right occipital channel 83 for own- and other-race conditions (own-race: *M* = 1.69, *SD* = .92; other-race: *M* = 1.78, *SD* = .88), at medial occipital channel 74 (*M* = 1.71, *SD* = .59) and 82 for female and male faces, respectively (*M* = 1.86, *SD* = .97). The presence of a 6 Hz response recorded over occipital regions indicates that the children visual system oscillated at the same frequency as the stimulus presentation rate. In order to qualitatively understand the variance within the group, one-sample *t*-tests were performed on each child's data to determine whether each child exhibited a SNR statistically greater than 1 over medial occipital regions. Detailed individual-level results are reported in Table 4.1.

	Left Occipital		***Medial Occipital***		***Right Occipital***	
Participant	***p (t)***	***M (SD)***	***p (t)***	***M (SD)***	***p (t)***	***M (SD)***
1	,351 (,387)	1,035 (,468)	**< ,001 (7,280)**	1,610 (,435)	**< ,001 (5,431)**	1,623 (,596)
2	**,004 (3,285)**	1,469 (,514)	**< ,001 (5,287)**	1,523 (,357)	,070 (1,579)	1,305 (,696)
3	**,005 (3,184)**	1,374 (,390)	**< ,001** (5,053)	1,987 (,648)	,083 (1,490)	1,176 (,390)
4	**,011 (2,604)**	1,384 (,552)	**< ,001 (6,166)**	2,151 (,698)	**,010 (2,658)**	1,349 (,491)
5	**,050 (1,775)**	1,315 (,663)	**< ,001 (4,313)**	1,392 (,340)	**,007 (2,860)**	1,439 (,574)
6	**< ,001 (4,788)**	1,660 (,477)	**< ,001 (4,776)**	1,435 (,315)	,071 (1,580)	1,164 (,361)
7	**< ,001 (3,827)**	1,313 (,365)	**< ,001 (6,884)**	1,869 (,564)	**,003 (3,080)**	1,484 (,703)
8	,187 (,952)	1,155 (,459)	**,005 (3,553)**	1,648 (,515)	**,009 (3,115)**	1,546 (,496)
9	**< ,001 (4,071)**	1,752 (,739)	**< ,001 (4,476)**	1,649 (,580)	**,019 (2,269)**	1,339 (,597)
10	**,010 (2,529)**	1,329 (,610)	**< ,001 (4,623)**	1,553 (,562)	**< ,001 (9,342)**	2,206 (,606)
11	**,004 (3,733)**	1,694 (,526)	**,004 (3,672)**	2,173 (,904)	**,007 (3,333)**	2,030 (,874)
12	**< ,001 (4,793)**	1,734 (,701)	**< ,001 (7,561)**	2,948 (1,180)	,070 (1,550)	1,120 (,353)
13	**< ,001 (4,435)**	1,607 (,474)	**< ,001 (4,399)**	1,786 (,619)	**,003 (3,386)**	1,516 (,528)
14	**< ,001 (5,554)**	1,710 (,639)	**< ,001 (5,932)**	1,47 (,461)	**< ,001 (8,439)**	2,019 (,604)
15	**,005 (3,683)**	1,393 (,282)	**,021 (2,595)**	1,745 (,760)	**,031 (2,300)**	1,539 (,620)

Table 4.1. SNR at the base frequency (6 Hz) recorded for each participant at each occipital ROI. Significant comparisons ($p < .05$) are marked in bold.

In order to investigate whether the SNR at the standard frequency (6 Hz) differed as a function of face race (own vs. other) and face gender (male vs. female), two repeated-measures ANOVAs were performed with ROI (left vs. medial vs. right occipital) and face race (own vs. other) or face gender (female vs. male) as within-subjects factors. Earlier studies reported that adults are more efficient in categorizing same-sex faces (Cellerino, Borghetti, & Sartucci, 2004). In order to control for the potential influence of participants' gender on neural responses to the gender of the stimuli, participants' gender was added as between-subjects factor in the analyses.

The analysis on the neural response to face race revealed a non-significant trend for face race, F (1,14) = 3.22; p = .094, $p\eta^2$ = .19, as own-race faces (M = 1.73) elicited greater occipital responses compared to other-race faces (M = 1.56). The analysis on the base rate frequency responses for face gender revealed significant main effects of face gender, F(1,13) = 4.88, p = .046, $p\eta^2$ = .27, and ROI, F(2,26) = 3.55, p = .043, $p\eta^2$ = .21 (Figure 4.2b). The main effect was qualified by a significant interaction between face gender, ROI and participants' gender, F (2,26) = 4.20; p = .026, $p\eta^2$ = .24. To further explore the interaction, two separate repeated-measures ANOVAs were performed on female and male children. Results for female participants revealed that the 6 Hz response was greater for male (M = 2.05) compared to female (M = 1.59) faces, face gender main effect F(1,5) = 8.403, p = .034, $p\eta^2$ = .63. There were also a spurious main effect of ROI, F(2,16) = 3.98, p = .039, $p\eta^2$ = .33, and a spurious ROI x Gender interaction, F(2,16) = 4.17, p = .035, $p\eta^2$ = .34, which failed to lead to significant post-hoc comparisons (Bonferroni-corrected, ps > .27).

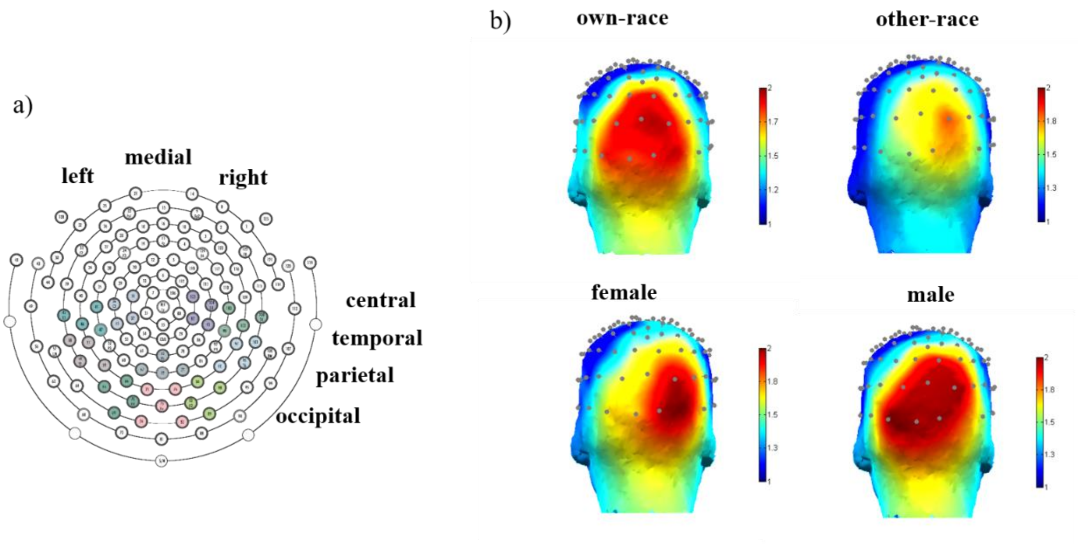


Figure 4.2. a) ROIs selected for analyses. b) Scalp map of 6 Hz SNR of each face category over posterior regions.

EEG responses at the oddball face discrimination frequency (1.2 Hz)

The 1.2 Hz response over all ROIs was examined with a one-sample *t*-test (one-tailed) against 1 (the signal equal to noise level) for each experimental condition. The signal was not significantly above the noise for either the race or gender conditions. Figure 4.3 represent the variability of 1.2 Hz oddball responses over the considered ROIs.

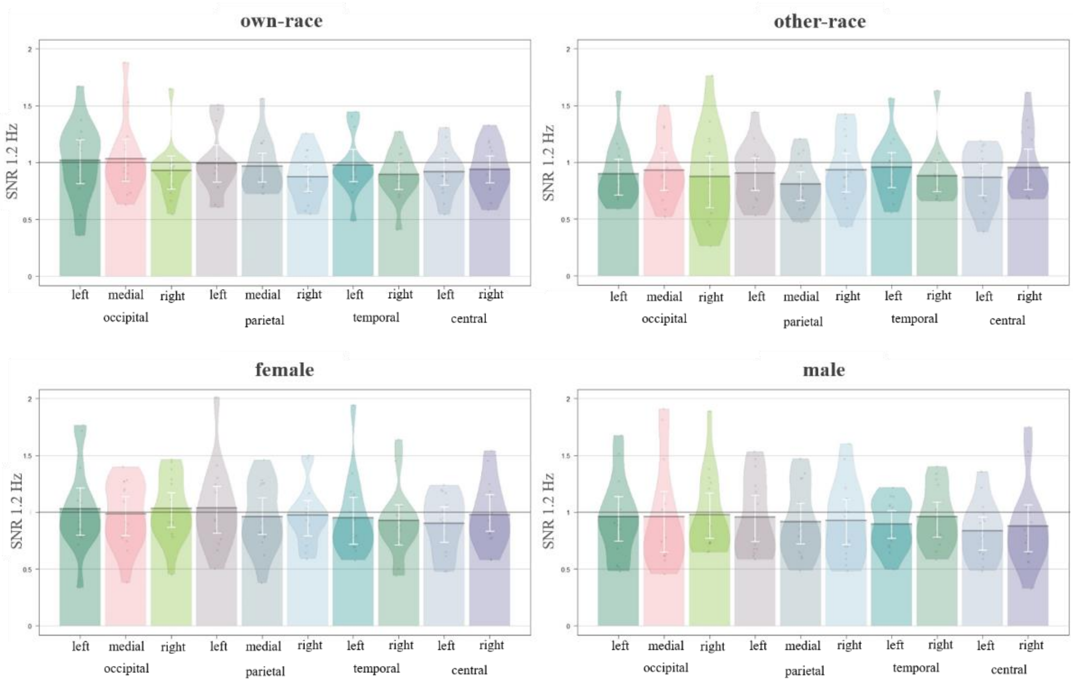


Figure 4.3. The SNR at 1.2 Hz oddball response for face race and face gender attributes. Bars include mean SNR averaged across electrodes within each region of interest. The bar plots include the mean (dark line) and 95% confident interval (white line) as well as the density of individual data points. The colors correspond to the colors of ROIs represented in Figure 4.2 (panel a).

Relations between scanning behavior and neural activity in encoding race and gender attributes

To explore possible relations between children's neural sensitivity to face race and gender and the scanning strategies they use to explore faces differing on these dimensions, the EEG responses measured during the FPVS task in the current study were correlated to all the eye movement measures derived from eye-tracking recording in Study 3. I considered the eye-tracking data of the sub-sample of participants of whom good neural categorization responses were recorded in Study 4. Both the base and the oddball responses to own-race, other-race, female and male faces over occipital areas (i.e., left occipital, medial occipital, and right occipital) were correlated to the proportion of total looking time and the number of fixations per second on each internal AOI, the proportional number of transitions across internal AOIs, the pupil size variations, and similarity scores of scan paths recorded for upright faces in Study 3. Overall, the results from correlation analyses should be considered as preliminary in light of the small sample size for both studies (N = 15).

For own-race faces, the base response in the right occipital ROI was positively related to the proportion of number of fixations on the nose area, *r* (14) = .54, *p* = .045, suggesting that children who showed synchronized response to own-race faces may have sampled more the nose of this category of stimuli. Moreover, positive relations were found between the looking time on the mouth of own-race faces and the oddball responses over both medial (*r* (14) = .67, *p* = .009) and right (*r* (14) = .68, *p* = .007) occipital channels. Together, these results suggested that a greater categorization response was related to a longer exploration of the mouth for own-race faces (Figure 4.4).

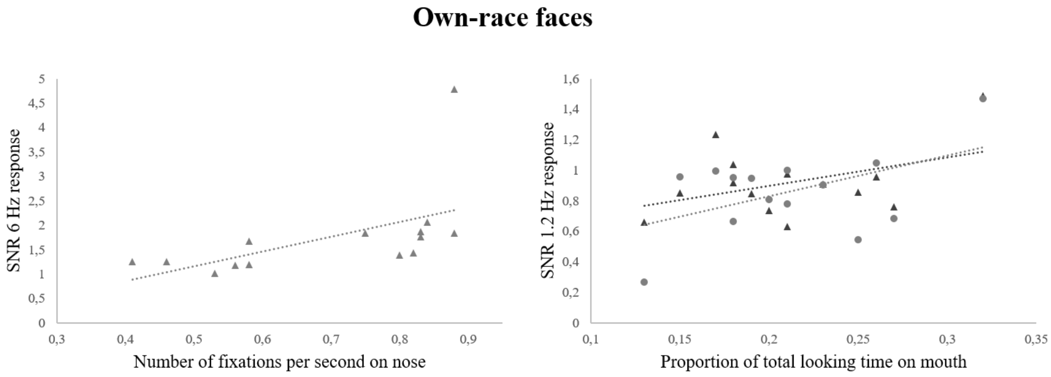
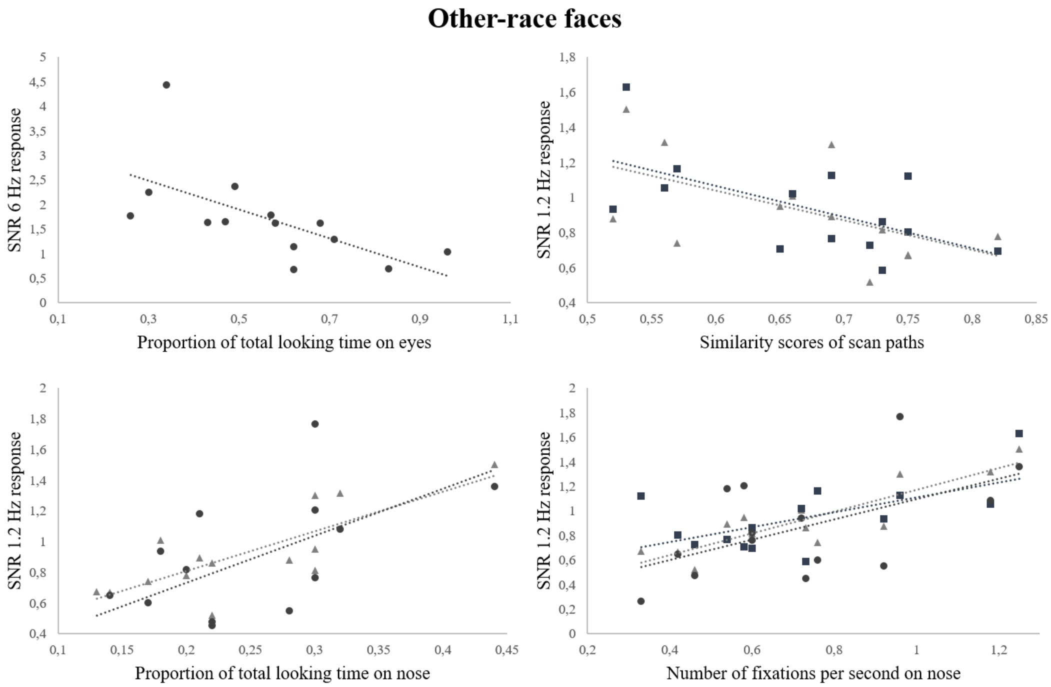


Figure 4.4. Scatterplots depicting the correlations between SNR of base rate (left) and oddball (right) responses and eye movements made for exploring own-race faces. Neural responses over medial occipital channels are depicted with triangles, while circles refer to neural responses over right occipital channels.

For other-race faces, the base response in right occipital ROI was negatively related to the looking time on the eyes, *r* (14) = -.63, *p* = .016, suggesting that children's perceptual responsiveness at the neural level was related to shorter sampling of the eyes in these faces.

Furthermore, the oddball responses over both medial (*r* (14) = -.56, *p* = .038) and left (*r* (14) = -.60, *p* = .022) occipital ROIs were negatively related to the similarity scores of other-race faces. These findings suggest that a greater categorization of other-race faces was related to a less consistent strategy in exploring those faces. Additionally, positive correlations were found between the looking time on the nose and the oddball response over medial (*r* (14) = .79, *p* = .001) and right (*r* (14) = .62, *p* = .018) occipital channels as well as between the number of fixations on the nose and the oddball response to other-race faces over all occipital ROIs (left: *r* (14) = .88, *p* < .001; medial: *r* (14) = .61, *p* = .020; right: *r* (14) = .55, *p* = .042). Together these results show that stronger categorization responses are associated to gaze movements directed towards the exploration of the nose of other-race faces (Figure 4.5).



Other-race faces

Figure 4.5. Scatterplots depicting the correlations between SNR of base (top-left) and oddball responses and eye movements made for exploring other-race faces. Neural responses over medial occipital channels are depicted with triangles, circles refer to neural responses over right occipital channels, while squares represent neural responses over left occipital ROI.

For female faces, the oddball response in left occipital ROI showed a positive relation with both the looking time on the mouth area (*r* (14) = .66, *p* = .011) and the proportional number of transitions (*r* (14) = .58, *p* = .029) for encoding such category of faces. These findings suggest that the categorization of female faces was combined to a longer exploration of the mouth as well as an encoding strategy characterized by frequent shifts between internal features of female faces. Interestingly, the base response in right occipital ROI was negatively correlated to the pupil area in response to female faces, *r* (14) = -.63, *p* = .016, suggesting that children’s perceptual responsiveness at the neural level was related to greater pupil constrictions in response to female faces (Figure 4.6).

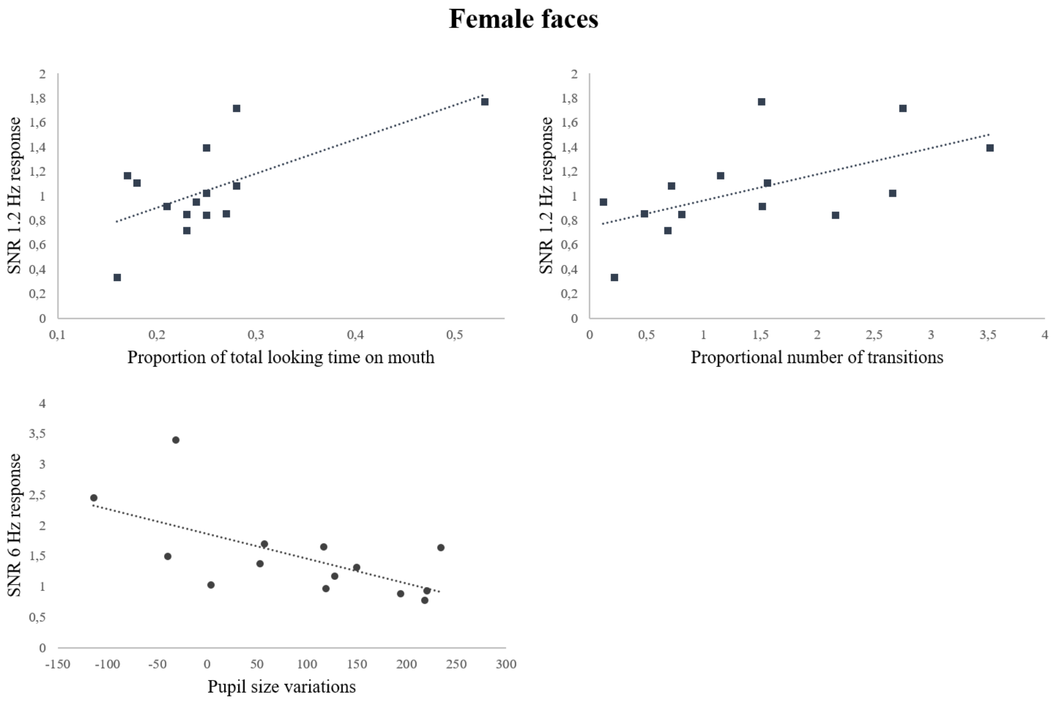


Figure 4.6. Scatterplots depicting the correlations between SNR of base rate (bottom) and oddball (top) responses and eye movements made for exploring female faces. Neural responses over left occipital channels are depicted with squared, while circles refer to neural responses over right occipital channels.

There were no significant correlations between neural responses and gaze scanning patterns of male faces, *r*s (14) < .44, *p*s > .119.

Discussion

Study 4 measured children's electrophysiological brain activity in response to race and gender attributes of faces. In the FPVS task used here, faces of a certain category were temporally embedded in a sequence of a different category of faces, so that every cycle of the same trial provided information about the neural underpinning of face race or face gender categorization. So far, children included in the current sample did not show neural signature of race nor gender categorization. However, although they showed non-significant differences in neural responsivity to different face types, the SNR at base rate frequency (6 Hz) over occipital channels was larger for own-race faces than for other-race faces, and in female children, it was also larger for male faces than for female faces.

As already mentioned only few studies examined the relation between race and gender biases in infants' face processing abilities (Kelly et al., 2007; Tham et al., 2015), and, to my knowledge, to date the question of whether and how face gender modulates sensitivity to other facial traits in children has remained unexplored. Answering this question is important for a full understanding of the development of face categorization, because, in everyday life, people simultaneously occupy multiple social categories, and this overlap could affect some aspects of social perception. Evidence from infant studies shows that by 3-4 months of life infants develop a preference for female faces of the race of the primary caregiver (Quinn et al., 2008). However, this pattern of preference seems to change already by the end of the first year, when infants no longer show any gender preference but exhibit a discrimination advantage for own-race faces (Liu et al., 2015; Tham et al., 2015). These findings may well stem from the different degree of homogeneity/heterogeneity in the race and gender composition of the infant's facial environment (Sporer, 2001). Indeed, Liu and collaborators (2015) reported that the transition from a female gender preference at 3-4 months and the absence of gender preference at 9 months is related to a significant increase in the amount of infants' experience with male individuals (Liu et al., 2015). These findings indicate that face processing abilities are not an all or none phenomenon and that, throughout development, category boundaries between face attributes likely adjust as a result of the changing properties of the experience provided by the individual's social environment.

Existing research using event-related potentials (ERP) in adult participants has shown that the adult brain responds to basic-level category changes (e.g., houses versus faces) at the level of the N170 ERP component (Caharel, d'Arripe, Ramon, Jacques, & Rossion, 2009; Rossion & Jacques, 2011) and face identity changes at the level of the N250 component (Rossion & Caharel, 2011; Schweinberger, Huddy, & Burton, 2004). In infants, the N290 and the P400 ERP components recorded over medial occipito-temporal regions have been identified as the developmental precursors of the adult N170 (for review, see de Haan, Johnson, & Halit, 2003). Both these components show sensitivity to the species of the face in 3- to 12-month-old infants (de Haan, Pascalis, & Johnson, 2002; Halit, de Haan, & Johnson, 2003), and in 9-month-old infants the N290 show sensitivity to the race of faces, being larger for own-race faces than for other-race faces (Balas, Westerlund, Hung, & Nelson, 2011, Vogel, Monesson & Scott, 2012). The N290 is also sensitive to face gender, being larger in response to female faces than to male faces in 7-month-old infants who accumulated extensive experience with female individuals, suggesting the presence in these infants of a processing advantage for female faces (Righi, Westerlund, Congdon, Troller-Renfree, & Nelson, 2014). Moreover, enhanced late positivity over occipital channels for male faces, recorded during rapid repetition ERP paradigm, seemed to reflect a potential effort increase in processing unfamiliar (male) face gender (Peykarjou, Pauen, & Hoehl, 2016). Overall, evidence from ERP studies with infants suggests that the electrophysiological response to faces develops alongside the changes in the amount of experience with different kinds of faces.

Moreover, the link between the neural sensitivity and the increase in experience with faces is evident at 6 months in enhanced neural activity in recognition of familiar faces (i.e., the mother’s face) compared to an unfamiliar face (i.e., the stranger’s face) (de Haan & Nelson, 1997). Such pattern of neural response is maintained in early childhood, when toddlers show greater ERP responses to the mother’s face than to a stranger’s face. However, an opposite pattern of neural activity is reported for older children (45-54 months), who show greater responses to a stranger’s than the mother’s face, likely due to the different social and cognitive tasks in which the children are engaged (i.e., relationship with teachers and other adult people; Carver et al., 2013). Indeed, such age-related differences in neural responses could reflect a greater interest in learning about other (less familiar) people, once a firmly relationship with the primary caregiver, thereby her facial representation, is established.

Categorization is a basic process that allow us to organize the world, offering a simple way to process the enormous amount of stimuli that individuals encounters every day. One of the EEG-based techniques that can be used to investigate face category discrimination and that is valuable for developmental studies is FPVS (for review, see Norcia, Appelbaum, Ales, Cottereau, & Rossion, 2015). Through the analysis of the ssVEPs, that reflect the synchronization of the perceptual system to the same rate or integer multiples of stimuli presentation frequency, this method provides a measure of stimulus discrimination. FPVS has primarily been used to investigate face processing in adults (for review, see Rossion, 2014), while few studies have used this technique to examine face processing in infancy

(Barry-Anwar et al., 2017; de Heering & Rossion, 2015; Farzin, Hou, & Norcia, 2012; Peykarjou et al., 2017). Both Farzin and colleagues (2012) and de Heering and Rossion (2015) compared the cortical responses to face versus objects in 4- to 6-month-old infants. They respectively found a face-related neural response with a bilateral topographic distribution over occipital areas compared to a neural response restricted to medial occipital region for objects (Farzin et al., 2012), and a right lateralized response for face categorization, which was not evident for objects neither scrambled stimuli (de Heering & Rossion, 2015). Recently, it has been reported that 9-month-old infants discriminate ape faces at individual level, showing right lateralized neural responses (Barry-Anwar et al., 2017). Furthermore, Peykarjou and colleagues (2017) reported that 9-month-olds rapidly categorize human and ape faces, but unfamiliar faces presented among human faces elicited an increase in the categorization response. These results likely reflect infants' habituation for the familiar (i.e., human) standard category, and stronger release for the unfamiliar (i.e., ape) category deviants (Peykarjou, Hoehl, Pauen, & Rossion, 2017).

Given the feasibility in examine infants' neural responses to high-level natural visual stimuli such as faces and objects by means of ssVEPs, it was tested children's category-level neural response to face race and face gender attributes. Unexpectedly, preliminary results revealed nonselective categorization responses in the analyzed regions of interest. Despite the null results of 1.2 Hz activity, children exhibited different responses at the fundamental frequency (i.e., 6 Hz) when presented to different category of faces.

Indeed, enhanced 6 Hz activity was recorded over occipital areas for own-race faces compared to other-race faces, suggesting larger neural sensitivity to faces of the more familiar race. Furthermore, participants' gender modulated neural responses to male and female faces. That is, while face gender did not modulate neural synchronization in male participants, female children showed enhanced occipital responses when viewing male faces. Although it has been reported that gender differences in the processing of male faces may emerge as male children become more motivated than female children to learn about male faces and other gender-relevant characteristics (Martin, Wood, & Little, 1990), result of Study 4 alternatively suggests larger neural responsiveness of female participant to process the less experienced face gender (i.e., male faces). Thus, the preference for female faces relative to male faces observed in infancy (Quinn et al., 2002) seems to change with increased age, therefore reflecting the increase in experience with male faces. Given the preliminary nature of the results, the small sample size and scarcity of available evidence in the literature on the interaction between face race and face gender in childhood, it will be important to examine with further studies the developmental trajectory of both race and gender biases in children.

Although preliminary, results from correlational analyses revealed interesting relations between neural responses elicited by race and gender facial attributes and the visual scanning strategies used by children while exploring faces of different races and gender. That is, enhanced 6 Hz responses to own-race faces related to both longer fixation durations on the mouth of these faces and less pupil dilatation when children viewed female faces. Moreover, the mouth area of both own-race faces and female faces was explored for longer time by children that exhibited stronger 1.2 Hz response for those categories of faces; likewise, more transitions between internal features of female faces were made by those children that exhibited greater categorization response (1.2 Hz) for female stimuli. Together these data suggest that less cognitive effort (i.e., pupil constriction) in processing female faces is associated to greater neural responsiveness to these stimuli. Moreover, shifting within internal feature as well as exploring the mouth region define the strategy used by children that better categorize the most experienced face attributes (i.e., own-race and female faces).

Furthermore, neural activity in response to other-races faces was related to a strategy in which participants explored more the nose and less the eye region of those faces. These findings seem to be at odds with evidence indicating that Caucasian adults focus on the eyes when exploring faces of all races (Caldara, 2017). Despite this, a central-based strategy could likely reflect the attempt to use an expert strategy for exploring less familiar faces and here it fosters other-race face categorization.

In conclusion, here it was reported that race and gender attributes are capable of modulating neural responsiveness in childhood. The constant experience with own-race faces influence children's neural responses to this face race, which were selectively enhanced for own-race faces. Instead, the enhance response to male faces found in girls could rely on their changing experience with other people beyond the primary caregiver as well on their developmental task to develop the self-mastery, which made female children more sensitive to the differences between female and male

GENERAL DISCUSSION

Study 3 and 4 provided evidence on the processing of face race and face gender attributes in preschool-aged children, by examining both visual scanning strategies and neural responses to own- and other-race, female and male faces.

Results of Study 3 revealed that the visual exploration strategies adopted by Caucasian children while exploring faces are not dissimilar from those adopted by Caucasian adults (Blais, Jack, Scheepers, Fiset, & Caldara, 2008; Caldara, 2017), as they sample more often and explore for a longer time the upper portion of the face, with a strong preference for the eyes. Notwithstanding this general preference, children showed different patterns of exploration of the nose and mouth regions as a function of face race and age. Indeed, children seemed to extract diagnostic information from faces scanning the mouth area of female own-race faces. Moreover, children fixated longer the nose of upright female faces, possibly reflecting the use of a holistic processing strategy that facilitates the simultaneous capture of information across the entire face. Similarly, the correlations between children's eye movements and neural responses revealed that greater 1.2 Hz activity in response to other-race faces were recorded for those children who used a center-based scanning strategy. This relation confirms that making fixations on the nose of the faces could reflect a mature strategy that support face categorization abilities.

These findings suggest that children use specific scanning strategies that characterize the exploration of faces with the same characteristics of their primary caregiver (i.e., female own-race faces) and provide support to the hypothesis that face processing system adapts to reflect children's experience in social environment. Given the large experience accumulated with own-race faces, mainly females (Rennels & Davis, 2008; Sugden & Moulson, 2014), it is also likely that children have developed individualized strategies for exploring the most often encountered category of faces. To address this question, analyses of the similarity scores of scan paths were more useful for characterizing similarities and differences of visual scanning patterns for each face category. Findings of Study 3 revealed that children used consistent, thereby similar each other, gaze patterns for exploring the less experienced combination of race and gender, namely other-race male faces.

Study 4 provided novel evidence on neural processing of face race and face gender attributes in children. It was investigated children's neural response at the exact same rate frequency of face presentation (i.e., base rate response/6 Hz) and at the oddball frequency (i.e., oddball rate response/1.2 Hz) for categorizing race and gender variations. Although no neural categorization of either face race or face gender was found at the oddball frequency, children's base rate responses seemed to be modulated by face category. Specifically, cortical responses over occipital areas were modulated by face race, showing enhanced neural responsiveness to own-race faces in all children.

In contrast, the neural response to face gender was not that clear, as shown by the opposite pattern of activity in female and male participants. Indeed, girls displayed occipital responsiveness to male faces, while boys' neural activity did not differed as function of face gender. This finding is partially at odd with previous evidence in infants, which showed a processing advantage for female faces at both the behavioral (Quinn et al., 2002; Ramsey, Langlois, & Marti, 2005) and neural level (Peykarjou et al., 2016; Righi et al., 2014). The female face advantage in infants has been attributed to the larger amount of experience gathered with female caregivers during early infancy (Rennels & Davis, 2008; Sugden & Moulson, 2014). Hence, it is reasonable to assume that, in children, the increase in the amount of exposure to individuals of both genders with respect to infancy results in an increased neural responsiveness to gender variations. Also, girls' sensitivity to male faces could reflect the increased processing effort for faces that do not match with the child's own gender nor with the gender of the primary caregiver.

While together the findings on neural activity do not necessarily constitute evidence of the neural categorization of racial and gender attributes, they indicate the presence of a neural substrate for attribute-specific responses to faces and provide novel evidence of the face processing in childhood. Furthermore, both eye tracking and electrophysiological data do not fully resolve whether the face processing is based on a hierarchical structure of social attributes of faces and whether the face biases are functionally related to the developmental tasks and to the variable face-diet of childhood. However, results of Study 3 and Study 4 suggest that face processing of race and gender attributes differs from previous ages depending on perceptual and emotional significance of faces during a particular point in development. Future studies should examine these age-related changes longitudinally, also considering the social and cognitive tasks in which the child is engaged

CONCLUSION

The present research focuses on the role of perceptual experience provided by social environment in shaping age, race and gender biases in face processing in infancy and childhood. In the series of studies presented in this dissertation, it was used a multi-method approach to explore how the face-processing system adapts to reflect changes in the individual's perceptual and social experience and in the developmental tasks that the individual is facing at each developmental stage, which may have an impact on the information that he/she needs to extract from faces.

There is ample evidence in the literature showing that, when different social attributes of faces are compared, the processing of some of them has priority over others, a phenomenon which gives rise to a number of so-called face-processing biases. For instance, 3-month-old infants have been shown to prefer female over male faces (Quinn et al., 2002), and to generalize such preference across adult and child faces (Quinn et al., 2010), but not across own-race and other-race faces (Liu et al., 2015; Quinn et al., 2008). Caucasian infants have also been shown to manifest a visual preference for adult over infant faces when viewing own-race faces, but not other-race faces (Heron-Delanay et al., 2016). In 3-year-old children, a recognition advantage for own-race over other-race faces has been shown to exist for adult faces but not for child faces (Macchi Cassia, Luo et al., 2014). Nevertheless, only few more years of experience with peer's faces seems enough for determining the emergence in 6-year-old children of a preference for own-race child faces (Heron-Delaney et al., 2017).

This variability in the magnitude and direction of face processing biases across development reflects the fact that, unlike race, for which experience typically remains stable across an individual's lifespan, age and gender are a more changeable dimension, for which experience varies across development. Due to the variable nature of facial dimensions' experience throughout development, researches on processing social attributes and on the interaction between those facial characteristics represent an ideal tool to investigate the way in which the face-processing system adapts to reflect individual variability in social experience, including exposure to specific face types and/or relevant face-to-face interactions.

It has been argued that social developmental tasks, namely salient tasks that are specific to a developmental stage (Havighurst, 1972), shape the individual's perceptual system, and ultimately entail superior recognition for some kinds of faces over others. That is, social, emotional, and contextual milieu of an individual's environment outline developmental tasks, so that the computational goals of the perceptual system (Marr, 1982) reflect the solutions to these tasks (Picci & Scherf, 2016; Scherf & Scott, 2012). For instance, it is likely that the formation of an attachment relationship with caregivers shapes the goal of the visuoperceptual system in tuning infant/child behavior toward an expert processing of facial attributes that are similar to those of the primary caregiver (Scherf & Scott, 2012). Evidence supports this hypothesis by showing that infants and young children are better at processing adult faces compared to infant faces (Macchi Cassia et al., 2014), and adult female faces compared to adult male faces (Quinn et al., 2010), unless the primary caregiver is male (Quinn et al., 2002).

The series of studies presented in this dissertation shows how experience with different social attributes shapes scanning strategies and neural responses to faces of different races, gender and ages in infancy and childhood. Specifically, Study 1 investigated how early experience with adult individuals affects face processing abilities as well as scanning strategies of infants, so as to modulate their processing bias towards young adult faces. Study 2 investigated how early experience with siblings as well as subsequent interactions with peers shape face-processing abilities of 5-year-old children. Finally, it was explored how everyday children’s experience with race and gender facial attributes modulates visual exploration (Study 3) and neural responses (Study 4) in preschoolers. All results corroborate the hypothesis suggested by Scherf and Scott (2012) of a reciprocal interplay between significant environmental inputs and specific developmental tasks in shaping developmental trajectories of face-processing behavior.

Results from Study 1 showed that perceptual narrowing towards adult faces occurs by the end of the first year of life, and that such tuning is directly related to differential exposure to various age groups within each infant's social environment. For first-born infants, the proportion of encountered face ages is greatly unequal, since they spend at least 80% of their waking time in interaction with adult individuals (Rennels & Davis, 2008; Sugden et al., 2014). First-born 9-month-old participants in Study 1 showed that the ability to discriminate among faces is selectively tuned towards adult faces and it is also typified by specific visual scanning of this face age. Although the eyes represent a crucial and highly explored region in both adult and child faces, gaze movements made on adult faces were spread out over all internal features, while those made on child faces were mainly restricted to the eyes.

Critically, exploration of adult faces was characterized by longer sampling of the mouth region with respect to child faces. This results is of particular interest as the mouth is the most attractive and informative region of the face at an age when infants are trying to make sense of linguistic input (Lewkowicz & Hansen-Tift, 2012). During the first year of life, infants begin to communicate and interact with the surrounding social world. Thereby, infants appear particularly good at sharpening on caregivers' faces as well as their speech, since the caregivers are important sources of social information. In this regard, specific visual scanning of adult faces can be viewed as the result of interactions between systems used for processing faces and speech, with the goal of social communication.

Results from Study 1 confirmed previous demonstrations that by the end of the first year of life the infants' perceptual system tunes toward adult faces (Macchi Cassia et al., 2014; Proietti et al., *submitted*). Besides, the study provides the first investigation of the visual scanning strategies utilized by infants while encoding and learning adult and non-adult faces. Results show that the discrimination advantage for adult over child faces is associated in 10-minth-old infants to the use of different scanning strategies. The most relevant finding from the study is that the mouth region is sampled more in adult faces than in child faces, suggesting that infants' processing of adult faces might be guided by their acquisition of language (Pascalis et al., 2014). Indeed, studies on the development of face and language processing have identified similarities between the two domains of perceptual processing, as both develop during the first years of life from a broad nonspecific system to a system tuned towards stimulus categories that are more salient within the infant's environment (for a review see Maurer & Werker, 2014). The hypothesis has been made that, in humans, perceptual narrowing is common to all perceptual and cognitive abilities involved in communication (Pascalis et al., 2014), and that language acquisition may act as a top-down factor in driving tuning in the face domain (Hadley, Rost, Fava, & Scott, 2014). Within this framework, infants of the present work look longer at the mouth region of adult faces than non-adult faces may indicate that, at 10 months, infants are using the mouth of familiar faces as a cue to extract information on language and audio-visual matching.

Study 2 explored visual scanning behavior of 5-year-old children with and without older siblings during recognizing adult and child faces, as well as the relations between children's temperamental traits and gaze movements made for exploring faces. Results showed that, regardless of sibling experience, children better recognized upright than inverted stimuli, with a marginal advantage for adult faces.

Despite the absence of a selective face age recognition, both face age and orientation of stimuli modulated the scanning strategies involved in learning faces. That is, the eyes of adult faces were explored longer and more frequently than those of child faces, irrespective of stimulus orientation. Furthermore, children utilized a central-based strategy (i.e., longer exploration and more sampling of the nose) while exploring inverted adult faces, which likely reflects an attempt of using an expert strategy for scanning that category of faces. Indeed, it is reasonable that children fixated the central area of adult faces trying to adopt a global strategy of scanning, to compensate the loss of configural information of those inverted stimuli.

These findings extend evidence on the age bias in preschoolers, suggesting that 5–year-old children equally well recognize adult and child faces. Results of Study 2, when considered alongside previous literature findings, show that at 5 years children exhibit similar recognition abilities to both older children (Hills & Lewis, 2011; Hills and Willis, 2016) and younger children with sibling (Macchi Cassia et al., 2012). Although preschool-aged children are focused on learning self-mastery, they are still depending on their primary caregiver. Such transitional status along with increasing experiences and interactions with peers may yield to a change in the goals of the children's visuoperceptual system, thereby producing similar recognition of adult and child faces in the present work. At the same time, though, preferential processing of adult over child faces is yet visible in children’s visual scanning patterns, which seem to reveal a subtle advantage for adult stimuli.

An additional finding from Study 2 was the association of children’s scanning strategies to specific temperamental traits. Children who exhibited high levels of activity and impulsivity, as measured by the Surgency temperamental dimension, made rushed scanning and more gaze movements when exploring faces, irrespective of face age. In contrast, children who exhibited a conscientious behavior and a willful regulation of attention, as measured by high levels of Effortful Control, spent more time and made more gaze shifts when exploring adult faces. These results underline the link between participants’ temperament and mechanisms that are used to process faces, suggesting the importance to control for individual traits when testing face recognition in children.

Studies 3 and 4 extended evidence on how 3- to 6-year-old children process both race and gender attributes, by means of an examination of their visual scanning behavior and neural responses to own- and other-race as well as female and male faces. Such studies aimed to investigate the interaction between race and gender attributes on visual scanning of faces and whether children’s neural categorization responses were influenced by face race and face gender attributes. Both Study 3 and Study 4 sought to define whether children showed a processing advantage for faces that share the same demographic characteristics of the primary caregiver, extending evidence of a caregiver-primacy model reported for young infants (Scherf, & Scott, 2012).

Results of Study 3 showed that children exhibited the typical pattern of scanning behavior shown by Westerners observers (Caldara, 2017), by distributing their fixations across the upper half of faces, with a specific preference for scanning the eyes over the nose and mouth areas. In spite of this, both the nose and mouth regions seemed to be crucial features that differentiated the exploration of face race and face gender attributes. Indeed, children preferentially directed their exploration towards the mouth of female faces of own-race, showing also central (nose-based) fixations when female faces are presented in their canonical upright orientation. Moreover, a strategy in which children’s gaze frequently shifted across internal features was specifically implemented for the exploration of female own-race faces. Such expert-like processing of female own-race faces was accompanied by significant pupil dilatation, indicating that these faces were processed in an effortful and deep manner.

Children also exhibited specific pattern of exploration for male faces, irrespective of face race. They explored these faces making few shifts across the internal features, thus using a less expert-like strategy that do not favor the extraction of configural information emerging from the spatial relations among the features. Moreover, by comparing all the participants’ scan paths for each face category, it was found that children adopted a more consistent strategy while exploring other-race male faces. This suggests that for the encoding of this unfamiliar face category they used a more undifferentiated, and thus more similar across participant, scanning strategy, while they used more differentiated and idiosyncratic strategies for exploring more familiar (i.e., female and/or own-race) faces. These results suggest that the growth of visual perceptual experience with female faces of own-race may act as a bottom-up factor that influences perceptual narrowing toward faces with the same attributes of the primary caregiver.

Importantly, to the best of my knowledge there are no studies investigating gender biases in face-processing abilities in childhood; yet, much of the work characterizing the developmental trajectory of race-related face processing biases reports no age-related changes in the magnitude of the own-race bias in early childhood (de Heering et al., 2010;

Sangrigoli & de Schonen, 2004). It should be noted that children's representational space for faces is tuned to represent the most common face race in their environment, which is not necessarily reflective of their ‘‘own’’ race (for review, see Scott et al., 2007). Unfortunately, no study has explored the amount of exposure that children typically get with individuals with specific demographic characteristics in their natural environment, as all available studies that quantify daily frequency and length of interactions with certain types of faces have focused on infancy and toddlerhood (Rennels & Davis, 2008; Sugden et al., 2014). However, it is likely to assume that, under typical conditions, children's experience with race facial attributes is quite stable, while exposure to face gender is by its nature more changeable. Given that, the influence of early experience could be very different with respect to race and gender attributes, and thus the developmental trajectories of race and gender biases in face processing could diverge. The results of Study 3 suggest that children's visual pattern of face exploration is mediated by the experience with the facial attributes of the primary caregiver. Notwithstanding, a hierarchical representation of those attributes is not that clear in childhood, probably due to the flexibility of representational system to continuously adapt to reflect ongoing experience with faces.

Study 4 extended the demonstration of the effects of race and gender attributes to neural responses underlying preschoolers' face categorization abilities. Using a Fast Periodic Visual Stimulation (FPVS) task, during which faces of a certain category were temporally embedded in a sequence of a different category of faces, every cycle of the same pair provided information about the neural underpinning of face race or face gender categorization. Although results did not show any modulation of race and gender on neural categorization responses, children did show different occipital responsiveness to the category of faces they were presented to. That is, the signal to noise ratio at base rate frequency (6 Hz) over occipital channels was overall greater for own-race faces compared to other-race faces, and in girls it was greater for male than for female faces.

The enhanced occipital responsiveness to own-race faces suggests that, in preschool years, neural circuitries sub-serving face processing are tuned to faces of the more familiar race. This finding is in line with those reported by infant studies showing that enhanced perceptual discrimination skills (Kelly et al., 2007) and electrophysiological brain responses for own-race faces (Balas et al., 2011; Vogel et al., 2012). Results of Study 4, considered alongside previous findings on race bias, show that the organization of face representation around the features that are diagnostic of the more familiar race is stable from infancy to early childhood. In contrast, neural responsiveness to face gender seems to show a different developmental trajectory, and to be influenced by participant's gender. Indeed, while face gender did not modulate neural synchronization in male participants, females did show enhanced occipital responsiveness for male faces, which induced larger signal to noise ratio at the base stimulation frequency (6 Hz) compared to female faces. These results suggest that, unlike face race, the representation of the facial cues that are diagnostic to gender show substantial changes from infancy to childhood. Indeed, as already discussed, earlier studies with infants has shown that the preference for female over male faces exhibited by 3-month-old infants (Quinn et al., 2002) disappears by the end of the first year of life (Liu et al., 2015; Tham et al., 2015). Moreover, this change on behavioral preference is coupled with a reduction of face-sensitive ERP responses (i.e., reduced N290 amplitude) to female compared to male faces (Righi et al., 2014) and with enhanced late positivity for male compared to female faces (Peykarjou et al., 2016) at the end of the first year of life.

These findings resonate well with the idea that the developmental trajectories of race and gender biases follow different pathways, possibly due to the more changeable nature of the experience accumulated by the individual with gender facial traits compared to race traits. Although infants' gender experience is focused on female individuals (Rennels & Davis, 2008; Sudgen et al., 2014), children start to be less dependent on their primary caregiver as their developmental task is no longer that of forming an attachment relation with the caregiver, but rather that of learning self-mastery. Such developmental task, together with the broadening of the child's social environment and increasing experience with peers, may boost the child's perceptual system to stress out the differences between female and male faces, yielding to enhance response to male faces that are deviant from the female-centered caregiver-based prototype. The finding that face gender modulated neural processing in female, and not in male, participants, fits well with earlier demonstration of sex difference in face processing, with adult women (Herlitz & Lovén, 2013) and young girls (Rehnan & Herlitz, 2006) showing higher face recognition abilities than males. In fact, girls in the present study were found to be more able than boys to extract gender cues from faces. It is important to note, however, that the current sample size is still limited, and the observed sex differences should be interpreted with caution until when they will be confirmed by data from a larger sample.

The results of the series of studies presented in the current dissertation provide an important contribution to our understanding of how experience affects face perception abilities across development, suggesting that the organization of face representation in young children is the result of multiple interacting factors (Smith & Thelen, 2003). It has been recently hypothesized that perceptual tuning during development is the result of a shift from primarily bottom-up processing to a combination of bottom-up and top-down influences. Bottom-up perspective describes perceptual processing as driven exclusively by external stimuli and/or their perceptual features (Sarter, Givens, & Bruno, 2001). Alternatively, top-down processing would involve the recruitment of high level and knowledge-driven mechanisms for guiding perceptual processing (Gilbert & Sigman, 2007). Within the domain of face perception, a combination of bottom-up (i.e. perceptual experience) and top-down influences (i.e. motivation derived from specific developmental tasks) could provide an exhaustive explanation of developmental trajectories of face-processing behavior. That is, both distinctive properties of early visual experiences, such as repeated exposure at close proximity to the frontal view of very few individuals from specific demographic groups (Jayaraman et al., 2015), and motivation to engage in significant social interaction with specific individuals or groups of individuals (e.g., peers) may guide attention to relevant facial features, that become embedded in the infant's and child's face representation. Face representation in infants would thus reflect the social environment in which individuals are embedded (de Haan, Johnson, Maurer, & Perrett, 2001).

Since experience with different facial attributes does not follow a linear increment, it makes sense that the developmental trajectory of face-processing biases follows a non-linear dynamic path (Smith & Thelen, 2003). The infant's visual world is initially dense with faces of a few up-close caregivers; these faces match the facial characteristics of the primary caregiver and, in turn, ensure that infants attend to those attributes of faces. In contrast, older children have a firmly established relationship with their caregiver and a stable representation of their facial attributes, and are relatively more interested in learning about other people, including peers. Hence, it is likely that during preschool years the child's perceptual system undergoes a period of reorganization as a result of changes in social experience and age-specific developmental tasks (e.g., developing self-sufficiency and building relationships with adults and peers).

In conclusion, results from Study 1 to 4 provide support to a dynamic interpretation of the development of face-processing biases, were experience provided to the individual by individual’s social environment and motivational factors related to age-specific developmental tasks contribute to define the trajectory of face-processing behavior

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