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"AND I'LL SEE YOU IN THE HIGH AND LOW"

The ontogenetic origins of sensitivity to facial cues to trustworthiness and emotion

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Someone said that the greatest gift
you can give a person is your time.
Viola, thank you.
It wouldn't have been possible without
your support and inspiration.

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Abstract

One fundamental component of humans' social competence is the ability to rapidly and spontaneously extrapolate facial cues of emotion and trustworthiness - i.e., whether others are likely to approach us friendly or hostilely. The fast and automatic nature of these responses to facial configurations has led to the claim that they derive from evolutionary pressure to detect signals of potential harm, and distinguish between friends or foes to enhance our chances of survival. However, the ontogenetic origins of these fundamental social skills are still debated (Over & Cook, 2018).

To explore this question, the studies reported in this doctoral dissertation investigated the nature of the visual information driving emotion discrimination and/or trustworthiness perception across the life span using the spatial filtering approach - i.e., the selective removal of portions of the spatial frequencies (SF) information contained in the image.

Specifically, this doctoral dissertation includes 5 studies aimed at investigating (1) the nature of the visual information on which adults' explicit judgments of trustworthiness are based (Study 1), (2) whether trustworthiness perception in adults (Study 2) and children (Study 3) generalizes across face-race and/or the nature of the visual information on which trustworthiness judgments are based differs for more versus less familiar face categories, (3) the nature of the visual information that triggers neural discrimination of facial cues to trustworthiness in preverbal infants (Study 4), and (4) the nature of the visual information that mediates visual discrimination of emotional facial expressions at birth (Study 5a and 5b).

Results of Study 1 showed that, although both global visual cues, conveyed by low-spatial frequency bands, and local visual cues, conveyed by high-spatial frequency bands, are sufficient to discriminate between levels of trustworthiness, the selective removal of global information negatively impacts trustworthiness perception.

Study 2 and 3 extended evidence on the nature of visual information involved in trustworthiness perception to faces underrepresented in the individual's social environment, other-race faces. We investigated whether the nature of the visual information on which trustworthiness perception is based differs for more versus less familiar face categories in adults (Study 2) and preschool and school children (Study 3).

Results showed that in the course of development, gradually with the maturation of the neural systems implicated and with the growing experience gained in the social environment, the visual information involved in own- and other-race trustworthiness perception changes.

Study 4 used a newly developed Electroencephalographic (EEG) visual discrimination paradigm, the Fast Periodic Visual Stimulation, to investigate which visual information, that is, lower and higher spatial frequencies, 6-month-old infants use to discriminate between trustworthy and untrustworthy faces. The infants' brain discriminated between high-trustworthy and low-trustworthy faces based on different types of visual information. Results are discussed for their implications for the understanding of the perceptual/neural mechanisms involved in early discrimination between positive and negative valence faces.

Study 5 explored the role of visual information in emotion perception at birth. 2-days-old newborns discriminate between happy and fearful facial expressions with both high and low spatial frequency information but they prefer happy faces when only high spatial frequencies remain. The

visual information present in the image modulates the salience of the facial cues to emotions from the first hours of life.

Altogether, using different measures and tasks, this doctoral project contributes to a better understanding of the underlying perceptual mechanisms involved in the processing of facial cues to emotion and trustworthiness across development -i.e., in newborns, preverbal infants, children and adults. Overall, results add to the existing literature suggesting that emotion and trustworthiness perception are based on an adaptive and evolutionary sensitivity early in life that is refined over the course of development as a result of the quantity and quality of facial experience in the social environment.

Keywords: facial cues; trustworthiness; emotions; spatial frequencies; visual information; ethnicity; development; infants; newborns; neural correlates; EEG; fast-periodic-visual stimulation; online experiments; visual preference paradigm; infant-control habituation paradigm.

Chapter 1
Theoretical background and Introduction to the studies

1.1 Faces as social stimuli: emotion and trustworthiness perception

Why are faces so special? Our understanding of the social world is highly influenced by the rapid and automatic evaluation we make on others based on the social stimulus par excellence, the face. The face is the body district that conveys the largest amount of information relevant to social communication: identity, gender, age, ethnicity, but also mental states and the emotional status of others. Indeed we, as humans, are sensitive to a number of invariant aspects of faces that allows us to categorize other people's ethnicity or gender and recognize their identities. Humans are also sensitive to more changeable aspects of faces, such as eye gaze or expressions, that allows us to infer other people's emotional status, mental state or intention, which are particularly important for social communication (Ambady & Rosenthal, 1993; Kramer & Ward, 2010; Rule & Ambady, 2010).

Thus, the ability to interpret, and eventually label, other individuals' emotions is a fundamental component of social cognition for adaptive social behavior (Celeghin, Mazzoni, & Mattavelli, 2020; Ekman, 1993; Green & Malhi, 2006; Grossmann, 2010). Emotions are defined as affective states occurring when the individual is in a situation that is of fundamental importance for their well-being (Ekman, 1993; Phillips, Drevets, Rauch, & Lane, 2003). Emotions' identification is thought to derive from evolutionary pressure that has taught us to pay attention to those facial cues signaling potential harm and behave accordingly (Phillips et al., 2003). Studies

on the neural basis of emotion identification emphasize the automatic and rapid emotional content identification from faces. The emotion-processing network includes the amygdala, receiving (and sending back) information from cortical areas, the superior temporal sulcus (STS) and fusiform gyrus. The amygdala receives some projections from a faster magnocellular pathway directly from the early visual cortex or through a subcortical collicular-pulvinar pathway (Leppänen & Nelson, 2009; Wang, Yang, Meng, & Ma, 2018). This network seems to emerge early in life and becomes more specialized during development (Leppänen & Nelson, 2009). The early emergence of emotion-related brain systems provides the basis for the quick acquisition of species-specific facial expression representations.

Another relevant social information humans rapidly and spontaneously extract from faces is facial trustworthiness, that is whether other people are likely to approach us friendly or hostilely, and, thus, whether we can trust them or better not (Over & Cook, 2018; Schaller & Skowronski, 2012; Zebrowitz, Fellous, Mignault, & Andreoletti, 2003). The necessity to distinguish between friends or foes in order to enhance humans' chances of survival (Zebrowitz et al., 2003) leads trustworthiness judgments to be fast, automatic, processed implicitly, based on very little information and performed with high consensus (Ames, Fiske, & Todorov, 2011; Bar, Neta, & Linz, 2006; Fox et al., 2000; Schupp et al., 2004; Sussman, Jin, & Mohanty, 2020; Swe et al., 2020; Todorov, Pakrashi, & Oosterhof, 2009). Not by chance, different studies showed that trustworthiness judgments are made after 100 ms exposure to novel faces and correlated with judgments made in the absence of time constraints (Willis & Todorov, 2006). More recently, Todorov and colleagues (2009) showed that trustworthiness discrimination emerged after only 33 ms of facial exposure also with subliminally presented faces. Moreover, even at the neural level, it seems that untrustworthy faces evoke electrophysiological responses at the level of early visual

and perceptual components (i.e., C1 and N170), as well as at the level of the later attentional components (i.e., early posterior negativity) (Dzhelyova, Perrett, & Jentzsch, 2012; Lischke, Junge, Hamm, & Weymar, 2018). Neuroimaging studies on the neural basis of trustworthiness from faces showed that the amygdala plays a crucial role in trustworthiness perception (Engell, Haxby, & Todorov, 2007; Freeman, Stolier, Ingbretsen, & Hehman, 2014; Winston, Strange, O'Doherty, & Dolan, 2002). In particular, trustworthy faces activate the amygdala bilaterally, the orbitofrontal cortex, the fusiform gyrus, and the superior temporal sulcus. Similarly, untrustworthy faces activated both the amygdala and the right insula (Winston et al., 2002).

Even though trustworthiness and emotion are two stand-alone concepts, the neural mechanisms of emotion and trustworthiness perception seem to partially overlap. Moreover, trustworthiness judgments are associated with specific facial features, defined in the literature as Trustworthiness Action Units (Jack & Schyns, 2015), which include the raising/wrinkling of the eyebrows, the curvature of the mouth and the curling of the nose. The information that allows inferring that a face is trustworthy or untrustworthy seems to be related to some facial details such as the mouth, the eyes and the eyebrow region, which are the same features that allow emotional identification (Dotsch & Todorov, 2012).

According to the Emotional Overgeneralization Hypothesis, there is a common susceptibility between the social cues that drive emotional identification and the ones that convey trustworthiness perception (Said, Sebe, & Todorov, 2009b; Zebrowitz et al., 2003). Therefore, trustworthiness judgments are closely related to emotion judgments: there seems to be a tendency to overgeneralize the approaching or avoidance responses to individuals whose faces recall emotional expressions of happiness or anger (Lischke et al., 2018). However, the Emotion Overgeneralization Hypothesis has been questioned by recent evidence showing that the

simultaneous movement of the muscles of the forehead, lips, and nose constitutes a unique configuration that generates trustworthiness perception. Thus, the cues that generate trustworthiness perception differ from any other facial configuration associated with the six fundamental emotions (Gill, Garrod, Jack, & Schyns, 2014). In particular, the lowering of the eyebrows, which typically communicates anger, is used to infer low levels of trustworthiness even when the face is not perceived as angry (Ames et al., 2011). Thus, although the Action Units are also involved in emotional perception, trustworthiness perception typically occurs for faces judged to be emotionally neutral. Therefore, although the neural networks mediating emotion and trustworthiness perception partially overlap, the majority of studies showed that trustworthiness' traits are attributed even to faces judged as emotionally neutral. Thus, a rigorous examination of the degree of homogeneity and heterogeneity of the Action Units that vehiculated respectively trustworthiness and emotion perception is still needed.

1.2 The ontogeny of human sensitivity to social cues from faces: how can we explore the question?

How do biological factors and experience contribute to determining human sensitivity to social cues from faces? Are we pre-programmed to recognize social traits from faces as a consequence of evolutionary pressure? Although they refer to different concepts, these questions fall into the dynamics of nature-nurture interactions and, thus, the ontogeny of social perception.

It has been nearly 150 years since Darwin started his studies on emotion expression in humans and animals. Starting from the thesis that emotions were expressed in the same way across cultures and different species, he noticed that there must be a hereditary component in emotion

expressions. In his book *The Expression of the Emotions in Man and Animals*, Darwin promoted the idea that emotion expressions are universal, innate and important for the survival of the species (Darwin, 1872). After 150 years, the question of genetic determinism versus environmental determinism remains crucial.

One of the aims of developmental psychology is precisely to understand how humans acquire mental representations of the world, where these representations come from and how they architecturally and functionally transform during development and ontogenesis. The crucial question concerns the relationship between cognitive changes and brain changes. More specifically, even though visual processing and social behavior appear to develop at the same time in infancy, the extent to which visual processing and social behavior development are related in the brain is a matter of controversy.

The neuroconstructivist approach of human development has proposed an alternative view to the dichotomy between nature and nurture, suggesting the view that the human mind is biologically prepared to be transformed through experience (Scerif & Karmiloff-Smith, 2005; Westermann et al., 2007). It is therefore necessary to constrain the study of the human mind's development to the study of the neural structures that support it, attempting to bridge the gap between these two levels. Nature and nurture are in continuous reciprocal interaction. Brain structures are in continuous interaction with the perceptual environment and experience to which they are exposed, which in turn constantly change during development (Meltzoff, Kuhl, Movellan, & Sejnowski, 2009). In other words, in a environment that offers countless constantly changing stimuli, social cues guides infants in identifying those aspects of the environment to which it is useful to pay attention, organizing and promoting the learning of new information (D'Souza & Karmiloff-Smith, 2017; Meltzoff et al., 2009; Scerif & Karmiloff-Smith, 2005; Westermann et al.,

2007). Thus, the basic-level processes, including visual processing, have subtle cascading effects on multiple domains, such as social behavior (D'Souza & Karmiloff-Smith, 2017).

In such terms, it is essential to investigate the basic visual processes that impact face perception. To put it another way, understanding which basic visual processes are involved in perception of social cues from faces, whether and how these processes change across development, allows us to understand which are the ontogenetic origins of sensitivity to social cues.

In the present dissertation, we explored the role of visual information in the perception of facial cues to trustworthiness and emotion across development using a spatial filtering approach, that is by selectively removing high or low spatial frequency bands from face images. Moreover, to explore the role of experience in modulating the nature of visual information involved in trustworthiness perception, we focused on more and less familiar face categories. We concentrated on faces of different ethnicities as a factor of differential experience between humans (Heine, 2015; Kitayama & Uskul, 2011).

Thus, the general aim of the present dissertation is to study basic visual processes during the life-span in own- and other-race faces as a way to identify the ontogenetic origins of sensitivity to social cues. We will explore these issues in the next paragraphs focusing on (1) the nature of visual information involved in emotions and trustworthiness perception (2) the development of sensitivity to facial cues to emotion and trustworthiness, and (3) the role of experience in shaping face perception.

1.3 Visual mechanisms underlying face processing: the contribution of high- and low-spatial frequency bands

We have already discussed the importance of identifying social cues to trustworthiness and emotion. Humans are programmed to identify potentially dangerous cues (i.e., threatening or untrustworthy faces) even in subliminal (Jessen & Grossmann, 2019; 2020b; Tamietto & De Gelder, 2010; Williams et al., 2004) and detrimental conditions (Hansen & Hansen, 1988; Mermillod, Droit-Volet, Devaux, Schaefer, & Vermeulen, 2010). The ontogenetic necessity to identify social cues from faces is reflected by the fast activation of the subcortical pathway in response to facial cues to emotions (Johnson, 2005; Johnson, Senju, & Tomalski, 2015). Thus, adult studies have shown that a fast face-sensitive subcortical pathway modulates activity in cortical regions selective to faces before the arrival of visual information through the cortical route (Johnson, 2005). A viable way to explore the involvement of the cortical and subcortical pathway is through the manipulation of the spatial frequencies (SF) content of the stimuli.

SFs are defined as the luminance variation over a distance expressed in cycle per degree of visual angle (Jeantet, Caharel, Schwan, Lighezzolo-Alnot, & Laprevote, 2018). SFs are selective for different types of visual information: while low spatial frequencies (LSF) provide information about global characteristics of the stimuli, and typify large-scale variations of luminance changes, high spatial frequencies (HSF) carry information about detailed features, and represent tighter gradients (Hughes, Fendrich, & Reuter-Lorenzet, 1990; Purghè, Stucchi, & Oliviero, 1999).

LSF and HSF activated two different brain pathways. The magnocellular pathway, the system that elicits fast processing of the visual information in the amygdala, is tuned to low spatial frequency (Grill-Spector, Weiner, Kay, & Gomez, 2017; Vuilleumier, Armony, Driver, & Dolan, 2003). The parvocellular pathway, the one involved in the slower process of fine discrimination

via the cortical visual system and the fusiform cortex, is tuned to high spatial frequency (Grill-Spector et al., 2017; Vuilleumier et al., 2003). Thus, while the parvocellular pathway prefers stimuli with high contrast or high luminance and high spatial frequencies, the magnocellular pathway prefers stimuli with low luminance, low contrast and low spatial frequencies (Ellemberg, Hammarrenger, Lepore, Roy, & Guillemot, 2002; Purghè et al., 1999).

All images can be decomposed through spatial filters: a low-pass filter maintains all the spatial frequencies below a given cut-off while removing the frequencies above the cut-off, while a high-pass filter maintains all the frequencies above a certain threshold while discarding those below it (Cannon & Fullenkamp, 1991; De Cesarei & Codispoti, 2013). Thus, a tool for understanding how the visual system decomposes a sophisticated visual input is the use of the spatial filtering approach (De Valois & De Valois, 1980). Indeed, the use of this methodological approach led to the conceptualization of the object processing model (Bar, 2003; Bar et al., 2006a). According to this model, visual objects' recognition implies a rapid and preliminary objects' analysis based on global configuration (LSF) through the dorsal magnocellular pathway. An analysis of the object based on the detailed information (HSF) through the slower ventral parvocellular pathway occurs only later. Moreover, the earlier processing of LSF provides a facilitation for the subsequent HSF processing by initiating top-down processes (Bar et al., 2006a).

Using SFs analysis, researchers have recently developed a specific interest in investigating the underlying visual mechanisms that support face processing (Morrison & Schyns, 2001; Ruiz-Soler & Beltran, 2006). Several studies show how there is an association between LSFs and configurational processes and between HSFs and analytical processes (Goffaux, Hault, Michel, Vuong, & Rossion, 2005; Goffaux & Rossion, 2006). Thus, a way to investigate the nature of the visual information used in the perception of faces is to measure the effects that the selective

removal of some portions of the visual information contained in the image causes on the subject's perception (Goffaux et al., 2005; Goffaux & Rossion, 2006).

Studies on the role of SFs in face processing have extended the object processing model to the face perception domain (Bar et al., 2006b; Johnson, 2005). As in the case of objects, the identity recognition from faces is immediate, based on low visual information and supported by the subcortical route. Only later an analytical analysis of the face, supported by the cortical pathway, takes place (Johnson, 2005; Johnson et al., 2015). Evidence for this dual route model of face processing comes from Bar and colleagues (2006b), showing how the performance in identity recognition is mediated by both LSF and HSF when the stimulus is presented for a long exposure time (1700 ms). On the contrary, for 39 ms of presentation, the accuracy is higher for LSF, processed quickly by the brain, compared to the HSF. Thus, a rapid global analysis occurs, followed by a local analysis through the HSF, which allows the slower identification of those face signals for the reconstruction of facial identity (Bachmann, 1991; Rossion, Dricot, Goebel, & Busigny, 2011). A precedence for LSF information in face processing followed by a HSF slower analysis, is congruent with the coarse-to-fine sequence in face perception (Gao & Bentin, 2011; Goffaux et al., 2011; Jeantet et al., 2019; Petras, Ten Oever, Jacobs, & Goffaux, 2019).

1.3.1 The role of spatial frequency information in the perception of facial emotions

In the case of emotion perception, emotion recognition from faces depends mostly on low spatial information (Holmes, Green, & Vuilleumier, 2005; Schyns & Oliva, 1999; Vlamings, Goffaux, & Kemner, 2009; Vuillemier et al., 2003). Neuroimaging studies show that the amygdala is particularly sensitive to fearful facial expressions compared to neutral expressions, only when

the fearful faces contain LSF (Vuilleumier et al., 2003). However, even though participants are more sensitive to fear in LSF, HSF are also involved in fear processing at a later time (> 170ms), supporting the dual route model of face processing (Vuilleumier et al., 2003).

It should also be considered that studies on SF on adults report contradictory results depending on the task and filtering method used and on the emotions shown to participants (Deruelle & Fagot, 2005; Goren & Wilson, 2006; Schyns & Oliva, 1999). Indeed, the "global precedence", supported by the dual route model, in which global components are perceived before local ones (Bar et al., 2006b; Laeng et al., 2010; Navon, 1977), has been recently challenged. Recent evidence suggests that the use of HSF and LSF could depend on the task demand (Jeantet et al., 2018). Indeed, it should be noted that vision is task-dependent in the sense that the task demand can influence and modify the visual information extracted from a visual stimulus (Deruelle & Fagot, 2005; Goffaux et al., 2005). A good example is the different demands of the two tasks used in Schyns & Oliva's study (1999). Participants were asked to identify whether or not the face presented expresses an emotion (identification task) and what emotion is being expressed (emotions' categorization task). Results showed that emotion identification involves deciding locally which details of the face produce the emotion (e.g., the sides of the mouth are straight or go upwards), and HSF are fundamental. While in emotion categorization, in classifying a face as happy or sad, a global analysis with LSF is sufficient (Schyns & Oliva, 1999). This result can be interpreted in light of different task demands requiring distinct facial features. Also, the non-ecological nature of the task can explain the bias for HSF in emotion identification. Indeed, discriminating between an emotion and a neutral face requires analytical details to understand if the configuration of the facial cues refers to a neutral face or an emotional face. On the contrary,

identifying the emotion expressed is a more automatic process, recognizable even with fewer details.

Not only the task demand but also the emotional expressions displayed can influence the use of visual information. Specifically, Kumar & Srinivasan (2011) showed how adults are better at identifying happy than sad faces in terms of both response times and accuracy. Moreover, LSF are fundamental for the identification of happy faces and HSFs are necessary for the identification of sad ones. Thus, the "global-happy" and the "local-sad" imply that the global advantage might be applied to the identification of happy faces (Johnson, 2005; LeDoux, 1996). LSF might activate the magnocellular pathway for the fast and automatic process of the "global-happy" stimulus and, only later, a slower process of fine discrimination of sad faces with HSF occurs. According to this model, the link between LSF and happy faces indicate the existence of a quick need to identify happy faces, the most salient between the two emotions presented (Kumar & Srinivasan, 2011).

Taken together, these results, although in some cases contradictory, show that low spatial information, mediated by the rapid and automatic magnocellular pathway, facilitates detection of evolutionarily salient stimuli (Zhu, Zhang, Dong, Chen, & Luo, 2021). Thus, facial expressions are processed through fast but coarse evaluation of emotional cues (Zeev-Wolf & Rassovsky, 2020), increasing in sensitivity discrimination adding higher SFs, thus details, to LSF faces (Van der Donck, Tang, Dzhelyova, Wagemans, & Boets, 2020).

1.3.2 The role of spatial frequency information in the perception of facial cues to trustworthiness

While the nature of the visual information involved in emotional perception has been extensively investigated, little is known about the nature of visual information involved in trustworthiness perception. The selective removal of SFs represents a useful method to explore the nature of the visual information involved in trustworthiness perception and to deepen the mechanisms overlapping between emotion and trustworthiness perception.

To the best of our knowledge, the few studies investigating the visual information involved in trustworthiness perception showed that both HSFs and LSFs are involved in trustworthiness perception. A recent study showed that the manipulation of the SF content of the image can rig the way a face is judged, either raising or diminishing the trustworthiness percept (Robinson, Blais, Duncan, Forget, & Fiset, 2014). The eye region with HSF and the mouth area in a wide range of SF increases trustworthiness ratings of faces. With LSF, the entire face seems to vehiculate trustworthiness ratings. This is in line with evidence showing LSF making the skin appear smoother and the face shape appear rounder and more baby-like, thus more trustworthy (Robinson et al., 2014).

An additional piece of evidence on the role of HSF and LSF in trustworthiness perception comes from the study of Said and colleagues (2009). They showed that both LSF and HSF components of the image provide enough information for the amygdala to distinguish between trustworthy and untrustworthy faces (Said, Baron, & Todorov, 2009a). In contrast to studies previously presented on emotional expression in which the amygdala response to fearful stimuli is primarily driven by LSF (e.g., Vuillemier et al., 2003), the lack of a similar spatial frequency segregation in this study could be due to visual differences between face fearfulness and face

trustworthiness. Face fearfulness, according to this interpretation, may be carried in coarser visual information than face trustworthiness.

It should be further considered that the primary role of LSFs in both trustworthiness and emotion discrimination has been challenged by studies showing no significant differences in amygdala responses to either low-pass or high-pass filtered faces (Montes-Lourido, Bermudez, Romero, Vicente, & Gonzalez, 2016; Morawetz, Baudewig, Treue, & Dechent, 2011). This result, discordant with previous studies showing faster ERP responses to fearful LSF faces at the levels of the P1 and N170 (Vlamings et al., 2009), could be explained by an integrated mechanism underlying face processing where both HSF and LSF are implicated (Montes-Lourido et al., 2016; Morawetz et al., 2011). Thus, it could be that the amygdala neurons are mainly sensitive to LSFs information that contributes to detect briefly presented threatening stimuli while, with longer exposure times, both HSF and LSF provide detailed information to the amygdala (Montes-Lourido et al., 2016; Morawetz et al., 2011; Morris, Ohman, & Dolan, 1999).

A similar integrated process may occur in the case of trustworthiness discrimination. The no-significant differences between amygdala responses to LSF and HSF components of filtered facial images does not exclude a better source of information in categorization tasks or a better detection at the level of P1 and N170 in ERPs with LSF faces. Future studies should better investigate this aspect.

In these terms, it seems necessary to better explore the nature of visual information involved in trustworthiness perception using different paradigms but, at the same time, keeping the procedure between studies as standardized as possible. Indeed, as we have seen in studies on emotional perception and spatial frequencies, not using standardized procedures makes it difficult to make any common consideration.

In conclusion, the different task demand, and, thus, the goal of the observer imposed by the situation or instructions, the dependent variables used, the different stimulus duration, the emotional expressions presented, and the spatial filter's type (i.e., Gaussian, Butterworth, Firl, etc.) and method (i.e., Bubble technique, Hybrid faces) might influence the SF information used by participants. Therefore, making the procedure as standardized as possible (e.g., always using the same type of filtering) allows for more generalizable considerations.

1.4 The development of sensitivity to social cues from faces

As discussed in previous paragraphs, the investigation of changes throughout development provides insight into the early origins of sensitivity to social cues.

It is now established that, right form birth, infants manifest a spontaneous attentional preference, the so-called face preference phenomenon, for stimuli that represent the human face even in a simplified way: three high-contrast blobs in a triangular formation corresponding to the position of the eyes and mouth in a face-sized stimulus (Goren, Sarty, & Wu, 1975; Johnson & Morton, 1991; Macchi Cassia, Turati, & Simion, 2004; Valenza, Simion, Macchi Cassia, & Umiltà, 1996). This phenomenon has led researchers to conclude that faces are a special stimulus for human infants, as they are the focus of infants' attention from the earliest stages of development, and this attentional response bootstraps learning of a various amount of information that faces deliver.

Indeed, three days of exposure to a typical social environment allows newborns to learn the perceptual appearance of the mothers' face and develop a learned preference for that face (Bushneil, Sai, & Mullin, 1989; Field, Cohen, Garcia, & Greenberg, 1984). Also, a small set of

studies suggests that newborn infants discriminate happy faces from other emotional facial expressions like disgust (Addabbo, Longhi, Marchis, Tagliabue, & Turati, 2018) and fear (Farroni, Menon, Rigato, & Johnson, 2007). This may be a learned response acquired through exposure to smiling faces in the early social environment. Indeed, there is evidence that newborns' preference for happy faces is apparent only for faces with direct gaze, the stimuli in the environment that maximize the chances of social connections with conspecifics (Rigato, Menon, Johnson, & Farroni, 2011).

Infants' discrimination of emotional expressions refines across development (Quinn & Johnson, 1997), and developmental trajectories of emotion recognition are emotion-specific (Herba, Landau, Russell, Ecker, & Phillips, 2006; Herba & Phillips, 2004). Happiness is the earliest, fastest, and most accurate emotion detected. Happiness detection requires just minimal signals and reaches adult levels from five to six years of age, remaining quite stable (De Sonneville, Verschoor, Njiokiktjien, Op het Veld, Toorenaar, & Vranken, 2002; Durand, Gallay, Seigneuric, Robichon, & Baudouin, 2007). If in the early stages of development emotions with positive valence, such as happiness, are more salient, gradually during the course of development become more salient emotions with which infants have less experience (Peltola, Leppänen, Palokangas, & Hietanen, 2008). Only between 5 and 7 months of age, fearful expressions are preferred to happy ones (Ludemann & Nelson, 1988; Nelson & Dolgin, 1985; Peltola, Leppänen, Mäki, & Hietanen, 2009). On that account, the preference for fearful faces between 5 and 7 months of age reflects the gradual development in terms of perceptual salience for new and evolutionary relevant stimuli (Peltola et al., 2008). Indeed, when infants begin to crawl or walk, fearful expressions become more relevant to direct their movement in the surrounding environment (Hoehl, 2014). In the literature on emotion discrimination in children there is less agreement on the trajectory of the

other basic emotions. Subsequent to happiness and fear, sad and angry faces are generally cited as the emotions that are detected most accurately and earliest, followed by disgusted and surprised faces, identified more gradually and slowly (Lawrence, Campbell, & Skuse, 2015; Rodger, Vizioli, Ouyang, & Caldara, 2015).

These results highlight how young infants discriminate between subtle differences in emotional facial expressions and how emotion perception is influenced by perceptual learning (Pollak, Messner, Kistler, & Cohn, 2009). Thus, social experience is fundamental in modulating emotion perception based on the frequency or salience of emotional expressions in one's environment (Bornstein & Arterberry, 2003; Hoehl, 2014; Leppänen & Nelson, 2009; Montague & Walker-Andrews, 2001; Wang, Zhu, Chen, & Fang, 2019).

In recent years, researchers have expanded their interest to the investigation the developmental trajectory of sensitivity to another type of non-emotional social cues delivered by faces, namely trustworthiness (Collova, Jeffery, Rhodes, Bothe, & Sutherland, 2021; Cook & Over, 2020; Eggleston, Geangu, Tipper, Cook, & Over, 2021; Eggleston, McCall, Cook, & Over, 2021; Li, Heyman, Mei, & Lee, 2019; Mondloch, Gerada, Proietti, & Nelson, 2019; Sutherland et al., 2020a). The awareness of the concept of trustworthiness seems to emerge quite early during development, consistent with the use of verbal and behavioral cues to determine whether or not they can trust someone (Harris, 2007; Heyman, 2008). 3-year-olds children are able to determine whether a person tends to be "mean" or "nice" based on his or her facial appearance, and by the age of 6, these judgments reach adult consistency (Cogsdill, Todorov, Spelke, & Banaji, 2014). Thus, it appears that trustworthiness judgments emerge from 3 or 4 years of age, becoming more adult-like as age increases (Baccolo & Macchi Cassia, 2020; Charlesworth, Hudson, Cogsdill, Spelke, & Banaji, 2019; Ewing, Caulfield, Read, & Rhodes, 2015). Indeed, when asked to rate the

level of trustworthiness from faces, children ages 7, 8, 10, and 12 years old show within-age concordance (Baccolo & Macchi Cassia, 2020; Cogsdill & Banaji, 2015; Cogsdill et al., 2014; Ma, Xu, & Luo, 2016).

Thus, the ability to discriminate between trustworthy and untrustworthy faces appears early in development, but refines and becomes progressively more consistent across childhood (Baccolo & Macchi Cassia, 2020; Caulfield, Ewing, Bank, & Rhodes, 2016; Charlesworth & Banaji, 2019). Thus, there is a developmental trend that becomes more consistent and fine-grained with age, a process that is not discontinuous moving from immaturity to maturity but rather expresses a continuity in line with the development of the neural areas underlying face processing (Picci & Scherf, 2016; Siddique, Sutherland, Palermo, Foo, Swe, & Jeffery, 2021).

This appears to be congruent with the development of emotional recognition. Children are able to discriminate between emotions early in development, but emotional expression recognition improves with age continuing to develop during childhood and becoming more adult-like with increasing ages (Germine, Duchaine, & Nakayama, 2011; Nelson & Mondloch, 2019). The social experience accumulated over the years, especially in reference to social experience with peers and in the school environment, shaped this sensibility as a result of exposure to the range of trustworthiness and emotion displayed in others' faces and behavior (Eggleston et al., 2021a).

The role of experience in modulating trustworthiness perception is further supported by twin studies. Sutherland and colleagues (2020a) showed that the personal experience and the unique environment, rather than genes, influence trustworthiness judgments (Sutherland et al., 2020a). In such terms, the increased social interactions and interest in relationships shape sensitivity to trustworthiness perception (Cook & Over, 2020; Siddique et al., 2021).

However, it must be noted that the tendency to form trustworthiness impressions is not driven bur rather shaped by the increased social experience, in light of the fact that from the earliest stage of development, humans manifest a precocious sensibility to trustworthiness (Baccolo, Quadrelli, & Macchi Cassia, 2021; Jessen & Grossmann, 2016, 2019; Sakuta, Kanazawa, & Yamaguchi, 2018). Behavioral data showed that 6-month-old infants discriminated between trustworthy and untrustworthy faces and, in particular, preferred trustworthy faces (Jessen & Grossmann, 2016; Sakuta et al., 2018). At the neural level, it seems that trustworthiness perception impacted object processing in a gaze-cueing paradigm, with infants orienting their attention to objects presented with trustworthy faces (Jessen & Grossmann, 2020a). Moreover, infants discriminate between different levels of trustworthiness with both supraliminally and subliminally presented stimuli (Baccolo, Quadrelli, & Macchi Cassia, 2021; Jessen & Grossmann, 2016; 2019). Thus, early during the first stage of development, an early sensitivity for facial cues that generates trustworthiness perception emerges.

Taken together, this evidence showed that both trustworthiness and emotion perception are based on precocious, evolutionary and adaptive sensibility with which infants are equipped early in life and that is shaped by the social environment in the course of development (Cook & Over, 2020; Siddique et al., 2021; Sutherland et al., 2020b).

1.5 The role of experience in shaping face perception: Evidence from cross-cultural studies

Other evidence supporting the early origins of sensitivity to facial cues to trustworthiness and emotions comes from cross-cultural studies conducted on the topic.

Culture encompasses a variety of environmental factors (e.g., language, behaviors, beliefs, conventions, and organizational structures) that are characteristic of human populations living in specific geographic areas influencing individual behavior and cognition (Caldara, 2017). The individual's cultural background appears to influence strategies used in exploring the surrounding environment (Jones et al., 2021; Miellet, He, Zhou, Lao, & Caldara, 2012; Miellet, Vizioli, He, Zhou, & Caldara, 2013).

Facial perception mechanisms are different between people from Eastern and Western cultures. In face recognition tasks, Westerns employed local high-spatial-frequency information while Easterners used global low-spatial-frequency information and are more tuned to coarse facial characteristics (Estéphan et al., 2018; Miellet, Caldara, & Schyns, 2011; Tardif et al., 2016). Likewise, in recognizing emotional expressions from different ethnicities, Eastern and Western observers use different visual strategies. Easterners use more local information from the eye region and Westerns use the configuration of all facial features and, when locally focused, draw emotional information from the mouth region rather than the eye one (Jack, Blais, Scheepers, Schyns, & Caldara, 2009; Jack, Caldara, & Schyns, 2012; Yuki, Maddux, & Masuda, 2007).

The face-processing literature provides many demonstrations of how experience within our social environment shapes not only the visual strategies but also the face perception abilities, giving rise to a number of so-called *face processing biases* (Scherf & Scott, 2012). The most well-known example of this is the *own-race bias* (e.g., Brigham & Malpass, 1985; Valentine, 1991), a reliable phenomenon across cultural and ethnic groups where faces belonging to ethnicities that are underrepresented in the individual’s social environment are recognized with greater difficulty with respect to those that are more frequently experienced. This phenomenon has been interpreted within an integrative framework where both social cognitive variables related to the in-group or

out-group status of the face and perceptual expertise derived from intergroup contact interact as they both contribute to an individual's ability to focus on diagnostic facial features (e.g., Lebrecht, Pierce, Tarr, & Tanaka, 2009; Young, Hugenberg, Bernstein, & Sacco, 2012). In particular, research in both adult and developmental populations has shown that environmental exposure to own-race faces during ontogeny leads to enhanced sensitivity to the featural and configural cues that differentiate individual faces from the over-experienced category (e.g., Rhodes, Hayward, & Winkler, 2006; Tanaka, Kiefer, & Bukach, 2004) and the construction of a well-refined representation of such category in face memory (e.g., Short, Hatry, & Mondloch, 2011).

Studies aiming to investigate the degree of generalizability of first impressions showed that at least some underlying structures of face impressions are similar across cultures and, thus, are predisposed by evolution (Sutherland et al., 2018; Zebrowitz et al., 2012).

In particular, the already discussed hypothesis that sensitivity to facial cues to trustworthiness is somehow rooted in our phylogeny also finds support in the results of the few cross-cultural studies conducted on the topic, in which trustworthiness judgments do not appear to be modulated by the perceiver's cultural background (Birkás, Dzhelyova, Lábadi, Bereczkei, & Perrett, 2014; Sakuta et al., 2018; Xu et al., 2012). Xu and colleagues (2012) showed that Chinese and Caucasian adults used similar facial information to generate explicit trustworthiness judgments from Caucasian faces, as they both relied on facial attractiveness, inner brow ridge, or skin shade. Similarly, Birkás et al. (2014) reported that Caucasian and Asian adults generalize their perception of trustworthiness to faces of different ethnicities (Caucasian, African, South Asian, and East Asian). Sakuta and colleagues (2018) even reported an attentional preference for trustworthy over untrustworthy Caucasian faces in preverbal Japanese infants, suggesting again that perception of

trustworthiness is a cross-cultural phenomenon and that facial cues to trustworthiness are somewhat universal.

Nonetheless, evidence from these same studies also showed that trustworthiness perception is to some extent modulated by an individual's expertise with own-race faces. For example, in the study by Birkás et al. (2014), Caucasian participants judged Caucasian faces as overall more trustworthy than other-race faces. Similarly, Sofer and colleagues (2017) showed that Caucasian adults perceived own-race typical faces as more trustworthy than other-race typical faces (Sofer et al., 2017). Moreover, unconscious and unintentional attitudes have an impact on trustworthiness perception. Stanley and colleagues (2011) revealed an association between implicit bias with someone's social group and trustworthiness judgments. Individuals with a pro-White implicit bias are more likely to consider White faces to be more trustworthy than Black faces (Stanley, Sokol-Hessner, Banaji, & Phelps, 2011).

Thus, although limited, available evidence suggests that sensitivity to facial cues to trustworthiness lies at the intersection of biological and experiential mechanisms, where innate sensitivity to faces and others' behavior facilitates and canalizes perceptual and cultural learning through ontogenetic experience.

Indeed, in a recent account of the origins of spontaneous face-traits inferences, Over and Cook (2018) propose that, during ontogeny and through associative learning, we become able to map the representation of individuals' facial appearance comprised in our face space (i.e., the multidimensional space within which the visual system represents the faces it encounters; Valentine, 1991) to the conceptual knowledge of others' personality traits as represented in our trait space (i.e., the multidimensional space within which we represent stable characteristics of an

individual that predict their likely responses and behaviors across a range of situations) (Over & Cook, 2018).

Within this view, experience plays a critical role in shaping trustworthiness perception, as both our face perception ability and our knowledge of other people's traits are subject to considerable environmental control. Therefore, it seems critical to extend the investigation of social cues' sensitivity to faces of different ethnicities to better investigate the nature of the underlying mechanisms (Cook & Overt, 2021).

1.6 Introduction to the studies

This doctoral thesis aims to address five specific questions: (1) Is trustworthiness perception mediated by the same bands of SF information across development, namely in adults (Study 1 and 2), children (Study 3) and preverbal infants (Study 4)? (2) Is trustworthiness perception modulated by face ethnicity, and does the SF information mediating trustworthiness perception differ for own-race and other-race faces in adults (Study 2) and/or children (Study 3)? (3) What SF information supports discrimination of facial emotional expressions at birth (Study 5)? An overview of the studies and corresponding chapters is shown in Figure 1.

Chapter 2 addresses the question of the visual information involved in adults' trustworthiness perception. In **Study 1,** we aimed to explore the effects of high-pass and low-pass spatial filtering on adults' explicit judgments of trustworthiness intensity using high-trustworthy and low-trustworthy realistic female face images. We used the two extremes of the continuum of Caucasian female faces used in Baccolo & Macchi Cassia (2020) and in Baccolo and colleagues (2021). With the plan to use these stimuli as stimulus material to test to a group of infants (Study

4), we filtered the images using two different cut-offs, one based on the visual acuity of adults and children (Dobkins & Harms, 2014) and one calibrated to the visual acuity of infants (Dobkins & Harms, 2014; Jessen & Grossmann, 2017).

The studies described in **Chapter 3** (**Study 2** and **Study 3**) expanded the evidence on the nature of visual information on which trustworthiness perception is based on other-race faces. In an online-delivered perceptive task (pairwise preference forced-choice task), Caucasian adults (**Study 2**) and 5- and 7-year-old children (**Study 3**) were asked to select the face they would trust more within pairs randomly selected from validated Caucasian and Asian broad-spectrum, low-pass filter, and high-pass filter trustworthiness continua. We thus used a 5-steps continuum of intensity varying from untrustworthy to trustworthy of Caucasian and Asian female faces, filtered using the cut-off based on visual acuity of adults and children (Dobkins & Harms, 2014).

The study presented in **Chapter 4** (**Study 4**) investigated whether the visual information that conveys trustworthiness perception in adults and children is the same involved in trustworthiness perception in infants. We here aim to explore the necessary and/or sufficient visual information infants use to discriminate between trustworthy and untrustworthy faces. We focused on 6-month-old infants, and not younger infants, for two main reasons. First, evidence showed that at this age, infants are able to process both lower and higher spatial frequencies (Gwiazda, Bauer, Thorn, & Held, 1997). Additionally, evidence converges to suggest that 6-month-old infants are able to perceive subtle differences between trustworthiness levels (Baccolo et al., 2021; Jessen & Grossmann, 2016, 2019). To conduct a qualitative investigation of age-related differences in brain sensitivity to trustworthiness cues from faces and to compare explicit judgments (Study 1) and implicit perception of the same faces, we also included a group of adult participants in the study. Thus, we here used the stimuli validated by an adult sample in Study 1. To examine infants' and

adults' neural sensitivity to trustworthiness cues, we adopted the Fast Periodic Visual Stimulation, an Electroencephalographic (EEG) visual discrimination paradigm (Norcia, Appelbaum, Ales, Cottereau, & Rossion, 2015), in which a rapid stimulus presentation at a constant frequency evoke changes in voltage amplitudes in the brain's electrical activity at the same frequency.

The study presented in **Chapter 5** (**Study 5**) addresses the question of the visual information involved in emotion perception at birth. We here aim at investigating if emotional perception in newborns is influenced by the global bias that emerges in identity perception and non-social stimuli processing, or if it instead relies on detailed information. 2-days-old newborns were presented with dynamic happy and fearful female expressions with the entire spectrum of spatial frequency or filtered for high and low spatial frequency. We here used both visual preference and habituation paradigm to investigate which spatial frequencies, whether high or low, are necessary and/or sufficient to evoke the preference response or to allow emotional discrimination at birth.

Note that female faces and the same filtering methods were used in all studies. Female faces were used based on evidence showing that they are the most frequent faces in infants' social environment during the first year of life (Ramsey-Rennels & Davis, 2008), and that infants are better at discriminating female than male faces (Quinn, Yahr, Kuhn, Slater, & Pascalils, 2002; Ramsey-Rennels & Langlois, 2006).

Finally, it is worth noting that we refer to high- and low-SFs throughout this thesis whenever the terms “detailed / analytical information" and "global / configural information" are employed.

Chapter 6, "Conclusion and General Discussion", presents an overall discussion of the obtained results, and their implications for future studies. Figure 1 depicts a synopsis of the chapters.

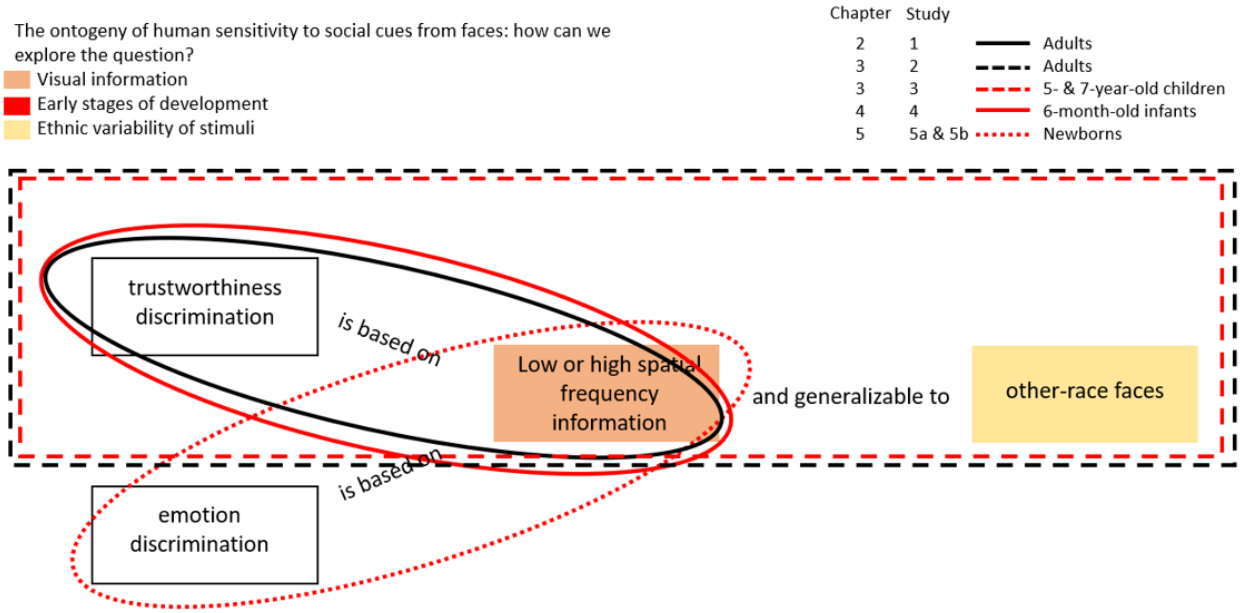

Figure 1. A schematic representation of the topics investigated in the five studies presented in the current dissertation.

Chapter 2

Study 1 - The role of visual spatial frequency information in adults' judgments of facial trustworthiness[1]

As already described in the Introduction of this thesis, humans are particularly sensitive to the social signals conveyed by faces from which they spontaneously derive first impressions about others' intentions, mental states and personality traits in a rapid, spontaneous and systematic fashion. We have previously discussed how adults make social judgments based on faces after only a few seconds of exposure and how they can distinguish between fine-grained variations in the facial cues on which such are based (Bar et al., 2006b; Jones, Kramer, & Ward, 2012; Todorov et al., 2009). Within this literature, much research has focused on the cognitive and neural processes that underpin adults' ability to evaluate facial trustworthiness (Adolphs, 2002; Freeman et al., 2014; Willis & Todorov, 2006; Winston et al., 2002), but few studies have looked into visual information inducing trustworthiness perception (Robinson et al., 2014; Said et al., 2009a).

As already discussed, research has shown that low visual spatial frequencies, which conveys global/configural visual information (Goffaux et al., 2005; Vlamings et al., 2009; Vuillemier et al., 2003), plays a crucial role in emotion recognition and discrimination (Holmes et al., 2005; Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005; Vlamings et al., 2009).

[1] The data presented here were discussed in the paper: Arioli, M., Silvestri, V., Baccolo, E., & Macchi Cassia, V. (in press). Il ruolo delle frequenze spaziali nella percezione dell'affidabilità. *Giornale Italiano di Psicologia*.

However, to the best of our knowledge only few studies explored what visual information is mainly involved in discrimination of facial cues to trustworthiness, so that available evidence is scarce and even inconsistent.

Said and colleagues (2009a), asked adult participants to indicate on a 4-point Likert scale the perceived trustworthiness of low-pass, high-pass faces, and faces while their brain's activity was scanned through Functional Magnetic Resonance Imaging (fMRI). The authors aimed at investigating the modulatory effect of HSFs and LSFs on amygdala activation in response to high-trustworthy and low-trustworthy faces. Since trustworthiness judgments are automatic and fast (Todorov et al., 2009), the authors hypothesized a greater activation of the subcortical neural circuitry, which includes the amygdala, in the LSF condition than in the other two conditions. Moreover, they expected that trustworthiness judgments for BSF faces would correlate with those for LSF faces, but not with those evoked by HSF faces. In contrast with their expectations, results showed that trustworthiness judgments made on LSF and HSF faces both correlated with judgments evoked by BSF faces, and that amygdala activation was comparable across the three different conditions (Said et al., 2009a).

The authors interpreted these findings as a consequence of the extended stimuli presentation time which, unlike previous studies on emotion discrimination (e.g., Bar et al., 2006b), may have resulted in the activation of the slow-responding parvocellular pathway, which is sensitive to high visual spatial frequencies. However, data collected outside the scanner from an additional group of subjects for whom neural activation was not recorded, showed a significantly higher correlation between judgments on BSF and LSF faces than between BSF and HSF faces. This can be explained by the fact that, as for emotional discrimination (Morawetz et al., 2011; Montes-Lourido et al., 2016), a flexible integrated mechanism that leads to amygdala activation

with both HSF and LSF for long exposure times exists. Therefore, both LSF and HSF visual information are sufficient to activate the amygdala but only LSFs result in better identification of facial cues that generate trustworthiness perception, as revealed by behavioral data showing higher correlation between LSF and BSF.

Furthermore, a recent study suggests that each region of the face appears to carry different cues that generate trustworthiness perception (Robinson et al., 2014). Perception of trustworthiness appears to depend on HSF in the eye region, on a wide range of SFs in the mouth region, and on LSF throughout the face by making the skin appearing smoother, and face shape rounder and more baby-like (Robinson et al., 2014).

In light of this limited and conflicting evidence, Study 1 aimed to explore the effects of high-pass and low-pass spatial filtering on adults' explicit judgments of trustworthiness intensity using high-trustworthy (HT) and low-trustworthy (LT) realistic face images. HT and LT faces were filtered using different cut-offs in order to remove larger or smaller portions of spatial frequencies bands. Contrary to previous studies on the role of SFs in emotion (Pourtois et al., 2005) and trustworthiness (Said et al., 2009a) perception, we here used color images, with the aim of increasing the ecological validity of the stimuli and maximizing perceptual performance (Devillez et al., 2019). We measured sensitivity to trustworthiness cues as the magnitude of perceived differences between trustworthy and untrustworthy faces (differential score). We hypothesized that trustworthiness perception, as fast and automatic, mainly relied on facial global configuration and, therefore, on LSFs. Specifically, assuming that both LSFs and HSFs would be sufficient to generate trustworthiness perception, we expected participants to be more sensitive to trustworthiness facial cues in LSFs conditions and, thus, the perceived difference between

trustworthy and untrustworthy faces would be larger in these conditions. On the contrary, we expected the perceived difference between the two types of faces to be smaller in HSF conditions.

Materials and methods

Participants

Participants were 70 adults (24 males; mean age= 26.9 years; SD= 3.3; range= 18-34 years) recruited online and through word of mouth. All participants were Caucasian, had normal or corrected-to-normal visual acuity and were all right handed. Sample size was determined through a priori power analysis using GPower software (Faul, Erdfelder, Lang, & Buchner, 2007) and data were not analyzed until data collection was completed. A power analysis for a repeated-measures ANOVA with two factors (trustworthiness intensity and filtering condition) revealed that a sample size of at least 31 would be sufficient to have a 95% probability of observing a significant effect with an alpha equal to .05 and a medium effect size (f = .25). All participants provided written informed consent before participating in this study. The study was performed in accordance with the WMA Declaration of Helsinki for research involving human subjects and the protocol was approved by the Ethics Committee of the University of Milano-Bicocca.

Stimuli

Stimuli consisted of 20 images of faces belonging to two female identities of Caucasian origin (10 per identity) obtained by manipulating the level of trustworthiness expressed (Low Trustworthy, LT, or High Trustworthy, HT) and the portion of visible spatial frequencies as a function of the different cut-offs used for filtering (5 filtering levels). The LT and HT versions of

each of the two identities were created using WebMorph (DeBruine, 2017) from an average face generated by merging three neutral expression identities selected from the Karolinska Directed Emotional faces (KDEF) Database (Lundqvist, Flykt, & Ohman, 1998). Through a morphing procedure, the neutral (N) average face obtained, was transformed into an HT face by merging it at 50% with an average face, in turn obtained from the union of three faces evaluated as maximally trustworthy and selected from the Chicago face Database (Ma, Correll, & Wittenbrink, 2015). The same procedure for creating HT faces was applied to create the LT versions (see details in Baccolo et al., 2021).

The four images obtained (two for each identity), were then filtered by removing some portions of spatial frequencies using a Matlab script available online at https://psy.van-diepen.com/pvdmatl.html (see Dobkins & Harms, 2014). In order to manipulate the band of SFs, the images were filtered using two different cut-offs: one based on adults' visual acuity and one calibrated on infants' visual acuity and used in previous studies on emotional discrimination in infancy (Dobkins & Harms, 2014; Jessen & Grossmann, 2017). Visual acuity in infancy is significantly reduced compared to adulthood and contrast sensitivity is maximal for lower spatial frequencies (Acerra, Burnod, & de Schonen, 2002). For this reason, cut-offs based on infants' resolution power remove an extremely broader band of HSF from images than cut-offs based on adults' visual acuity (Figure 2.1).

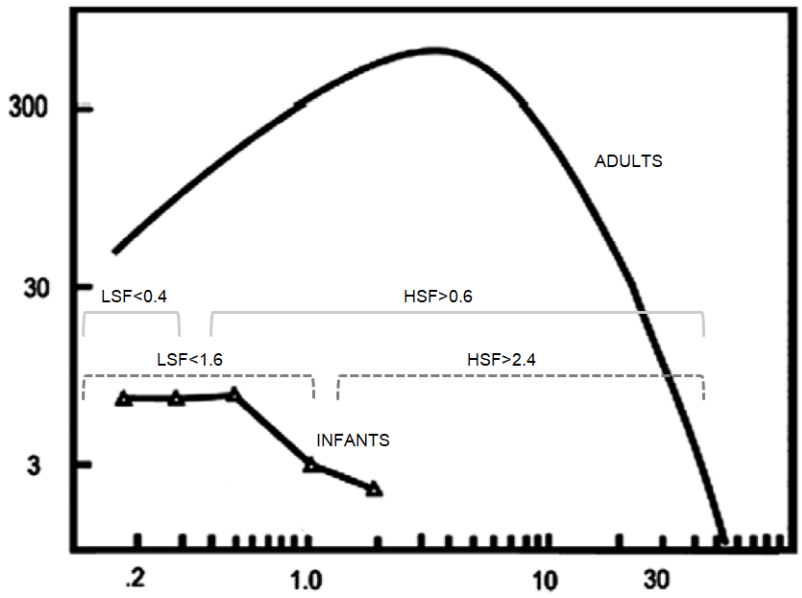

Figure 2.1. Contrast Sensitivity Function (CSF) of adults and infants in the first-year of life, and the cut-offs based on the infants CSF (grey lines) and the adult CSF (dotted lines) used to generate the LSF and HSF faces.

For stimuli containing only LSFs, the infants' cut-off included removal of all frequencies above 0.4 c/d (LSF<0.4), while the adults' cut-off included removal of only frequencies above 1.6 c/d (LSF<1.6). For HSF images, the infants' cut-off included removal of all frequencies lower than 0.6 c/d (HSF>0.6), while the adults' cut-off required the removal of all frequencies lower than 2.4 c/d (HSF>2.4) (Figure 2.2).

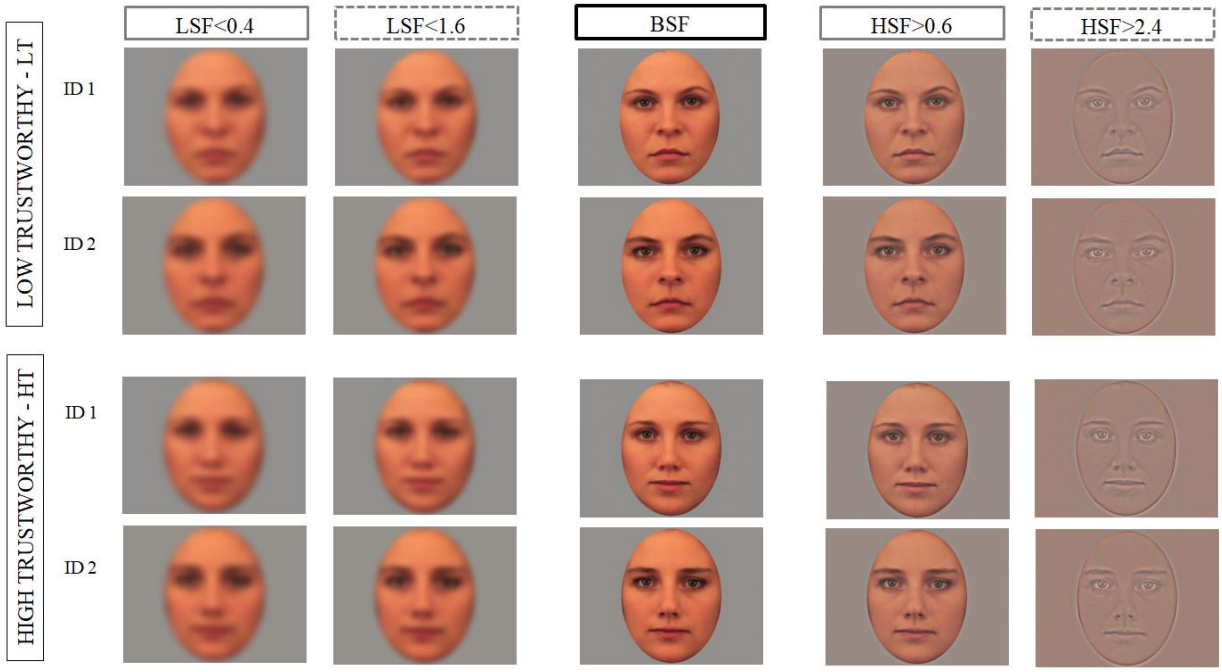

Figure 2.2. The 10 variations of each of the two identities (ID1 and ID2) used as stimuli in the study. The HT and the LT version of each identity was presented in five different filtering conditions: two including only LSFs (LSF<04 and LSF<1.6), two including only HSFs (HSF>0.6 and HSF>2.4), and one including the entire spatial frequency band corresponding to the original unfiltered image (BSF).

Consistent with other studies on the role of SFs in face perception (Harel & Bentin, 2009; Munsters, van de Boomen, Hooge, & Kemner, 2016), the luminance of the stimuli differed between conditions (p = .002). Faces were contained in a virtual square (10 x 13.5 cm) and at a distance of about 30 cm from the screen, subtended approximately 18° of visual angle vertically and 24° horizontally.

Apparatus and Procedure

The experiment took place online, and participants provided their responses using Qualtrics (Qualtrics, Provo, Utah, USA, https://www.qualtrics.com). They all ran the experiment on a desktop or portable computer, and were instructed to sit approximately 30 cm from the monitor, which, for all participants, was no smaller than 20 x 26.5 cm, thus, minimum 13 inch or larger with a resolution of at least 1280 × 800 pixels. The size of the images was kept constant regardless of the resolution and size of the screen on which they were presented. Participants accessed the online questionnaire in which faces were shown one-by-one and were asked to indicate the degree of trustworthiness on a 9-point Likert scale where 1 indicated very untrustworthy and 9 indicated very trustworthy. Subjects were told to respond by "using their gut". They started each trial by pressing the mouse, and the stimuli remained on the screen until a response was made. Stimuli were presented in five blocks corresponding to the five different filtering conditions, where each block consisted of 4 trials. To ensure a progression in the amount of visual information available to subjects within the two conditions (LSFs and HSFs), the order of the spatial filtering blocks was fixed across participants. They all completed the LSF blocks first, followed by the HSF blocks and then the BSF blocks: LSF<0.4 - LSF<1.6 - HSF>2.4 - HSF>0.6 - BSF. Within each block, the order of presentation of identity (identity 1 and identity 2) and level of trustworthiness (HT and LT) was counterbalanced across participants.

Results

Dependent variables were the mean trustworthiness scores assigned to the HT and the LT faces in each of the five filtering conditions, and the differential trustworthiness score, obtained for each filtering condition by subtracting the scores assigned to the LT faces from those assigned

to the HT faces. The differential trustworthiness score provides a measure of the perceived difference between the two levels of trustworthiness, and reflects the easiness with which facial cues to trustworthiness are perceived under different spatial filtering conditions.

Mean Trustworthiness Scores

Mean trustworthiness scores were analyzed through a repeated-measures Analysis of Variance (ANOVA) with trustworthiness intensity (HT, LT) and filtering condition (LSF<0.4, LSF<1.6, HSF>0.6, HSF>2.4, BSF) as within-subjects factors. The analysis revealed that both factors were significant (both *ps* < .001), as was the interaction between them, $F(4,276) = 5.48$, $p < .001$, partial $\eta^2 = .07$.[2] Post-hoc comparisons (Bonferroni corrected) revealed that, although under all filtering conditions HT faces are judged as more trustworthy than LT faces (all *ps* < .001), selective removal of different spatial frequency bands affected the intensity of perceived trustworthiness only in the case of HT faces, but not LT faces (all *ps* > .442). For HT faces, trustworthiness scores were significantly higher for the BSF and HSF>0.6 faces than for the LSF<0.4 (*ps* < .001) and HSF>2.4 (*ps* < .001) faces (Figure 2.3).

[2] Our a priori computation of the minimum sample size was confirmed by a posteriori computation. Given the effect size of the critical trustworthiness intensity x filtering condition interaction ($\eta p^2 = .07$, effect size $f = .27$), and the degrees of freedom associated with a repeated-measures ANOVA and an alpha equal to .05, we estimated the power of the effect for a sample of 70 participants to be .99.

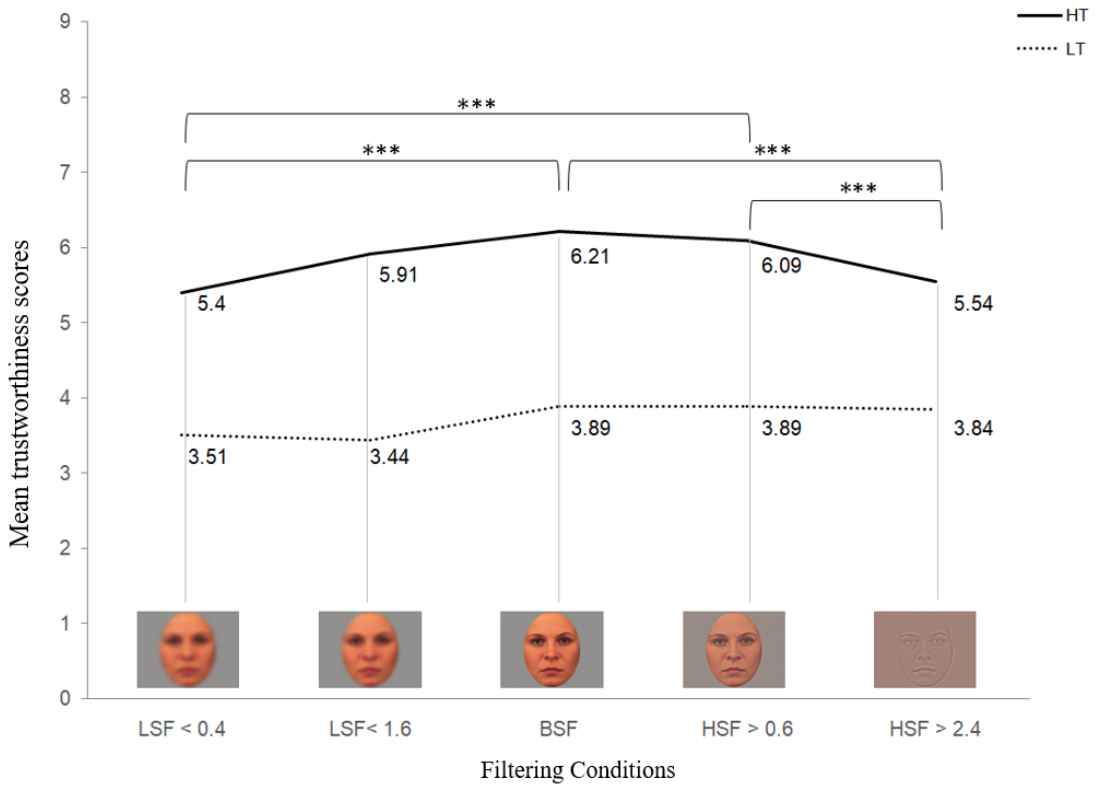

*Figure 2.3. Mean trustworthiness scores for the HT faces (black line) and the LT faces (dotted line) in the five filtering conditions. Error bars refer to standard errors of the means. * $p < .05$. ** $p < .005$. *** $p < .001$.*

Differential Trustworthiness Score

To compare the magnitude of the perceived difference between HT and LT faces across the different filtering conditions we performed a repeated-measures ANOVA with filtering conditions as the within-subjects factor. The analysis proved significant, $F(4,276) = 5.48$, $p < .001$, partial $\eta^2 = .07$, with larger perceived differences in the BSF and the LSF<1.6 conditions than in the HSF>2.4 (*p*s < .005). No other differences were significant (all *ps* > .066) (Figure 2.4).

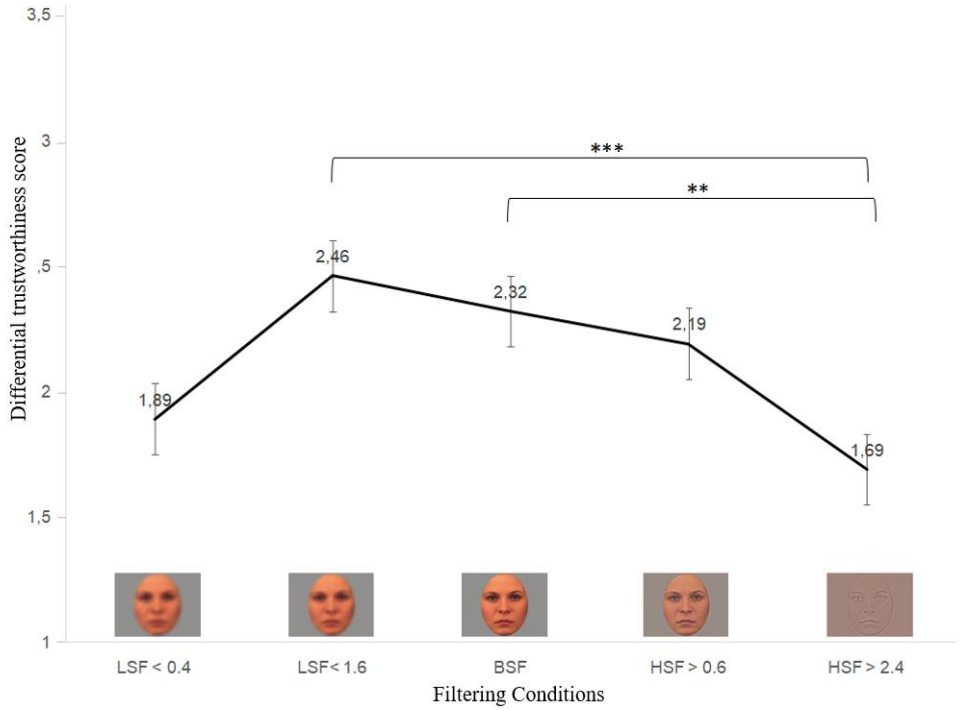

*Figure 2.4. Differential trustworthiness score (HT - LT) in each of the five filtering conditions. Error bars refer to standard errors of the means. * $p < .05$. ** $p < .005$. *** $p < .001$.*

Discussion

The present study investigated the nature of the visual information necessary to elicit trustworthiness judgments from faces by adopting an image spatial filtering approach. To investigate the contribution of different spatial frequency bands, we used two filtering cut-offs, one based on adults' visual acuity and one calibrated on infants' visual acuity. Due to the different resolution power of infants and adults, the two cut-offs extremize the portions of spatial frequencies contained in the image: while infants' cut-offs contained less LSFs and more HSFs, conversely, adults' cut-offs contained more LSFs and less HSFs.

Results show that adults are able to distinguish between faces expressing high and low trustworthiness under all filtering conditions, attributing higher ratings to HT faces than to LT faces irrespectively from the portion of visual SF available in the images. In line with Said and colleagues (2009), our data revealed that, regardless of the amount of visual information available (i.e., irrespective of the cut-off used to perform the low-pass or the high-pass filtering), both LSF and HSF information is sufficient to allow the observer to capture the perceptual cues that are associated with perception of trustworthiness intensity.

Despite that, results also showed that spatial filtering affected trustworthiness judgments for high trustworthy faces, which were judged as more trustworthy when the full range of spatial frequencies was visible in the image than when only the lowest frequency bands (LSF<0.4) or only the highest frequency bands (HSF>2.4) were available. This was not the case for low-trustworthy faces, for which participants' ratings did not change according to the spatial frequency content of the images. The impermeability to visual manipulation of low trustworthy faces could be explained by the salience of the facial cues associated with the perception of untrustworthiness. Indeed, from an adaptive and evolutionary point of view, low trustworthy faces would ensure the manifestation of avoidance behaviors, just as happens in the case of negative valence emotions (Vieira, Tavares, Marsh, & Mitchell, 2017). Accordingly, there is evidence that selective removal of visual information from emotional faces affects perception of positively valenced emotions but not of negatively valenced one (McBain, Norton, & Chen, 2010).

The easiness with which participants captured the facial cues to trustworthiness intensity under the different spatial filtering conditions is optimally represented in our data by the differential trustworthiness score, which is a measure of the perceived difference between the two trustworthiness intensities. Results indicated that, while perceived difference among

trustworthiness intensities was significantly reduced when the low-spatial frequency content of the stimuli was removed (HSF>2.4) compared to when all spatial frequency bands were visible in in the original unfiltered faces (BSF), selective removal of the higher-spatial frequency content of the images (LSF<0.4) did not affect participants' perception of trustworthiness intensity. This indicated that while a small portion of LSF is sufficient to induce a modulation of trustworthiness judgments similar to that generated by the original images, the availability of only HSF (HSF> 2.4) is not sufficient to generate similar discrimination. The differential score in HSF>2.4 condition is lower than the differential score in both the BSF and LSF<1.6 conditions. On the contrary, the differential score in the LSF<1.6 condition almost overlaps with the differential score for the BSF condition. This, again, seems to indicate that low spatial frequencies play a critical role in the discrimination of perceptual cues that evoke trustworthiness judgments.

Our data are in line with behavioral data of Said and colleagues (2009), showing significant correlation between judgments on BSF and LSF faces, but not between BSF and HSF faces. These findings are also in line with the conceptualization that there is a flexible integrated mechanism in emotion perception (Morawetz et al., 2011), with both LSF and HSF information sufficient to generate emotion perception but only LSFs resulting in better identification of salient facial cues (Morawetz et al., 2011). Similarly, while both visual information are sufficient to evoke trustworthiness perception, LSF seems necessary and their absence negatively impacts trustworthiness ratings. It is plausible that, as in emotional perception (Morawetz et al., 2011; Vuilleumier et al., 2003), also in trustworthiness perception the magnocellular system, activated by low spatial frequencies and responsible for the rapidity and automaticity with which social judgments are generated, seems to play a crucial role.

Although the purpose of the present study was not to directly compare the degree of overlap between visual mechanisms underlying emotional and trustworthiness perception, they suggest that the perceptual mechanisms involved in the perception of the two social dimensions may partially overlap. While not providing direct evidence in support of the Emotion Overgeneralization hypothesis, these data seem in line with the interpretation that trustworthiness judgments are based, at least in part, on the same visual information involved in emotional expressions. In other words, the visual information vehiculating the generation of trustworthiness perception is the same underlying emotional perception.

In conclusion, although the main limitation of the study concerns the generalizability of the results as a consequence of the use of a limited number of identities belonging to only one gender, the results offer important indications on the sensitivity to visual cues that generate trustworthiness perception. These preliminary results add further evidence to the evolutionary meaning of the necessity to recognize trustworthiness from faces even in detrimental conditions (filtered faces) and on the fundamental role of global information.

In addition, results on stimuli based on infants' visual acuity constitute a validation of these stimuli that can be used in future studies on developmental populations to further investigate the ontogenetic origins of trustworthiness. In the present dissertation, we used these validated stimuli in Study 4 with 6-month-old infants.

Chapter 3

Study 2 and Study 3 - The role of visual spatial frequency information in trustworthiness perception of own-race and other-race faces in adults and children

In Study 1 we illustrated the contribution of different spatial filtering bands in trustworthiness judgments. We showed how different portions of spatial frequency are sufficient for adults to distinguish between high-trustworthy and low-trustworthy faces. Although both global and local, conveyed respectively by low- and high-spatial frequency bands, are sufficient information to discriminate between levels of trustworthiness, the selective removal of LSFs negatively impacts trustworthiness perception, reducing the perceived difference between trustworthy and untrustworthy faces.

It should be noted that holistic and configural processing in face perception are influenced by the amount of experience accumulated with the most present stimuli in the social environment (Le Grand et al., 2002; 2004). Indeed, holistic face processing is selective for own-race faces, with which one has more visual experience in one's social environment (Michel, Rossion, Han, Chung, & Caldara, 2006). Previous research has shown that holistic processing plays an important role in expert face recognition (DeGutis, Cohan, & Nakayama, 2014). The holistic bias is the result of expertise development that occurs when adults get more experience in face processing (Richler, Cheung, & Gauthier, 2011). Thus, the visual information on which individuals rely in identity processing from faces depends on several factors, as personality (Yovel, Revelle, & Mineka,

2005), perceptual skills (DeGutis, Cohan, & Nakayama, 2014) and culture (Masuda & Nisbett, 2001).

In the same vein, it is possible that experience gained with faces overrepresented in the social environment shapes the nature of visual information necessary to generate trustworthiness perception. According to this hypothesis, it is possible that the mechanism that leads to the differentiation between trustworthy and untrustworthy faces with low-spatial frequency is peculiar to faces of one's own ethnicity. On the contrary, it may be that with less familiar faces, more analytical information for a fine-grained analysis of the faces is necessary.

Within this view, it would be reasonable to further explore whether the visual information used to make trustworthiness judgments differs depending on the participants' expertise with specific face types (i.e., faces underrepresented in participants' social environment)

As already discussed in the Introduction, the processing biases (Scherf & Scott, 2012), such as the *own-race bias* (Brigham & Malpass, 1985; Valentine, 1991), represented a good example of how experience within our social environment shapes innate face perception abilities. The theory that sensitivity to facial cues to trustworthiness is somehow grounded in our phylogeny is backed up by the few cross-cultural studies conducted on the topic, showing that trustworthiness judgments are not modulated by the perceiver's cultural background, with participants generalizing their perception of trustworthiness intensity to faces of different ethnicities (Birkás et al., 2014; Xu et al., 2012). However, the same studies showed that the expertise with own-race faces influenced trustworthiness perception. Individuals in different cultures seem to employ typicality cues when judging trustworthiness, but these cues are culture dependent. Own-race faces are judged as more trustworthy than other-race faces (Birkás et al., 2014; Sofer et al., 2017).

Moreover, implicit bias with a particular social group (i.e. White faces) modulates these judgments with own-race faces considered as more trustworthy (Stanley et al., 2011).

Thus, this limited evidence points out the intersection of biological and experiential mechanisms in generating sensitivity to facial cues to trustworthiness. Examining the nature of visual information necessary to elicit trustworthiness judgments from own- and other-race faces in adults (Study 2) and children (Study 3) allows to further deepen the role of experience with overrepresented faces in the individual's social environment in the ontogenetic origins of trustworthiness perception.

Study 2[3]

Although much research has been conducted to establish which distinct facial pieces of information evokes trustworthiness perception in the perceiver (e.g., Dotsch & Todorov, 2012; Jack & Schyns, 2015), so far only few studies have investigated how the spatial resolution in which such pieces of information are visually processed impacts trustworthiness ratings (Charbonneau, Robinson, Blais & Fiset, 2020; Robinson et al., 2014; Said et al., 2009a).

The study of Robinson and colleagues (2014) indicated that the eye and eyebrow region modulates trustworthiness judgments when their HSF components are available, while the mouth plays a role when revealed in its broad range of SF. When only LSFs remain, the whole face is judged as more trustworthy in light of the fact that the face appears more baby-like and rounder (Robinson et al., 2014). Thus, trustworthiness perception is modulated by the facial information

[3] The data presented were discussed in the paper: Silvestri, V., Arioli, M., Baccolo, E., & Macchi Cassia, V. (*submitted*). The role of spatial frequencies in trustworthiness discrimination of own- and other-race faces. *Plos One*, which is currently in his second round of review.

individuals pay attention to. Moreover, the manipulation of the SF content of some facial features increases or decreases trustworthiness judgments (Robinson et al., 2014).

Moreover, other two studies adopted the spatial filtering approach to explore whether the information on which trustworthiness judgments are based differs according to participants' expertise with specific face types (Charbonneau et al., 2020; Said et al., 2009a).

The first study, already mentioned in Chapter 1, tested for the modulatory effects of image spatial frequency filtering on the amygdala response to very trustworthy and very untrustworthy faces using fMRI (Said et al., 2009a). In contrast with the authors' predictions based on previous work on emotional expressions (Vuilleumier et al., 2003), neuroimaging results showed comparable amygdala sensitivity to variations in trustworthy intensity in LSF and HSF images. This result suggests that trustworthiness information is carried by both coarse and fine resolution visual signals. The authors also recorded behavioral responses by asking participants to rate the faces on perceived trustworthiness, and obtained mixed results. Consistent with the amygdala neuroimaging results, for participants who provided their responses inside the scanner, ratings made on both HSF and LSF faces significantly correlated with ratings for the original unfiltered faces. However, consistent with previous work on emotion discrimination (Bar et al., 2006b), for a second group of participants tested outside the scanner, ratings for the unfiltered face images correlated better with LSF ratings than with HSF ratings.

A second, more recent study manipulated trustworthiness intensity (high, neutral, low trustworthiness) and the coarse versus fine-grained information and SF bands available in White and Black faces by means of the Bubbles method (Gosselin & Schyns, 2001) to pinpoint the perceptual information used by European participants to successfully decide which of two faces was the most trustworthy (Charbonneau et al., 2020). Results showed that, although similar facial

features were used to rate trustworthiness intensity of own- and other-race faces, individuals with stronger implicit racial biases relied more on LSF information in their rating of the former than the latter faces.

In light of these conflicting results and the scarcity of studies on trustworthiness perception across face ethnicity, the current study had three main aims: (a) to explore the effects of high-pass and low-pass spatial filtering on trustworthiness discrimination, (b) to test whether trustworthiness discrimination generalizes across face ethnicity, and (c) to investigate whether coarse and fine resolution information contribute differently to trustworthiness perception in own- and other-race faces.

Based on previous demonstrations that trustworthiness judgments mimic the valence evaluation of faces (e.g., Oosterhof & Todorov, 2008) and based on the result of stronger implication of global information found in Study 1, we predicted greater sensitivity to differences in trustworthiness intensity for LSF images compared with HSF images. However, based on evidence of greater holistic/configural processing for own-race than other-race faces in identity discrimination tasks (e.g., Michel et al., 2006), we also expected to observe greater contribution of LSF information to trustworthiness discrimination of own-race faces compared to other-race faces.

Participants' sensitivity to differences in trustworthiness intensity was inferred from their performance in an online version of a *Pairwise Preference task* used in previous studies on trustworthiness perception in adults and children (Baccolo & Macchi Cassia, 2020). Participants were asked to indicate which face they would trust more within a pair randomly selected from a five-step trustworthiness continuum, and the participant's response was used to compute a trustworthiness score for each face of the continuum.

Materials and methods

Participants

One-hundred eighty-five participants were tested, and 20 were excluded from the final sample as they did not finish the experiment. The final sample included 165 young adult participants (125 females; M age = 23 years; range = 18–35 years); all were Caucasian, had normal or corrected-to-normal vision, were right-handed and without history of any psychiatric or neurological disorders. Participants were either undergraduate or graduate university students receiving course credits or recruited from the community by word of mouth on a voluntary basis, and they gave their informed consent before completing the task. The protocol was carried out in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Ethics Committee of the University of Milano-Bicocca.

Based on other studies on face-traits of own- and other-race faces (Charlesworth & Banaji, 2019), a sensitivity power analysis was performed using G*Power (Faul, Erdfelder, Buchner, & Lang, 2009) indicated that the final sample size had sufficient power (.80) to detect significant odds ratios (OR) of 0.59 and 1.68, or a critical z = +/- 1.64 at an alpha of .05, indicating that the sample was large enough to detect significant small effects in a logistic regression.

Stimuli

Stimuli were realistic grayscale Low-Spatial-Frequency (LSF), High-Spatial-Frequency (HSF), and Broad-Spatial-Frequency (BSF) images of five variations of one Caucasian female face identity and five variations of one Asian female face identity. For both ethnicities, the five

variations reflected a continuum of trustworthiness that ranged from 1 (very untrustworthy) to 5 (very trustworthy), interleaved by a neutral face (Figure 3.1). The Caucasian continuum was obtained by selecting a subset of 5 faces (i.e. by excluding the two trustworthiness extremes) from a previously validated seven-step continuum (see Baccolo & Macchi Cassia, 2020). The Asian continuum was generated following the same procedure adopted to create the Caucasian stimuli (see details in Baccolo & Macchi Cassia, 2020) - i.e. by morphing an averaged neutral face toward an averaged untrustworthy and an averaged trustworthy face using an online program for image transformation (WebMorph, DeBruine, 2017). The averaged trustworthy and untrustworthy faces were created by merging three different face identities taken from by the Chicago Face database (Ma, Correll, & Wittenbrink, 2015), in which faces are rated on the trustworthiness dimension. The averaged neutral face was obtained by merging four neutral identities taken from the same database. The averaged neutral face was morphed towards the trustworthy and untrustworthy averaged references obtained from the three most trustworthy and the three most untrustworthy Caucasian or Asian identities available in the Database by two steps (30% and 60%), thus obtaining a five-step trustworthiness continuum which included the neutral face.

To create the LSF and the HSF versions of each face, a spatial frequency filter was applied to each image using a Matlab script available online at https://psy.van-diepen.com/pvdmatl.html (see Dobkins & Harms, 2014). For LSF images, the filtering was done around a frequency cutoff of 1.6 cycles/° (or 24 cycles/face width), so that these images contained frequencies primarily below 1.6 cycles/°. HSF images were similarly filtered with a high-pass cutoff of 2.4 cycles/° (or 36 cycles/face width); cut-off values were chosen after Dobkins and Harms (2014). The unfiltered original images were used as BSF stimuli (Figure 3.1).

All images measured 12 cm x 8 cm. Participants were instructed to sit at 30 cm from the computer screen, so that each image subtended approximately 22° of visual angle vertically and 15° horizontally. As in other studies exploring the impact of spatial frequency filtering on face processing (e.g., Harel & Bentin, 2009; Munsters et al., 2016; Van den Boomen, Munsters, & Kemner, 2019) the BSF, LSF and HSF images differed in terms of Root Mean Square (RMS) (BSF: 8.91 cd/m^2; LSF: 8.78 cd/m^2; HSF: 2.67 cd/m^2) contrast, a commonly used index for perceived contrast in natural images. Contrarily, the BSF, LSF and HSF images did not differ in luminance ($p > 0.9$, as calculated based on the RGB values using Matlab), as in other studies using the same filtering procedure (e.g., Dobkins & Harms, 2014; Jessen & Grossmann, 2017).

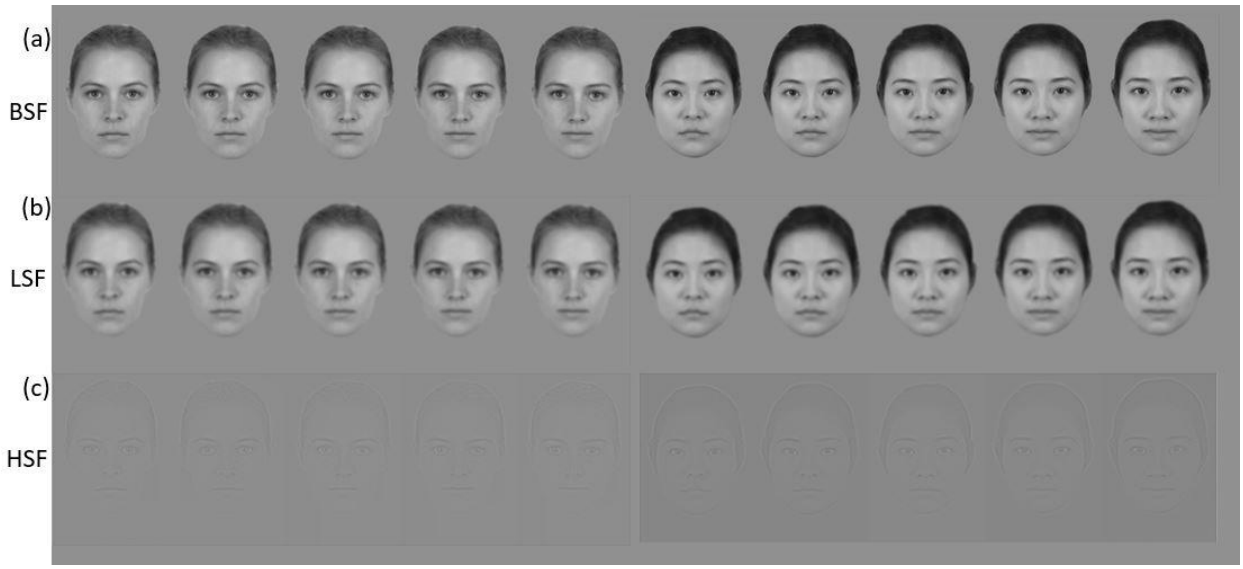

Figure 3.1. The original unfiltered images of the five variations of the female Caucasian identity and the female Asian identity used as stimulus material in the Broad-Spatial-Frequency (BSF) condition, representing two trustworthiness continua ranging from 1 (very untrustworthy) to 5 (very trustworthy) (a). The Caucasian and Asian Low-Spatial-Frequency (LSF) (b) and High-Spatial-Frequency (HSF) (c) trustworthiness continua generated by filtering the original images.

Stimuli Validation

Details of the validation procedure for the original seven-step continuum from which the five Caucasian faces were taken is described in full in Baccolo & Macchi Cassia (2020). Here we ran a further validation study to ensure that the five selected Caucasian faces and the five newly created Asian faces actually reflected a continuum of expressed trustworthiness. To this end, we asked an independent sample of 53 Caucasian adults (40 females; Mage = 22.45 years; range = 19–30) to rate perceived trustworthiness for each Caucasian and Asian BSF face on a scale ranging from 1 (I wouldn't trust this person at all) to 9 (I would definitely trust this person). Face ethnicity was blocked across trials, and the order in which trial blocks were presented was counterbalanced across participants. Participants provided their ratings through an online Questionnaire delivered on Qualtrics (Qualtrics, Provo, Utah, USA, https://www.qualtrics.com). Adults' ratings were entered into a repeated-measures ANOVA with trustworthiness intensity (1, 2, 3, 4, 5) and face ethnicity (Caucasian, Asian) as within-subjects factors. The analysis revealed a main effect of trustworthiness intensity, $F(4,208) = 16.99$, $p < .001$, $p\eta^2 = .25$; a test of within-subjects contrasts revealed a significant linear trend, t (208) = 7.91, $p < .001$, CI lower = .56, CI upper = .93, indicating that the higher the position along the trustworthiness continuum, the higher the trustworthiness scores attributed by the participants. No significant effects involving face ethnicity were observed.

Apparatus and Procedure

The experiment took place online, and participants provided their responses using Qualtrics (Qualtrics, Provo, Utah, USA, https://www.qualtrics.com). They all ran the experiment on a desktop or portable computer, and were instructed to sit approximately 30 cm from the monitor, which, for all participants, was 13 inch or larger with a resolution of at least 1280 × 800 pixels. Participants performed a *Pairwise Preference task* (see Baccolo & Macchi Cassia, 2020) where, on each trial, two faces randomly selected from the same trustworthiness continuum simultaneously appeared on the screen, and they were asked to select the face they trusted more by clicking the mouse. Subjects were told to respond by "using their gut". They started each trial by pressing the mouse, and the stimuli remained on the screen until a response was made. The task consisted of a 2 (face ethnicity: Caucasian, Asian) x 3 (spatial filtering: LSF, HSF, BSF) conditions design. Trials from each of the six conditions were presented in blocks, and participants completed 10 trials per condition, corresponding to all possible pairwise combinations of the five faces of the continuum (60 trials in total). Each face of the continuum was compared to all other faces of the same continuum for a total of four times; the position of the faces on the screen was randomized across trials, and trials within each block were presented in random order. The order of the spatial filtering blocks was fixed across participants: they all completed the LSF blocks first, followed by the HSF blocks and then the BSF blocks. Face ethnicity was alternated between blocks, with the ethnicity of faces in the first block counterbalanced across participants.

Results

Response Accuracy

One-sample *t* tests (vs. 50%) on percent accuracy, that is the percentage of trials in which the face displaying more intense cues to trustworthiness was selected, confirmed that, for both

Caucasian, *p*s < .001, and Asian faces, *p*s < .001, participants systematically selected the more trustworthy face in the pair under all spatial filtering conditions.

To explore how SF filtering affected the likelihood that participants selected the more trustworthy face in the pair participants' response accuracy on each single trial of each condition, expressed as 0-1 scores (0 if the selected face was the less trustworthy in the pair, 1 if it was the more trustworthy one) was entered as dependent variable into generalized mixed-effects logistic regression models. The analysis was performed using the GAMLj 2.3.0 module in the Jamovi software (Version.1.6.15; The jamovi project, 2021). Following the recommendations of Meteyard and Davies (2020), the models' parameters selection was driven by the research question, and so we only included relevant interactions, which also helps avoiding overfitting issues. Specifically, we included face ethnicity (Caucasian, Asian) and spatial filtering (BSF, LSF, HSF) as fixed factors, and random intercepts for the participants to control for potential between-subjects differences in performance. We did not include any random slope because, as we had no reason to believe that other factors would affect the results and to keep the models as simple as possible.

The analysis revealed a significant effect of spatial filtering, $\chi^2 = 64.08$, $p < .001$, as participants' performance was more accurate in the BSF condition than in the HSF condition ($\beta 1 = 0.72$, SE = 0.056, z = - 5.95, $p < .001$, 95% CI [0.64, 0.80]). There was also a significant spatial filtering x face ethnicity interaction, $\chi^2 = 23.83$, $p < .001$, indicating that spatial filtering affected participants' performance differently for Caucasian and Asian faces.

Post-hoc comparisons (Bonferroni corrected) showed that, for Caucasian faces, participants performed more poorly in the HSF condition than in both the BSF, exp $\beta = 1.28$, $p = .02$, and the LSF conditions, exp $\beta = 0.54$, $p < .001$, and more accurately in the LSF than in the BSF condition, exp $\beta = 0.69$, $p < .001$. For Asian faces as well, participants performed more poorly in

the HSF condition than in both the BSF, exp $\beta=1.51$, $p < 0.001$, and the LSF conditions, exp $\beta=0.79$, $p = .046$, but no other comparisons attained significance, ps > .342. Cross-ethnicity comparisons revealed a significant advantage in response accuracy for Caucasian over Asian faces in the LSF condition, exp $\beta=0.67$, $p < .001$, but not in the other SF filtering conditions, ps > .99 (Figure 3.2).

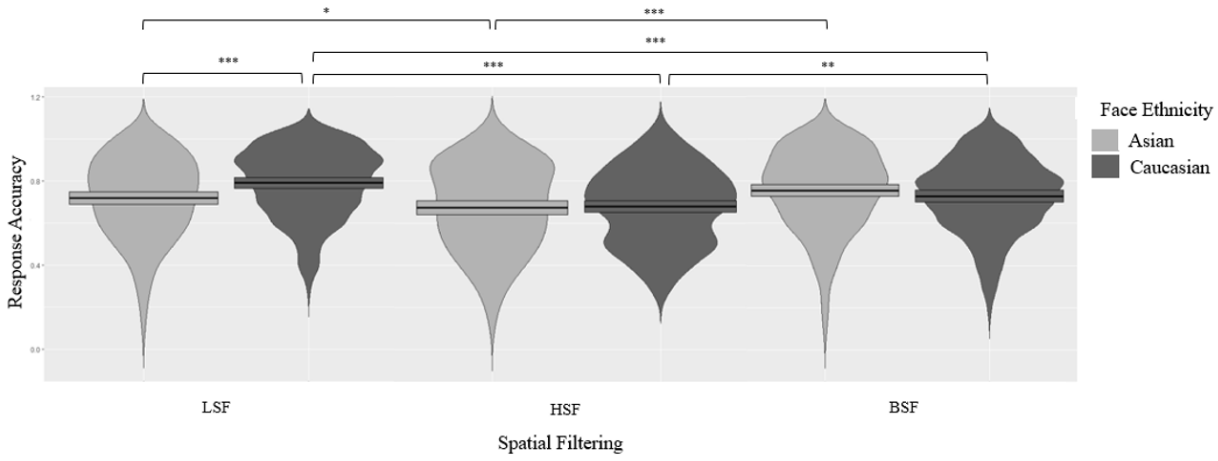

*Figure 3.2. Response accuracy for Caucasian and Asian faces plotted as a function of the spatial frequency condition (Broad-Spatial-Frequency, High-Spatial-Frequency, and Low-Spatial-Frequency) * $p < .05$. ** $p < .005$. *** $p < .001$.*

Trustworthiness Scores

To obtain a measure of how consistently each face from each trustworthiness continuum was selected as the more trustworthy in the pair, participants' response on each trial of the Pairwise Preference Task was used to compute a trustworthiness score for each face. For each subject and each trial, we gave a score of 1 to the selected face and a score of 0 to the non-selected face, and

the trustworthiness scores obtained by each face were summed across trials. Since each face from each continuum appeared for a total of four times as it was paired with all the other faces of the same continuum, the related trustworthiness score could range from 0 (if never selected as most trustworthy) to 4 (if always selected as more trustworthy).

Trustworthiness scores were analyzed through linear mixed-effects models (LMMs) with three fixed factors (face ethnicity, spatial filtering, and trustworthiness intensity) and random intercept for participants. Moreover, since we were interested in how face ethnicity and spatial frequency affected the slope of the relationship between trustworthiness intensity and decision outcome, we also performed the polynomial contrasts of trustworthiness intensity across the different conditions. LMMs were preferred over repeated-measures Analysis of Variance (ANOVA) to unravel the unexplained differences among participants following the practice guidance for LMMs (Meteyard & Davies, 2020).

The analysis revealed a Trustworthiness intensity main effect, $F(4,8) = 757.23$, $p < .001$, which was qualified by significant two-way interactions between this factor and both face ethnicity, $F(4,8) = 11.79$, $p < 0.001$, and spatial filtering, $F(8,16) = 8.97$, $p < 0.001$, and by a significant three-way interaction between face ethnicity, spatial filtering, and trustworthiness intensity, $F(8,16) = 4.12$, $p < .001$.

Polynomial contrast analysis revealed that trustworthiness scores varied overall linearly across the five trustworthiness intensity steps, β=1.53, $p < .001$, but the slope was steeper in the BSF condition (β = 1.75, $p < .001$) than in the HSF condition (β = 1.34, $p < .001$), β = -0.41, $p < .001$, with no difference between the BSF and LSF (βLSF = 1.72, $p < .001$) conditions, β = -0.03, $p = .65$. The slope was also overall steeper for the Caucasian faces (β=1.69, $p < .001$) than for the Asian faces (β = 1.52, $p < .001$), β=0.17, $p = .004$, but this difference was also modulated by the

spatial frequency content of the images, as it reached significance in the LSF condition (βCaucasian = 2.03, $p < .001$ vs. βAsian = 1.39, $p < .001$), $\beta = 0.78$, $p < .001$, but not in the HSF (βCaucasian = 1.35, $p < .001$ vs. βAsian = 1.33, $p < .001$), $\beta = 0.16$, $p = .26$, and the BSF (βCaucasian = 1.68, $p < .001$, vs. βAsian = 1.82, $p < .001$), $\beta = -0.14$, $p = .16$ conditions.

To explore the impact of spatial frequency filtering within each face ethnicity, we ran two separate 3 (spatial filtering) x 5 (trustworthiness intensity) LMMs, one for Caucasian faces and one for Asian faces.

For Caucasian faces, trustworthiness scores varied overall linearly across the five trustworthiness intensity steps, β=1.69, $p < .001$, but the slope was steeper in the LSF condition ($\beta = 2.03$, $p < .001$) than in the other two conditions (βHSF = 1.35, $p < .001$; βBSF = 1.68, $p < .001$), all $ps < .01$ (Figure 3.3).

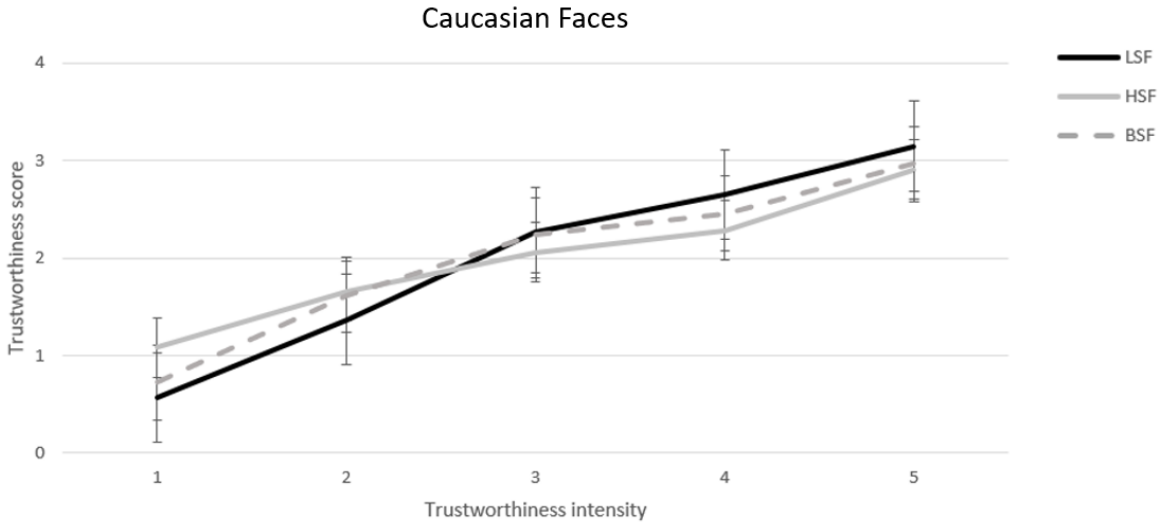

Figure 3.3. Mean trustworthiness scores for each of the five Caucasian faces composing the trustworthiness continuum in the Low-Spatial-Frequency (LSF), the High-Spatial-Frequency (HSF), and the Broad-Spatial-Frequency (BSF) conditions. Error bars refer to standard errors of the means.

For Asian faces the trend was overall linear across the five trustworthiness intensity steps, β=1.52, $p < .001$, but the slope was the steeper in the BSF condition (β = 1.82, $p < .001$) and the gentler in the HSF condition (β = 1.33, $p < .001$) with the LSF condition (β = 1.39, $p < .001$) in between the two, all *ps* < .001 (Figure 3.4).

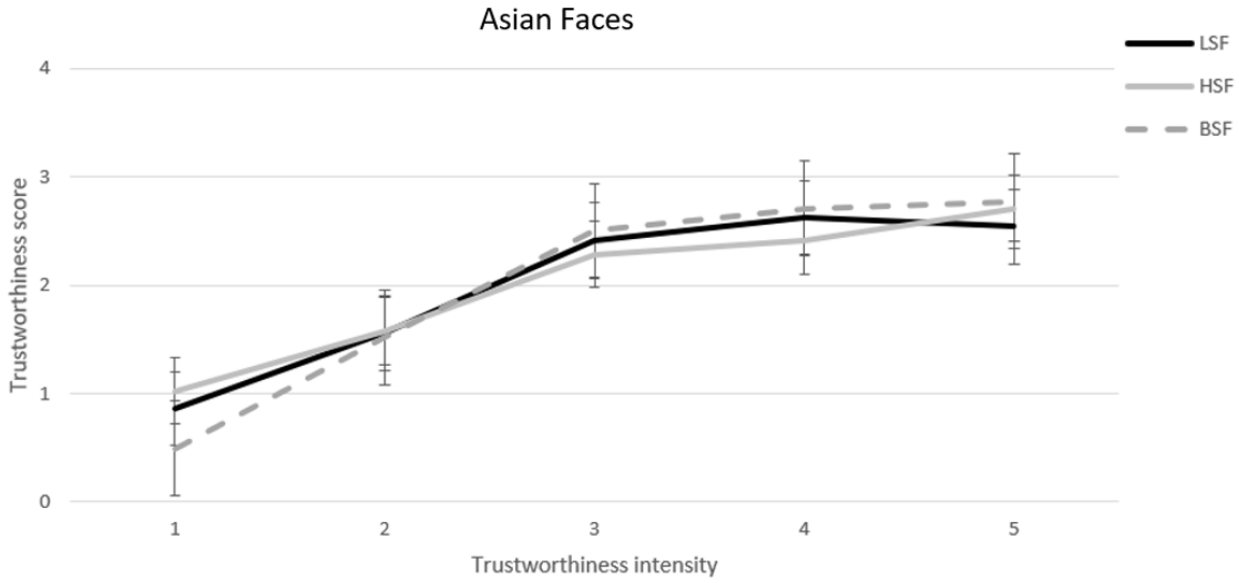

Figure 3.4. Mean trustworthiness scores for each of the five Asian faces composing the trustworthiness continuum in the Low-Spatial-Frequency (LSF), the High-Spatial-Frequency

(HSF), and the Broad-Spatial-Frequency (BSF) conditions. Error bars refer to standard errors of the means.

Discussion

The present study, through an image spatial filtering approach, explored the contribution of coarse and fine resolution information to trustworthiness perception in own- and other-race faces.

The first aim of the study was to investigate the effects of spatial filtering on trustworthiness perception. Results showed that trustworthiness intensity is discriminated with both LSF and HSF information, but such discrimination is easier (i.e., less prone to errors) when only coarse, as compared to fine, resolution information is available in the images. These results are in line with results of Study 1, in which both LSF and HSF were sufficient to allow discrimination between very trustworthy and very untrustworthy faces, but only LSFs removal negatively impacted trustworthiness ratings. In the same vein, in the present study, for both Caucasian and Asian faces, participants performed above chance when asked to select the more trustworthy face in a pair in all spatial filtering conditions, and the trustworthiness scores varied linearly according to the position of the faces along the continuum. This means that trustworthiness intensity for each of the five Caucasian and Asian faces varied linearly as a function of the stimuli position along the trustworthiness continua, regardless of the SF content of the images.

At the same time, though, both accuracy data and trustworthiness scores also showed that the selective removal of the LSF content of the stimuli had negative effects on participants' performance, as participants were more accurate in the BSF condition than in the HSF condition,

and the linear slope of the trustworthiness scores was steeper in the former than in the latter condition. This indicates that the detection of physical cues to trustworthiness relies more heavily on the LSF content than on the HSF content of the images. This is consistent with previous evidence that emotion categorization occurs faster for LSF than HSF faces (e.g., Schyns & Oliva, 1999), and fits with the conceptualization that trustworthiness judgments are overgeneralized responses to facial configurations that resemble emotional expressions (Said et al., 2009a; Zebrowitz et al., 2003). Specific facial features (i.e., Action Units, see Jack & Schyns, 2015) that are also involved in emotion perception, such as up/downturned eyebrows, upward/downturned curving mouth, and a wrinkling nose, appear to be implicated in trustworthiness judgements. According to the emotion overgeneralization hypothesis, facial cues like lowered eyebrows, which, if stressed, could indicate anger, would lead the perceiver to make a dispositional assumption about an otherwise emotionally neutral face, resulting in social perception of unfriendliness (Ames et al., 2011).

By testing whether spatial filtering differentially affects trustworthiness discrimination of (frequent/familiar) own-race and (infrequent/unfamiliar) other-race faces, the involvement of LSF and HSF bands to trustworthiness perception was investigated in the current study in relation to face familiarity. Since discrimination accuracy for the original unfiltered faces did not differ for Caucasian and Asian faces, accuracy data confirmed earlier demonstrations that trustworthiness perception generalizes across face ethnicity (Birkás et al., 2014; Xu et al., 2012).

Nonetheless, comparing the slope of the linear trend of the trustworthiness scores along the Caucasian versus the Asian continuum, we found that it was steeper for the former than for the latter face-race category. These findings extend evidence by previous studies comparing trustworthiness ratings of different ethnic versions of low- medium- and high-trustworthy faces

(Birkás et al., 2014; Charbonneau et al., 2020; Sofer et al., 2017; Xu et al., 2012), by showing a more fine-grained sensitivity to variations in perceptual cues to trustworthiness intensity in own-race faces compared to other-race faces.

The finding of a greater LSF contribution to trustworthiness discrimination for Caucasian faces compared to Asian faces in our data also indicated differential sensitivity to facial cues to trustworthiness in own-race versus other-race faces. Indeed, we found a significant discrimination advantage for Caucasian over Asian faces when only LSF information was present in the stimuli. Furthermore, while selective removal of LSF had a negative effect on discrimination accuracy for both Caucasian and Asian faces, we observed an accuracy advantage for Caucasian faces when only LSF information was available in the stimuli versus when the entire SF bands were available in the intact BSF faces. This result was unexpected, considering that both LSF and BSF images contained the same full low spatial frequency bands.

It appears that the HSF information included in the intact BSF images actually reduced trustworthiness discrimination, indicating that detection of facial cues to trustworthiness in own-race faces is specifically mediated by the LSF content of the stimuli. This finding is consistent with previous evidence of greater modulation of brain activity in response to LSF emotional faces as compared to intact, unfiltered faces (e.g., Carretié et al., 2007; Maratos et al., 2009). This finding has been interpreted in the context of a LSF specificity in response to emotional facial cues, which would be masked by the presence of HSF information in the intact faces.

The presence of a LSF own-race advantage in trustworthiness discrimination was also evident from the trustworthiness preference scores. We found steeper slopes for Caucasian than for Asian faces in the LSF condition, but not in the HSF and the BSF conditions. Moreover, the

slope varied more linearly along the LSF continuum compared to the HSF and BSF continua for Caucasian faces, but not for the Asian ones.

Again, these findings indicate that trustworthiness perception in own-race faces was magnified when only LSF information was available in the images, and that reliance on LSF information was stronger for Caucasian than Asian faces in our European participants. These findings are in line with those obtained by Charbonneau and colleagues (2020), showing that Caucasian individuals with stronger implicit racial biases needed more LSF information to discriminate trustworthiness intensity in Caucasian faces compared to Black faces.

Overall, current findings of differential sensitivity to facial cues to trustworthiness in Caucasian versus Asian faces are consistent with previous findings indicating trustworthiness perception differs for own-race and other-race faces in Caucasian participants (Birkás et al., 2014; Charbonneau et al., 2020; Sofer et al., 2017). However, unlike most of these previous findings (Birkás et al., 2014; Sofer et al., 2017) that showed a generalized positivity bias for own-race faces (i.e., own-race faces were perceived as overall more trustworthy than other-race faces), our results indicate that different perceptual processes are involved in the detection of facial configurations driving trustworthiness judgments in frequent/familiar and infrequent/unfamiliar face categories.

It is well-known that perceptual expertise for over-represented faces in the individual's social environment translates into heavier reliance on holistic/configural cues to facial identity (e.g., Michel et al., 2006; Yao & Zhao, 2019), and that holistic/configural processing in vision relies on relatively LSF more than on relatively HSF (e.g., Lamb & Yund, 1993). To the best of our knowledge, our results add to the only other existing evidence provided by Charbonneau and colleagues (2020) that the SF content of the images affect trustworthiness perception differently for own-race and other-race faces in individuals with stronger implicit racial biases. Current

findings extend these earlier findings to female faces and a different category of other-race faces, and generalize them to a different spatial filtering methodology, providing further evidence that the LSF-mediated holistic/configural advantage for faces from highly familiar ethnic groups in identity recognition extends also to perception of physical cues to social traits.

Study 3

Results from Study 2 have shown that adults' discrimination of trustworthiness intensity relied more heavily on the LSF content of the images for own-race faces compared to other-race faces. In line with previous neurophysiological evidence of a greater modulation of brain activity for emotional faces with LSFs (Carretié et al., 2007; Maratos et al., 2009), the detection of facial cues to trustworthiness specifically for own-race faces is mediated by global/holistic information. In this sense, fine resolution visual signals seem even less relevant in overrepresented faces in one's social environment. The use of visual information in trustworthiness processing is modulated by the experience with overrepresented faces in the individual's social environment.

According to this perspective, the experience in the social environment accumulated in different stages of development could modulate the visual information on which trustworthiness perception relies on. Study 3 extended the investigation on the information on which trustworthiness judgments are based on preschool and school children.

As discussed in the Introduction, different evidence showed that trustworthiness sensibility emerges quite early during development becoming more fine-grained with age (Charlesworth et al., 2019; Cogsdill et al., 2014; Jessen & Grossmann, 2016; 2017; 2019; Sakuta et al., 2018). However, to our knowledge, the only study investigating children's trustworthiness discrimination

across faces of different ethnicities adopted an implicit task to determine individual's likelihood of performing certain behaviors and showed similar performance with both White and Black faces (Charlesworth & Banaji, 2019). Thus, it is an open question whether children's explicit discrimination of trustworthiness from faces generalized across face ethnicity.

Furthermore, none of the studies investigated what visual information is implicated in children's trustworthiness perception of own- and other-race faces. Indeed, the few studies investigating how the age of the viewer modulates the perception of visual information focused on identity and emotional perception.

Different evidence showed that the use of visual information underlying emotion discrimination changes with age (Van Den Boomen, van der Smagt, & Kemner, 2012; Vlamings, Jonkman, & Kemner, 2010). While adults are more tuned to global information in emotion discrimination (Méndez-Bértolo et al., 2016; Vlamings et al., 2009; Vuillemier et al., 2003), children from 3 to 8 years are more tuned to detailed information (Deruelle & Fagot, 2005; Gao & Maurer, 2011; Vlamings et al., 2010).

Studies on identity discrimination in children seem to moving in the same direction by showing how 7- and 8-year-old children appear to use HSFs for identity discrimination, and subsequently their use of HSFs decreased as their dependence on medium spatial frequency (MSF) increased (Leonard et al., 2010; 2011; 2013). Specifically, numerous research studies have shown that among children aged 10-13 years, LSFs and MSFs are the most commonly identified and employed ranges for face processing. Thus, a shift from featural to configural or holistic face processing appears to occur in late childhood/ preadolescence (Gao & Maurer, 2011; Miki et al., 2015; Peters, Vlamings, & Kemner, 2013).

The higher reliance on HSF in children is explained by the maturation of systems activated by high- and low-spatial frequencies (Adams & Courage, 2002; Madrid & Crognale, 2000; Peters & Kemner, 2017). Indeed, although newborns are more sensitive to low spatial frequencies (de Heering et al., 2008; Macchi Cassia et al., 2002), the magnocellular pathway does not appear to reach full maturation until early adolescence or, more specifically, until 12-13 years of age (Madrid & Crognale, 2000; Grose-Fifer, Lobel, diFilipo, & Gordon, 2020; Peters et al., 2013; Rokszin et al., 2018). It is possible that children are more likely to rely on high spatial frequencies around age 3-4 because it corresponds to the period in which the parvocellular system reaches full maturity (Adams & Courage, 2002). Therefore, it appears that by adolescence, following full maturation of neural systems, in 14- and 15-year-olds an adult-like pattern emerges, with higher reliance on global information in emotion and identity discrimination (Peters et al., 2013).

In conclusion, this evidence converges to indicate that the maturity of the visual system may aid in the modification of SFs used in face processing during development (Jeantet et al., 2018).

Considering the evidence on the visual information underlying emotion and identity discrimination in children, we here aimed to explore the visual information involved in trustworthiness perception in children. Moreover, considering the scarcity of studies and contradictory results on trustworthiness perception across face ethnicity, we here aimed to 1) confirm whether children's trustworthiness discrimination generalizes across face ethnicity, 2) investigate the effects of high-pass and low-pass spatial filtering on trustworthiness discrimination, and 3) explore the contribution of visual information in trustworthiness perception from own- and other-race faces.

To explore these issues, we here adopted the same filtering method and procedure used with adults in Study 2. As in previous studies on trustworthiness perception with both adults and children (Baccolo & Macchi Cassia, 2020), participants' sensitivity to little changes in trustworthiness intensity was investigated using an online version of a *Pairwise Preference task*. Children were asked to choose the face they would trust more within a pair of randomly selected faces from the five-step continuum. Children responses were used to calculate both accuracy and trustworthiness score, to respectively obtain the response participants systematically selected the more trustworthy face in the pair under all conditions varying in face ethnicity and spatial filtering presented and a measure of how consistently each face from each trustworthiness continuum was selected as the more trustworthy in the pair. Indeed, asking children to discriminate between extremely trustworthy and very untrustworthy faces may limit the assessment of their fine-grained sensitivity to facial clues to trustworthiness in real-life circumstances, when we usually process and decode even the tiniest difference from our interlocutor faces.

Moreover, computer-generated faces, even controlled, may not fully reflect participants' competence in face processing as real faces. Indeed, previous research has shown that computer-generated faces had lower trustworthy judgments and discrimination accuracy than real faces (Balas & Pacella, 2017). This is particularly true for male computer-generated faces than female faces (Balas, Tupa, & Pacella, 2018). For these reasons, we here used a five-step trustworthiness continuum of morphed from different real faces female identities.

This approach enables to track developmental differences in children's perceptual sensitivity to fine-grained variations in visual cues to trustworthiness encoded in highly familiar face category (i.e., female faces) children are more exposed to (Quinn et al., 2002; Ramsey-Rennels & Langlois, 2006).

For different reasons, we selected 5- and 7-year-olds to be included in the sample. First, during this period, children distinguished "own" and "other" race categories of faces, but, at the same time, are still tuning their facial perception based on their experience with faces in the environment (Balas, Westerlund, Hung, & Nelson III, 2011; Bar-Haim, Ziv, Lamy, & Hodes, 2006; Short et al., 2011). Moreover, children in this age range are able to complete the *Pairwise Preference task* used with adults, allowing across-age comparisons (Baccolo & Macchi Cassia, 2020). Lastly, comparing preschoolers to schoolchildren allows for a better understanding of age-related differences (de Souza et al., 2018; Denervaud, Mumenthaler, Gentaz, & Sander, 2020).

Materials and methods

Participants

Two-hundred and fifty-five participants ages 5 and 7 were tested, and fifty-five were excluded from the final sample as they did not finish the experiment (N=49) or were distracted during the task (N=6). The final sample included 200 children participants (108 females; M_{age} = 6.11 years; SD_{age} = 0.98), 89 5-year-olds children and 111 7-years-olds children; they were recruited in different regions of Italy and all were Caucasian, had normal or corrected-to-normal vision, were right-handed and without history of any psychiatric or neurological disorders. Data were not analyzed until data collection was completed and no sequential testing was performed as we included all children who completed the online task in the sample.

In line with the only study investigating trustworthiness discrimination in own- and other-race faces in children (Charlesworth & Banaji, 2019), a sensitivity power analysis was performed using G*Power (Faul et al., 2009) indicated that the final sample size had sufficient power (.80) to

detect significant odds ratios (OR) of 0.53 and 1.89, or a critical z = +/- 1.64 at an alpha of .05, indicating that the sample was large enough to detect significant small effects in a logistic regression.

Families were recruited from the community by word of mouth on a voluntary basis or through a database at the Department of Psychology (University of Milan-Bicocca), in which the contacts of the parents of children who previously participated in other experiments and expressed the consent to participate in other experiments, were stored. The parents of the children signed a written informed consent before the children completed the task. The protocol was carried out in accordance with the ethical standards of the Declaration of Helsinki and was approved by the Ethics Committee of the University of Milano-Bicocca.

Stimuli

The stimuli are the same as those used in the study with adult participants (Study 2). Stimuli are five variations reflecting a continuum of trustworthiness that ranged from 1 (very untrustworthy) to 5 (very trustworthy), interleaved by a neutral face of Caucasian female face identity and Asian female face identity. We used the original unfiltered faces and the two filtered continua, one with only low spatial frequencies (< 1.6 c/g) and one filtered by keeping only high spatial frequencies (> 2.4 c/g; we show the image of the faces for ease in Figure 3.1).

Apparatus and Procedure

The experimental procedure is the same as that adopted with the adult participants in Study 2. The experiment took place online, and participants provided their responses using Qualtrics (Qualtrics, Provo, Utah, USA, https://www.qualtrics.com). They all ran the experiment on a desktop or portable computer, which, for all participants, was 13 inch or larger with a resolution of at least 1280 × 800 pixels. Participants performed a *Pairwise Preference task* (see Baccolo & Macchi Cassia, 2020) where, on each trial, two faces randomly selected from the same trustworthiness continuum simultaneously appeared on the screen, and they were asked to select the face they trusted more by clicking the mouse. Parents were asked to prepare the experimental setting by opening the task on the computer and placing the child 30 cm away.

The task consisted of a 2 (face ethnicity: Caucasian, Asian) x 3 (spatial filtering: LSF, HSF, BSF) conditions design. Trials from each of the six conditions were presented in blocks, and participants completed 10 trials per condition, corresponding to all possible pairwise combinations of the five faces of the continuum (60 trials in total). Each face of the continuum was compared to all other faces of the same continuum for a total of four times; the position of the faces on the screen was randomized across trials, and trials within each block were presented in random order. While face ethnicity was alternated between blocks, with the ethnicity of faces in the first block counterbalanced across participants, the order of the spatial filtering blocks was fixed across participants (LSF-HSF-BSF).

To avoid tiring the children, we gave families the option of deciding whether to complete the task in one session or in 3 different sessions (the first LSF and the last BSF with HSF between the two) on 3 consecutive days.

Different stories were created to induce the concept of trustworthiness in children. All stories were presented at the beginning of each session through a video in which the children were

asked for help in completing a game. A little bunny asked the child for help in identifying the real princess of whom many copies had been created by an evil witch. The child was asked to identify in each couple of faces presented on the screen the real princess among the many copies, the only one that could be trusted. The bunny video appeared in the middle of the task to motivate the child to continue the activity and at the end to reward the child. In each of the three sessions these videos with different stories were used to induce the concept of trustworthiness and keep the child's motivation high to complete the task. Finally, parents were asked to help report at the end of the session if the child was distracted or if there were any problems in completing the task. Children who were distracted or did not complete the task were excluded from the sample (N = 55).

Results

Response Accuracy

One-sample t tests (vs. 50%) on percent accuracy, that is the percentage of trials in which the face displaying more intense cues to trustworthiness was selected, confirmed that, for both Caucasian, all *ps* < .001, and Asian faces, all *ps* < .001, participants systematically selected the more trustworthy face in the pair under all spatial filtering conditions.

We here adopted the same statistical approach of Study 2. Children' response accuracy was entered as a dependent variable into generalized mixed-effects logistic regression models, using the GAMLj 2.3.0 module in the Jamovi software (Version .1.6.15; The jamovi project, 2021).

We included face ethnicity (Caucasian, Asian), spatial filtering (BSF, LSF, HSF) and age of participants (5 and 7) as fixed factors. We included random intercepts (1) for the participants to control for potential between-subjects differences in performance, (2) for spatial filtering to control

over potential intrinsic and extrinsic factors (as experimental conditions that impact perception of spatial frequencies relative to task completion over different but consecutive days/the same day or under different lighting conditions), and (3) for ethnicity to control over the variability in the degree of ethnic homogeneity of children's social environment as a function of the geographic area of origin.

The analysis revealed a significant effect of age group, $\chi^2 = 12.16$, $p < .001$, as 7-year-old participants' performance was more accurate than 5-year-old participants ($\beta 1 = 0.33$, SE = 0.09, z = 3.52, $p < .001$, 95% CI [1.16, 1.67]). There was also a significant interaction between age group and face ethnicity, $\chi^2 = 4.79$, $p = .03$, with 7-year-old children more accurate with Caucasian than Asian faces ($\beta 1 = 0.17$, SE = 0.08, z = 2.30, $p = .02$, 95% CI [1.03, 1.38]) and with 7-year-olds more accurate than 5-year-olds only with Caucasian faces ($\beta 1 = 0.46$, SE = 0.10, z = 4.37, $p < .001$, 95% CI [1.28, 1.93]) (Figure 3.5).

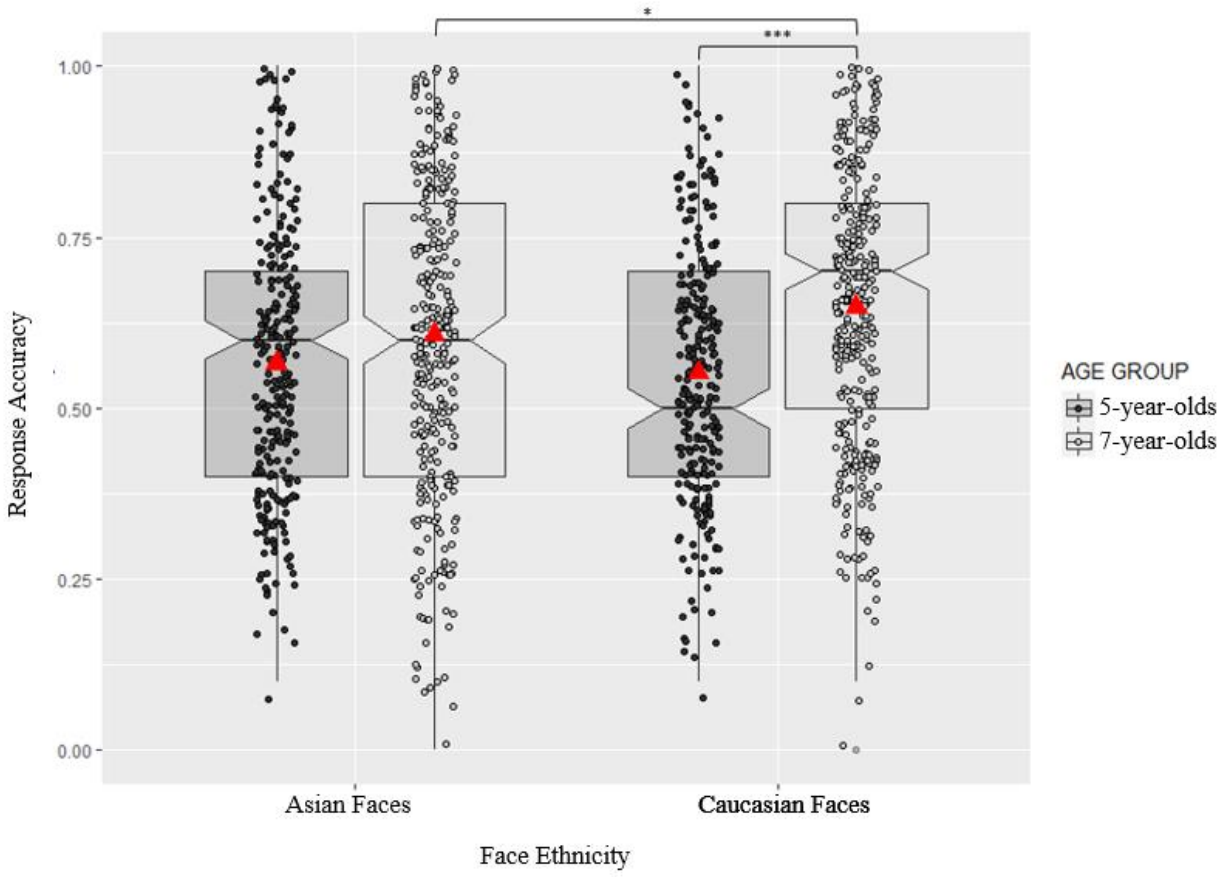

*Figure 3.5. Response accuracy for Asian and Caucasian faces in the two age groups (means are represented in red into the notched boxplots). * $p < .05$. ** $p < .005$. *** $p < .001$.*

The analysis revealed a significant interaction between face ethnicity and spatial filtering, $\chi^2 = 17.84$, $p < .001$, with higher accuracy for Caucasian than Asian faces in HSF condition ($\beta 1 = 0.25$, SE = 0.08, z = 3.19, $p = .001$, 95% CI [1.10, 1.50]), and an almost significant higher accuracy for Asian than Caucasian faces in LSF condition ($\beta 1 = -0.16$, SE = 0.07, z = -1.95, $p = .052$, 95% CI [0.73, 1.00]). Moreover, with Asian faces, children are more accurate in the BSF condition than in the HSF condition ($\beta 1 = -0.18$, SE = 0.08, z = -2.34, $p = .02$, 95% CI [0.71, 0.97]) (Figure 3.6).

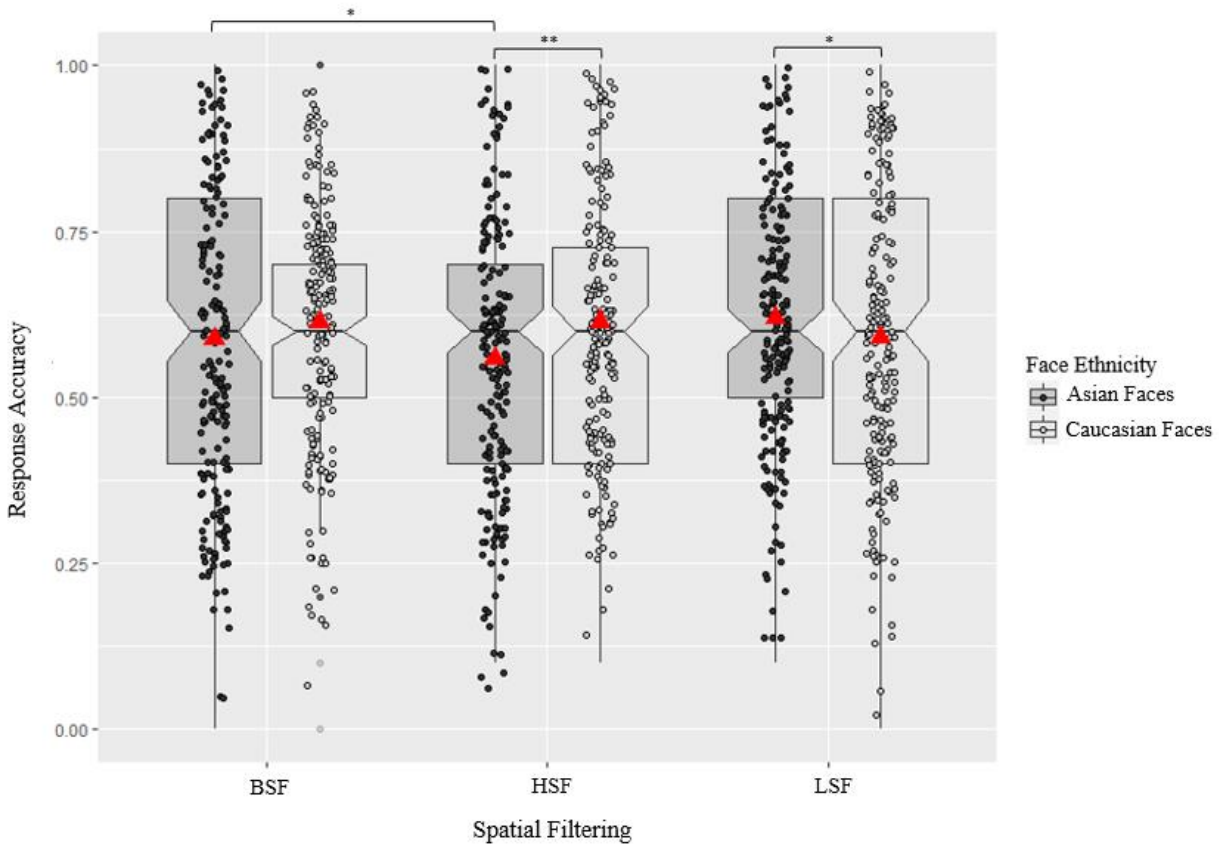

*Figure 3.6. Response accuracy for Caucasian and Asian faces plotted as a function of the spatial frequency condition (Broad-Spatial-Frequency, High-Spatial-Frequency, and Low-Spatial-Frequency). Means are represented in red into the notched boxplots. * $p < .05$. ** $p < .005$. *** $p < .001$.*

In light of the statistically significant effects involving the factor age group (main effect and in interaction with face ethnicity), two separate mixed models were conducted, each for the two age groups, using the same design as the analysis previously presented.

For 5-year-olds the analysis revealed an interaction between filtering condition and face ethnicity, $\chi^2 = 12.41$, $p = .002$, with higher accuracy for Asian than Caucasian faces in LSF

condition (β1= -0.29, SE = 0.11, z = -2.79, p = .005, 95% CI [0.61, 0.92]). Moreover, with Asian faces, children are more accurate in the BSF condition than in the HSF condition (β1= -0.30, SE = 0.10, z = -2.90, p = .004, 95% CI [0.60, 0.91]), while with Caucasian faces, children are more accurate in the BSF condition than in the LSF condition (β1= -0.22, SE = 0.11, z = -2.02, p = .044, 95% CI [0.65, 0.99]) (Figure 3.7).

For 7-year-olds the analysis revealed a main effect of face ethnicity, $\chi^2 = 4.20$, p = .04, with higher accuracy for Caucasian than Asian faces, (β1= 0.18, SE = 0.09, z = 2.05, p = .04, 95% CI [1.01, 1.43]), and an interaction between filtering condition and face ethnicity, $\chi^2 = 6.13$, p = .047, with higher accuracy for Caucasian than Asian faces in HSF condition (β1= 0.33, SE = 0.12, z = 2.77, p = .006, 95% CI [1.10, 1.74]). Moreover, with Asian faces, children are more accurate in the LSF condition than in the BSF condition (β1= 0.25, SE = 0.12, z = 2.11, p = .035, 95% CI [1.02, 1.61]), while with Caucasian faces, no differences were found between spatial frequency conditions (all *ps* > .75) (Figure 3.7).

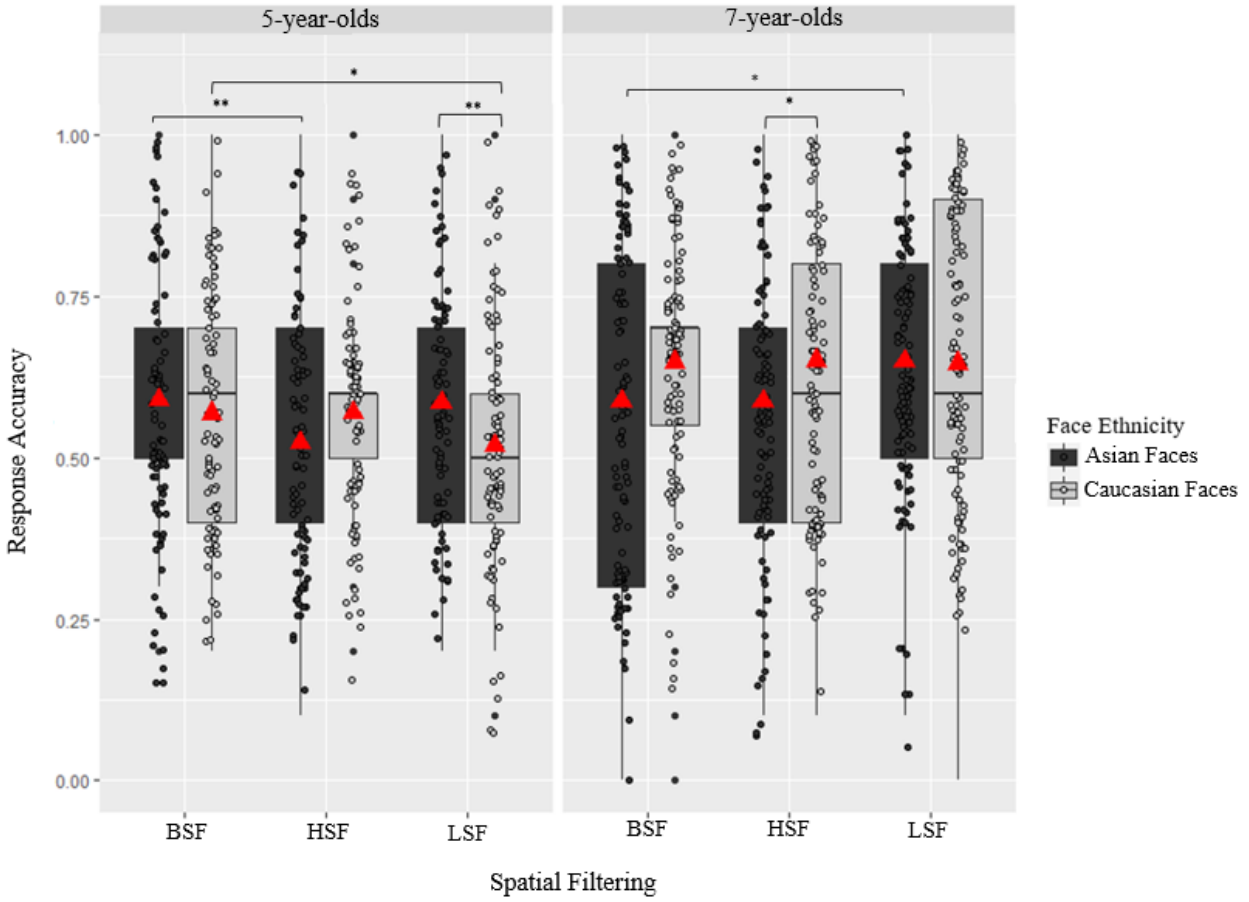

*Figure 3.7. Response accuracy in 5 and 7-year-olds for Caucasian and Asian faces plotted as a function of the spatial frequency condition (Broad-Spatial-Frequency, High-Spatial-Frequency, and Low-Spatial-Frequency). Means are represented in red into the boxplots. * $p < .05$. ** $p < .005$. *** $p < .001$.*

Trustworthiness Scores

The trustworthiness score, obtained by the sum of the times each face was selected as more trustworthy in a pair, was analyzed through linear mixed-effects models (LMMs) with four fixed

factors (face ethnicity, spatial filtering, trustworthiness intensity and age group) and random intercept for participants, face ethnicity, and spatial filtering.

Moreover, since we were interested in how face ethnicity and spatial frequency affected the slope of the relationship between trustworthiness intensity and decision outcome, we also performed the polynomial contrasts of trustworthiness intensity across the different conditions.

The analysis revealed a trustworthiness intensity main effect, $F(4,8) = 136.19$, $p < 0.001$, which was qualified by significant two-way interactions between this factor and both face ethnicity, $F(4,8) = 3.67$, $p = 0.005$, and with age group, $F(4,8) = 17.10$, $p < 0.001$. The analysis revealed 3 significant three-way interactions: first, between face ethnicity, spatial filtering, and trustworthiness intensity, $F(8,16) = 3.80$, $p < .001$, second, between face ethnicity, age group, and trustworthiness intensity, $F(8,16) = 2.46$, $p = .043$, and third, between age group, spatial filtering, and trustworthiness intensity, $F(8,16) = 2.49$, $p = .01$.

To better interpret data and in light of the statistically significant effects involving the factor age group, two separate mixed models were conducted, using the same design as the analysis previously presented.

The analysis with 5-year-olds revealed a trustworthiness intensity main effect, $F(4,8) = 27.86$, $p < .001$ and an interaction between face ethnicity, spatial filtering, and trustworthiness intensity, $F(8,16) = 2.25$, $p = .02$.

Polynomial contrast analysis revealed that trustworthiness scores varied overall linearly across the five trustworthiness intensity steps, $\beta=1.53$, $p < .001$, but the slope was steeper in the BSF condition ($\beta = 0.58$, $p < .001$) than in the HSF condition ($\beta = 0.33$, $p < .001$), $\beta = -0.24$, $p = .027$, with no difference between the BSF and LSF (βLSF = 0.41, $p < .001$) conditions, $\beta = -0.16$,

p = .13. No differences in linearity of the slope were found between Caucasian (β=0.41, p < .001) and Asian faces (β = 0.48, p < .001), β= -0.07, p = .41. This was true for both LSF (βCaucasian = 0.24, p < .001 vs. βAsian = 0.58, p < .001), β = -0.15, p = .47, and the BSF (βCaucasian = 0.48, p < .001, vs. βAsian = 0.67, p < .001), β = -0.18, p = .25 conditions. However, the difference between Asian and Caucasian faces reached significance in the HSF condition, β = 0.48, p = .027, with the slope for Asia faces (β = 0.19, p = .09), non-significantly linear in respect to the slope for Caucasian face (βCaucasian = 0.49, p < .001). Indeed, for Asian faces the trend was linear only in BSF (β = 0.67, p < .001) and LSF (β = 0.58, p < .001) conditions, with no difference in linearity between the two, p = .59, but not in HSF (β = 0.19, p = .09), differing from the other two conditions, all *ps* < .002. On the contrary, for Caucasian faces no difference in linearity between the three conditions was found LSF (βLSF= 0.25, p = .02, βHSF= 0.49, p < .001, βBSF= 0.49, p < .001), all *ps* > .11 (Figure 3.8).

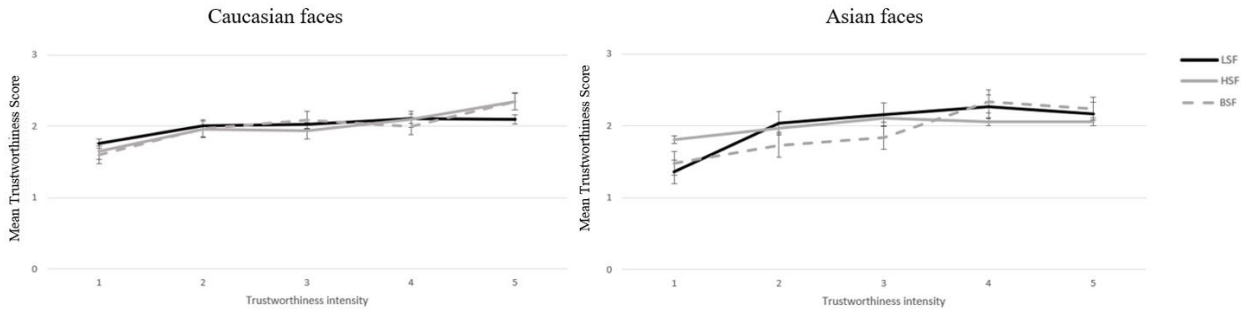

Figure 3.8. Mean trustworthiness score in 5-year-olds for each of the five Caucasian (left) and Asian (right) faces composing the trustworthiness continuum in the Low-Spatial-Frequency (LSF), the High-Spatial-Frequency (HSF), and the Broad-Spatial-Frequency (BSF) conditions. Error bars refer to standard errors of the means.

The analysis with 7-year-olds revealed a trustworthiness intensity main effect, $F(4,8) = 135.67$, $p < .001$, in interaction with both face ethnicity, $F(4,8) = 4.85$, $p < .001$, and spatial filtering, $F(4,8) = 2.63$, $p = .007$. These interactions were qualified by a three-way interaction between face ethnicity, spatial filtering, and trustworthiness intensity, $F(8,16) = 2.25$, $p = .02$.

Polynomial contrast analysis revealed that trustworthiness scores varied overall linearly across the five trustworthiness intensity steps, β=0.94, $p < .001$, but the slope was almost steeper in the LSF condition ($\beta = 1.07$, $p < .001$) than in the BSF condition ($\beta = 0.88$, $p < .001$), $\beta = -0.24$, $p = .051$, with no difference between the BSF and HSF (βLSF = 0.85, $p < .001$) conditions, $\beta = -0.02$, $p = .82$. The slope was also overall more steeper for Caucasian faces (β=1.07, $p < .001$) than for the Asian faces ($\beta = 0.80$, $p < .001$), β= 0.27, $p < .001$, but this difference was also modulated by the spatial frequency content of the images, as it reached significance in both the BSF (βCaucasian = 1.15, $p < .001$, vs. βAsian = 0.61, $p < .001$), $\beta = 0.54$, $p < .001$, and the LSF (βCaucasian = 1.02, $p < .001$ vs. βAsian = 1.13, $p < .001$), $\beta = -0.64$, $p = .001$, conditions but not in the HSF (βCaucasian = 1.05, $p < .001$ vs. βAsian = 0.66, $p < .001$), $\beta = -0.14$, $p = .47$. Moreover, for Caucasian faces no difference in linearity between the three conditions was found (βLSF= 1.02, $p < .001$, βHSF= 1.05, $p < .001$, βBSF= 1.15, $p < .001$), all *ps* > .35. For Asian faces the trend was overall linear across the five trustworthiness intensity steps, β=0.80, $p < .001$, but the slope was steeper in the LSF condition ($\beta = 1.13$, $p < .001$) than in both the BSF condition ($\beta = 0.61$, $p < .001$) and in the HSF condition ($\beta = 0.66$, $p < .001$), both *ps* < .001, with no difference between the latter two ($p = .69$) (Figure 3.9).

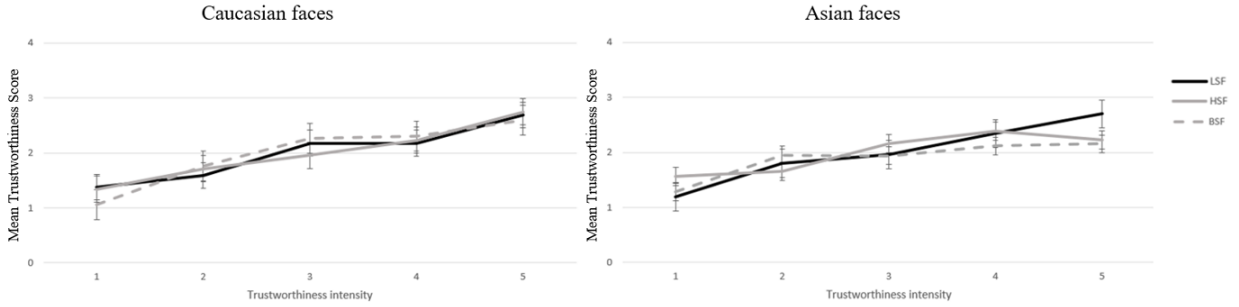

Figure 3.9. Mean trustworthiness score in 7-year-olds for each of the five Caucasian (left) and Asian (right) faces composing the trustworthiness continuum in the Low-Spatial-Frequency (LSF), the High-Spatial-Frequency (HSF), and the Broad-Spatial-Frequency (BSF) conditions. Error bars refer to standard errors of the means.

Discussion

The present study investigated the contribution of coarse and fine resolution information to trustworthiness perception in own- and other-race faces through the image spatial filtering approach in preschoolers and school children.

The first aim of the study was to explore whether trustworthiness discrimination generalizes across face ethnicity in children. We found that discrimination accuracy for the original unfiltered faces did not differ for Caucasian and Asian faces in the whole children group.

However, when investigating for possible age differences, we found generalization of trustworthiness discrimination across face ethnicity only for 5-year-olds. Indeed, 7-year-olds were more accurate with Caucasian than Asian trustworthy faces. Moreover, 7-year-olds were more accurate than 5-year-olds with Caucasian faces.

Studies on identity discrimination showed that the increased familiarity with face categories influences the own-race bias, as does a lack of familiarity with less-represented in the social environment face categories. As a matter of fact, 3-month-old infants, who have limited experience with other-race faces, have an early preference for own-race faces over other-race faces (Bar-Haim et al., 2006). Later in development, there are mixed findings about the existence of the own-race bias in young children. Although findings in literature are consistent in showing the own-race bias in identity recognition in children older than 7, the results in children between 5 to 7 years of age are varied, often reporting an absence of the own-race bias in children younger than 7 (Anzures et al., 2014; Anzures, Quinn, Pascalis, Slater, & Lee, 2013; Chien, Tai, & Yang, 2018; Goodman et al., 2007; Walker & Hewstone, 2006). Findings showing the emergence of own-race bias in children older than 7 reflected the potential impact of increasing experience with people of one's own race and extended lack experience with people of other races (Anzures et al., 2014; Anzures et al., 2013). The absence of an own-race bias in 5-year-olds confirmed earlier demonstrations in infants and adults that trustworthiness perception generalizes across face ethnicity (Birkás et al., 2014; Xu et al., 2012). Our result is consistent with the only study investigating trustworthiness implicit discrimination between faces of different ethnicities in children aged 5-13 (Charlesworth & Banaji, 2019). Charlesworth & Banaji (2019) showed that both Black and White faces pre-judged as trustworthy are rated as "nice" in an implicit task, with no differences between the two ethnicities.

Unlike younger children, the 7-year-olds showed an own-race bias in trustworthiness discrimination, which was also apparent in the slope of the trustworthiness scores, which was steeper for the Caucasian continuum than for the Asian one. These findings extend the evidence provided by previous studies that compared trustworthiness ratings of different ethnic versions of

low- medium- and high-trustworthy faces (Birkás et al., 2014; Charbonneau et al., 2020; Sofer et al., 2017; Xu et al., 2012), by showing a more fine-grained sensitivity to variations in perceptual cues to trustworthiness intensity in own-race faces compared to other-race faces. Critically, the present findings showed that this own-race advantage in trustworthiness discrimination emerges by age 7, and remains stable into adulthood (see Study 2).

Results from the two spatial filtering conditions showed that, for both younger and older children, LSF and HSF were both sufficient to allow discrimination of trustworthiness intensity. Indeed, for both Caucasian and Asian faces, participants performed above chance when asked to select the more trustworthy face in a pair in all spatial filtering conditions. Accordingly, the trustworthiness scores of the older children varied linearly for both the Caucasian and Asian continua in all filtering conditions.

Nonetheless, this was not the case for the younger children, whose trustworthiness scores in the HSF condition varied linearly for the Caucasian continuum but not for the Asian one, indicating that removal of LSF information negatively impacted their sensitivity to variations in trustworthiness intensity in other-race faces. This finding was also confirmed by the accuracy data, showing that the selective removal of LSF negatively impacted trustworthiness discrimination for Asian faces, resulting in an own-race bias when only HSF information was available in the stimuli. In contrast, in the LSF condition we observed a discrimination advantage for Asian over Caucasian faces. These findings indicate greater reliance on HSF information in trustworthiness perception of own-race faces, and greater reliance on LSF information in trustworthiness perception of other-race faces.

When splitting the analyses according to children's age, we found that selectively removing HSF bands negatively impacted trustworthiness perception of Caucasian faces in 5-year-old

children, while removing LSF bands decreased 5-year-olds' discrimination of Asian faces. In a similar vein, selective removal of HSF improved 7-year-olds' discrimination of Asian faces, while removing LSF bands decreased discrimination performance for Asian faces, resulting in an own-race advantage. Thus, unlike adults, trustworthiness perception of own-race faces in children rely more on HSF information, while trustworthiness perception of other-race faces rely more on LSF information.

Indeed, in contrast with adults' discrimination advantage for Caucasian over Asian faces driven by holistic information (Study 2), in younger children trustworthiness perception from own-race faces relies on analytical information. This result seems in line with the literature on SF implicated in emotional and identity perception in developmental population (Deruelle & Fagot, 2005; Gao & Maurer, 2011; Leonard et al., 2010; Vlamings et al., 2010). Children as young as 7 years are more tuned to analytic information driven by high spatial frequency, and a shift from featural to configural/holistic face processing appears to occur in late childhood (Miki et al., 2015; Peters et al., 2013). The higher reliance on HSF in children has been attributed to the maturation of the parvocellular system, which reaches full maturity precisely in this age group (Adams & Courage, 2002; Peters et al., 2013).

Moreover, face processing mechanisms in adults and children have been studied extensively using a variety of techniques including inversion, part-whole, and composite face methodologies (Maurer, Le Grand, & Mondloch, 2002; Pellicano, Rhodes, & Peters, 2006; Tanaka et al., 2004). Overall, these studies have shown that children and adults both analyze faces holistically, while children perform worse than adults. So as in emotion and identity perception, also in trustworthiness perception from own-race faces adults rely more than children on holistic

processing reflecting the outcome of expertise development that comes as result of adults' increased experience with processing faces (Richler, Cheung, & Gauthier, 2011).

Indeed, a more plausible explanation of younger children's higher reliance on HSF in own-race trustworthiness perception comes from the model proposed by Over & Cook (2018), according to which there is a representational space, "trait space", requisite for face-trait mapping. The trait space and the face perception ability on other people's traits are shaped during development by experience. Features and their global configuration defines the representation of social traits of emotion or trustworthiness. It is, thus, possible that in the construction of trustworthiness representation from faces, detailed information is crucial. Detailed information is fundamental for faces on which this representation is being built, faces most represented in the social environment. It may be that children are more focused on details because it is the information that allows them to create trustworthiness representation. Later in development, once these representations are formed, details are superfluous and, therefore, adults are more tuned to the holistic information.

The visual information involved in trustworthiness perception in other- and own-race faces seems different. Indeed, in 7-year-olds, removing high spatial frequencies improves accuracy with other-race faces and in 5-year-olds diminishes accuracy with own-race faces, resulting in an other-race advantage with LSFs. Thus, it appears that perception of social cues to trustworthiness from faces of other-race in 5- and 7-year-old children is based on global spatial information (LSF). Thus, even in adults (Study 2), the selective removal of LSF had a negative effect on trustworthiness discrimination accuracy for Asian faces.

This is in line with studies of identity perception in adults in which other-race faces are also processed holistically (Wong, Estudillo, Stephen, & Keeble, 2021). In one recent cross-

cultural study adopting the spatial filtering approach to investigate the perceptual processing in own- and other-race faces (Zhang, Wang, Wu, & Zhao, 2017), the authors found that race categorization mainly relies on low spatial frequencies. Specifically, they found that other-race faces were classified more accurately with both BSF and LSF than HSF information. Moreover, the categorization of other-race faces was faster than the categorization of own-race faces (i.e., other-race categorization advantage, ORCA) in both BSF and LSF conditions. The ORCA was more evident in LSF than BSF condition. Thus, these results pointed out the crucial role of global information for other-race faces perception. It appears that the HSF information included in the intact BSF images actually negatively impact on the other-race faces categorization. Similarly, Harel and Bentin (2009) found that LSF removal negatively impacted categorization of faces by race, which was unaffected when the HSF was removed. Thus, also for trustworthiness perception LSF information is essential for other-race perception in adults and children.

Moreover, neurophysiological studies (Ding, Fu, & Lee, 2014; Zhou, Liu, Ding, Fu, & Lee, 2016) found higher activation in children for other- than own-race faces in right middle frontal gyrus, inferior frontal gyrus and left cuneus. The authors discussed the higher activation for other-race faces in children as a probable novelty preference effect for the most salient other-race faces (Ding et al. 2014).

Thus, it is possible that removing high spatial frequency information, which is useful for emotional, identity and trustworthiness perception in familiar faces in children, makes faces less present in children's social environment more salient. Thus, the novelty preference effect for other-race faces could be enhanced by global information. In other words, although children are more tuned to high spatial information, they are also able to process faces holistically. This is especially

true for faces to which they are less exposed. Thus, global characteristics enhance the salience of novel faces, to which children are less exposed.

Taken together, our findings may support the "social-categorization" model (Sporer, 2001). This model claims that when viewing other-race faces, observers focus more on coarse rather than fine information, whereas when viewing own-race faces, individuals focus more on analytical information, indicating a more fine-grained processing (Bernstein, Young, & Hugenberg, 2007). Therefore, also in trustworthiness perception, in early stages of development, children with own-race faces are more tuned to fine processing and with other-race faces are more tuned to coarse elaboration.

However, experience plays a crucial role. The adults' increased experience with own-race faces and the greater experience of processing faces results in the higher reliance on global information in trustworthiness perception in own-race faces.

Conclusions and common considerations

The studies presented in this chapter explored the nature of visual information necessary to elicit trustworthiness judgments from own- and other-race faces in adults (Study 2) and children (Study 3).

To the best of our knowledge, our results are the first to provide evidence on visual information conveying trustworthiness perception in faces of different ethnicity in children. Our findings show how visual information conveying trustworthiness perception is modulated by

experience with faces most represented in the individual's social environment. The expertise in face processing changes the visual information required to elicit trustworthiness perception with adults and children relying on different visual information in processing own-race faces. Moreover, the visual information present in the image modulates the perceived salience of facial cues to trustworthiness in adults and children, with low-SF contributing critically to the salience of less familiar faces.

It should be considered that three methodological aspects of the two studies may limit the interpretation of the current findings. The first relates to the online nature of the study, which reduced our control over the experimental setting, potentially affecting variability in the parameters of stimulus presentation that are relevant in relation to image spatial filtering manipulation (e.g., distance from the screen, screen luminosity, environmental lights). Although this remains true, it is important to note that, since we applied the same spatial filtering manipulations to both Caucasian and Asian face stimuli, any intervening variable on stimulus parameters would have had the same effect on participants' performance in both face ethnicity conditions.

A second methodological aspect that might have impacted on the results relates to the stimulus material. First, the use of morphed face images may have influenced participants' sensitivity to differences in trustworthiness intensity in our task. Indeed, previous research has shown that computer-generated faces had poorer absolute trustworthy judgments and discrimination accuracy than real faces (Balas & Pacella, 2017), although this is especially true for male faces, as opposed to female faces (Balas, Tupa, & Pacella, 2018). It may be that trustworthiness perception was not disrupted in our study because stimuli were female faces. However, in light of the current debate concerning whether computer-generated faces are

appropriate to explore face processing expertise (e.g., Crookes et al., 2015), future studies may investigate the generalizability of the current results to real face images. It is indeed plausible that non-morphed real face images would trigger larger face-race effects in participants' trustworthiness discrimination than morphed faces did.

A second aspect with regard to stimuli concerns to contrast differences between our BSF, LSF and HSF faces, which might have affected participants' perception of the filtered images, thus constraining conclusions about the mere influence of spatial frequencies on the obtained results (see e.g. Perfetto, Wilder & Walther, 2020). Nonetheless, previous studies in adults (Harel & Bentin, 2009; Munsters et al., 2016; Vlamings et al., 2009) and infants (van den Boomen et al., 2019) showed that contrast differences do not account for spatial filtering effects on discrimination of social cues from faces. Future studies might use normalized images to test whether the current findings would be replicated in the absence of any confounding between the SF and the power content of the filtered images.

The inclusion of participants from only one ethnic group is a third methodological aspect of the current study that may constrain the interpretation of the obtained results. This did not allow us to determine whether participants' cultural background affected the source of visual information mediating trustworthiness perception. Moreover, it is often argued that the absence of a cross-cultural comparison limits the interpretation of the observed face race effects as driven by perceptual expertise for own-race faces, as those same effects might well be driven by differences in low-level stimulus characteristics rather than race per se. Cross-cultural research on face processing suggests that culture influences the nature of visual information extracted from faces, with Westerners relying more on fine resolution information, and Easterners relying more on coarse information (e.g., Tardif et al., 2016). In light of this, future studies conducted on Easterner

individuals may explore whether the own-race LSF advantage in adults and the own-race HSF advantage in children in trustworthiness discrimination observed in the current studies is a cross-cultural phenomenon or it generalizes in those individuals to other-race faces.

Chapter 4

Study 4 - The role of visual spatial frequency information in infants' neural sensitivity to facial cues to trustworthiness

Results from studies 1-3 have shown that both HSFs and LSFs provide sufficient visual information to allow adults and children to discriminate facial cues to trustworthiness to the point of differentiating between high-trustworthy and low-trustworthy faces.

A further contribution to the investigation of ontogenetic origins to social cues to trustworthiness comes from the exploration of an early sensitivity to trustworthiness in infants.

Although recent evidence indicates that sensitivity to subtle differences in facial cues to perceived trustworthiness is apparent from the early stages of development (Baccolo, Quadrelli, & Macchi Cassia, 2021; Jessen & Grossmann, 2016, 2019; Sakuta et al., 2018), the question of what visual information mediates this sensitivity remains unexplored.

Specifically, several electrophysiological studies showing that infants discriminate between different levels of trustworthiness with both supraliminally and subliminally presented facial cues (Baccolo et al., 2021; Jessen & Grossmann, 2016; 2019). Infants showed increased amplitude for P400 at occipital regions and Nc at frontal and central areas to neutral compared to either high trustworthy or low trustworthy faces (Jessen & Grossmann, 2016). When subliminally presented, untrustworthy faces elicited larger Negative Slow Wave (NSW) response in frontal and

central areas compared to neutral ones (Jessen & Grossmann, 2019). While failing to provide evidence of differentiation between trustworthy and untrustworthy faces, these studies showed that the infants' brain differentiate between facial cues to trustworthiness intensity. Indeed, results are in line with evidence from adult studies showing maximal amygdala activation in response to both positively and negatively valenced faces at the extremes of the trustworthiness continuum, and weaker activation in response to faces that are perceived as neutral with respect to the trustworthiness dimension (Said et al., 2009a; Said et al., 2010).

A more recent electrophysiological study (Baccolo et al., 2021), whose goal was to replicate evidence on infants' discrimination between levels of trustworthiness with more ecological stimuli (i.e., morphed images of real female faces), showed that infants discriminated between variation in trustworthiness intensity. More specifically, infants differentiated between trustworthy and untrustworthy faces at the level of P400, and the amplitude of the P400 differential response was modulated by infants' temperamental traits (Baccolo et al., 2021).

Taken together, these findings indicate that there is an early sensitivity to facial cues to trustworthiness during the earliest stage of development.

While most studies focused on exploring the existence of an early sensitivity to trustworthiness, little is known about the perceptual mechanisms that underpin it. Indeed, the majority of studies investigating the visual mechanisms underlying facial perception in infancy focused on identity (de Heering et al., 2008) and emotional (Jessen & Grossmann, 2017b; van den Boomen et al., 2019; Vlamings et al., 2010) processing.

Specifically, the only study exploring the nature of visual information necessary for identity discrimination, focused on newborns (de Heering et al., 2008). In line with evidence on

the early limitations of the visual system, which biases newborns' perception towards the low-SF bands of visual images (Acerra et al., 2002), they found that low spatial frequencies are necessary in detecting face identity at birth.

The few studies that explore the nature of visual information necessary for emotional discrimination, focused on older infants (Di Lorenzo et al., 2021; Jessen & Grossmann, 2017b; Munsters et al., 2016; van den Boomen et al., 2017; van den Boomen et al., 2021). In particular, studies on emotional processing converged in showing that infants from 7 months of age discriminate between fearful and happy emotional expressions when only high spatial frequencies remain in the stimuli (Di Lorenzo et al., 2021; Jessen & Grossmann, 2017b; Munsters et al., 2017; van den Boomen et al., 2017). The differential responses to emotional expressions emerged even before 7 months of age. Nevertheless, a recent study showed that a specific group of 5-month-old infants with high quality of social interaction with caregivers (e.g., show more attentiveness to the caregiver, positive and negative affect, and liveliness) are able to discriminate between fearful and neutral faces, regardless of the spatial content (van den Boomen et al., 2021).

This finding is in line with other evidence showing that under particular circumstances, infants as young as 5 months could discriminate between emotional expression with dynamic instead of static facial expressions (Addabbo et al., 2018; Heck et al., 2016) or with multimodal (i.e., audio-visual) stimuli (Flom & Bahrick, 2007). Moreover, it is plausible that 5-month-old infants discriminated between neutral and fearful faces regardless of SF presented due to the perceptual salience of fearful faces in this age group (Peltola et al., 2008). Indeed, even in Jessen & Grossmann study (2017b) only fearful faces elicited a similar Nc attentional response with both HSF and LSF, suggesting that fearful faces are detected regardless of SF content. It is, therefore, possible that infants are more tuned to high spatial information in emotional discrimination but

that under particular conditions of visual salience, even low spatial information is sufficient to allow them to discriminate between fearful and neutral faces.

Adults use both high- (HSF) and low-spatial frequency (LSF) in trustworthiness perception (Robinson et al., 2014; Said et al., 2009a), however, during development it is still unknown what information infants use in discriminating social cues that lead to the perception of trustworthiness. Within this context, it seems necessary to investigate whether global and/or local information are sufficient for infants to disentangle between trustworthy and untrustworthy faces.

Since almost all existing studies used computer-generated faces, which might fail to reflect infants' face processing expertise and limit the generalizability of the results, we here used morphed from different real faces female identities used in Study 1.

Here, we adopted a newly developed Electroencephalographic (EEG) visual discrimination paradigm, the Fast Periodic Visual Stimulation (FPVS), recently used with adults in implicit trustworthiness perception (Swe et al., 2020; Verosky, Zoner, Marble, Sammon, & Babarinsa, 2020), in which a rapid stimulus presentation at a constant frequency evokes changes in voltage amplitudes in the brain's electrical activity at the same frequency. In both studies (Swe et al., 2020; Verosky et al., 2020), adults discriminated between high- and low-trustworthy faces even without explicitly distinguishing between the two and with a significant response in medial and occipital regions, indirectly reflecting the amygdala activation.

Here, to conduct a qualitative investigation of age-related differences in brain sensitivity to trustworthiness from filtered faces, a group of adults was also tested using the same paradigm.

Thus, infants and adults were presented with high- and low-trustworthy faces as standard and oddball (i.e., deviant) stimuli. Oddball category (high/low trustworthiness) was varied within-

subjects. Stimuli were presented at a fixed rate of 6 Hz (baseline) following an oddball paradigm, in which every 5th image, the deviant stimulus was introduced, creating a trial sequence containing changes in trustworthiness intensity at a frequency of 1.2 Hz. FPVS responses were analyzed at both frequencies of interest and their harmonics as a function of oddball type (high- vs. low-trustworthy). The visual spatial frequencies (SF) content of the stimuli corresponding to featural (High-SF) vs. configural (Low-SF) information was manipulated using a spatial filtering approach similar to that used to test infants' emotion discrimination (Jessen & Grossmann, 2017).

Materials and methods

Participants

Twenty-seven young subjects composed the final adult sample (19 females, M_{age} = 24.59 years; *SD* = 3.53; range: 19 – 35 years). All of them were either undergraduate or graduate university students receiving course credits or recruited from the community by word of mouth on a voluntary basis and they gave their informed consent before taking part in the EEG session. All subjects were Caucasian, had normal or corrected-to-normal vision, were right-handed and did not report history of neurological or psychological disorders. We also tested four additional adults, which were excluded as a consequence of excessive EEG artefacts (*N* = 3) or lack of enough surviving conditions (*N* = 1).

Thirty eight 6-month-old healthy infants composed the final infant sample (18 females, M_{age} = 198.7 days; *SD* = 7.81; range: 178 – 211 days). All infants were Caucasian, born full-term and had a normal weight at birth (M= 3,344 g, SD=350 g). All infants met the screening criteria for normal delivery (gestational age > 37 weeks), and had no history of neurological, visual or auditory impairments. We also tested 20 additional infants, which were excluded as a consequence of

fussiness (*N* = 10), excessive artefacts (*N* = 8) or because an entire condition had to be excluded during preprocessing (*N* = 2).

The sample size is comparable to previous electrophysiological studies on facial expression processing with SF in infancy (e.g., di Lorenzo et al., 2021; Hoehl & Striano, 2010; Jessen, & Grossmann, 2017b; van den Boomen et al., 2019). We also estimated our minimum sample size on a Power Analysis for a rmANOVA model performed using G*Power 3.0.1, that revealed that 25 participants in each group would be required to have an 95% chance to detect an effect size for the target Spatial filtering x Condition x ROI of f = .25, at the conventional alpha level of .05, assuming a correlation among repeated measures of r = .50.

In accordance with the terms provided by the local ethics committee of Milano-Bicocca University, written informed consent was obtained from their parents. The protocol of the study was carried out in accordance with the ethical standards of the Declaration of Helsinki (BMJ 1991; 302:1194) and was approved by the ethics committee of the University of Milano-Bicocca.

Stimuli

The faces used in the study are a part of the stimuli used with adults in Study 1. The two female face identities used as experimental stimuli were created with WebMorph (DeBruine, 2017) to express two levels of trustworthiness: Low Trustworthiness (LT) and High Trustworthiness (HT). We averaged a set of faces selected from the Karolinska Directed Emotional Faces (KDEF) Database (Lundqvist et al., 1998) to obtain two neutral facial identities, one dark-haired (average of three dark-haired identities) and one blonde (average of three blonde-haired identities). In order to obtain a prototype of trustworthiness/untrustworthiness, the three most untrustworthy and the

three most trustworthy faces of the Chicago Face Database were averaged (Ma et al., 2015). The two neutral female face identities were then morphed towards the two references by 50% in order to obtain a Low Trustworthy (LT) and a High Trustworthy (HT) face for each identity. The four faces were then cropped into an oval shape to reduce the influence of low-level differences among the stimuli.

These four faces were then filtered, removing some portions of spatial frequencies through a Matlab script (adapted from https://psy.van-diepen.com/pvdmatl.html, see Dobkins & Harms, 2014). We here used the cut-offs calibrated on the visual acuity of infants and used in previous studies on emotional discrimination in 7-month-old infants (Jessen & Grossmann, 2017b). Thus, High-pass faces contained spatial frequencies > 0.6 c/g, while Low-pass faces contained spatial frequencies <0.4 c/g (see Figure 4.1). We used images filtered on infants' visual acuity to have comparable results between adults and infants (see Study 1). Images did not differ in terms of luminance (Wilcoxon test, $p > .12$) or Root Mean Square (RMS) contrast (Wilcoxon test, $p > .25$).

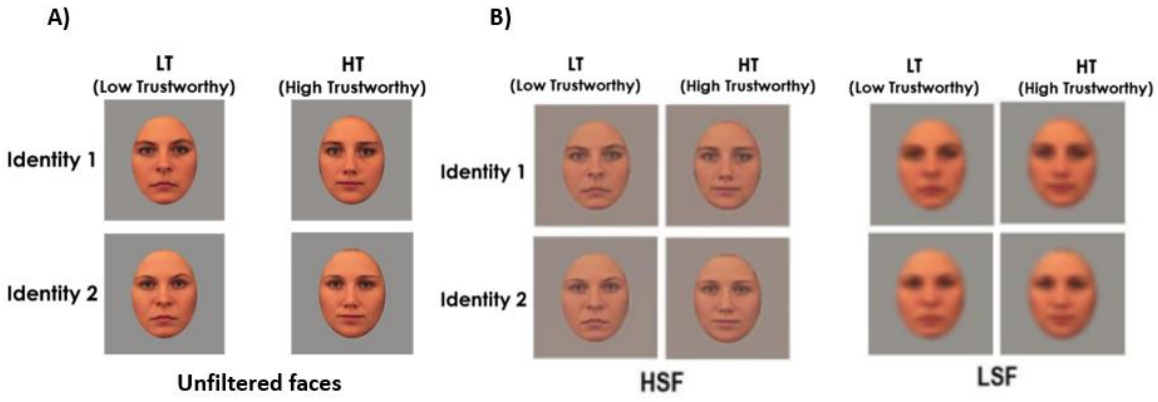

Figure 4.1. A) Original unfiltered faces. B) Experimental stimuli: two face identities expressing two levels of trustworthiness, Low Trustworthiness (LT) and High Trustworthiness (HT), for both High-pass filtered faces, HSF (left) and Low-spatial frequencies, LSF (right).

Procedure

Data acquisition of all participants took place in an audiometric and electrically shielded cabin. For the stimulus's presentation A 24-inch monitor was used. Participants seated at approximately 60 cm away from the screen. We asked adult participants to sit as still as possible during the entire procedure. The same instruction was given to parents and infants always seated on their parent's legs in front of the screen. Parents were also asked to avoid interfering with the experimental session. In the case of infants, the whole experimental session was recorded by an infrared video camera connected to the data acquisition computer and hidden over the monitor to look at the infants during the testing and pause or terminate the session as soon as the infant manifested fussiness.

Stimuli were presented through a MATLAB (Mathworks Inc.) script (adapted from Barry-Anwar, Hadley, Conte, Keil, & Scott, 2018). Subjects viewed four different conditions. The Low-pass filtered condition is composed of one condition where the Standard stimulus was LT, low trustworthy, and the Oddball was HT, high trustworthy (High-Oddball condition), and one where the Standard stimulus was HT and the Oddball was LT (Low-Oddball condition). The High-pass filtered condition is composed of one condition where the Standard stimulus was LT and the Oddball was HT (High-Oddball condition), and one where the Standard stimulus was HT and the Oddball was LT (Low-Oddball condition). The order at which conditions were presented was

counterbalanced across participants. We, thus, used an Oddball paradigm where stimuli were presented at a Baseline frequency of 6 Hz. Every fifth face the trustworthiness level changed (Oddball frequency of 1.2 Hz). To avoid neural responses related to low level stimuli characteristics, both contrast (from 0% to 100%), size and screen position (of 1 angle degree from the screen center) changed (Figure 4.2).

Each High- and Low-Oddball condition was composed of a total of 4 trials, each lasting 15000 ms, where a cycle of 4 Standard stimuli and one Oddball was repeated 18 times. For each trial, each facial identity was shown 9 times, and the same facial identity could not be shown more than 3 times in a row. Attention getters (i.e. moving puppets) were used between trials to reorient infants' attention, and started each trial as soon as the infant was looking at the screen. The entire presentation lasted between four to seven minutes.

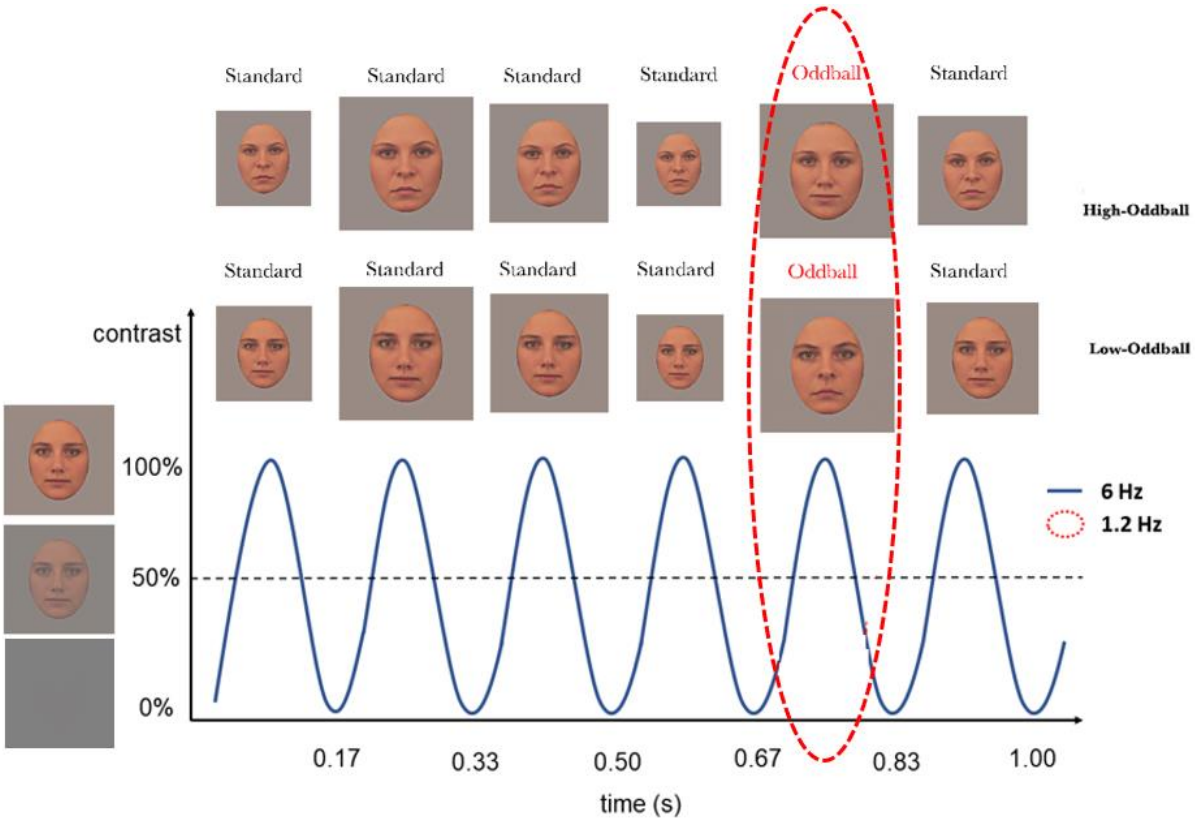

Figure 4.2. Example of Fast periodic visual stimulation (FPVS) with High-pass faces (HSF) for both High-Oddball condition (top) and Low-Oddball condition (bottom). Six faces were shown within one second (6 Hz Baseline frequency), and the trustworthiness level changed every 5 faces (1.2 Hz Oddball frequency, see the red circle). Stimuli were presented by a sinusoidal contrast modulation (from 0% to 100%) and varied in size and screen position (of 1 angle degree from the screen center).

EEG acquisition

Electroencephalographic (EEG) data were recorded through a 128-electrode HydroGel Geodesic Sensor Net (Electrical Geodesic Inc., Eugene, OR), with the vertex electrode (Cz) used as reference. Signals were amplified using an EGI NetAmps 300 amplifier with a sampling rate of 500 Hz and an online band-pass filter of 0.1–100 Hz. Impedances were checked online before the session started and they were considered as adequate if lower than 50 KΩ.

EEG data analysis

Preprocessing

We processed EEG data through Letswave 6 (http://nocions.webnode.com/letswave) in Matlab 2016b (The Mathworks, Inc), similarly to Quek and colleagues (2018). EEG data was first band-pass filtered at 0.1–100 Hz with a Butterworth filter with a slope of 24 dB/octet. The continuously recorded filtered data was then segmented in order to obtain 15-seconds segments (duration of each trial). The peripheral 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 the analyses as usually characterized by noise.

As a next step bad channel values were substituted with the average voltage from up to 6 neighbouring channels (not more than 10% of the electrodes). On average across adult participants 7.8% of electrodes (SD=2.9%) were interpolated and for infants 8.9% of electrodes (SD=2.8%) were interpolated.

Frequency-domain processing

Then, a common average reference computation was applied to all channels. All trials underwent a windowed Fast Fourier Transform (FFT) at a frequency resolution of 1/15 s. SNR values were computed as the ratio of the amplitude at the frequency of interest to the average of the 6 neighbouring frequency bins (3 on each side). If participants did not show an SNR of at least 2 for the Baseline frequency (either at 6 or 12 Hz) in occipital electrodes (70, 75 and 83) the corresponding trial was excluded from analyses. An average of 0.98 trials (SD = 0.79) in the adult sample and an average of 1.09 (SD = 0.78) in the infant sample was excluded due to non-significant base rate response.

For each participant, the remaining trials were then averaged in the time-domain across conditions with the aim to increase the signal-to-noise ratio (SNR).

To estimate the number of informative harmonics, we assessed the significance of the responses at different harmonics by calculating Z-scores on the FFT grand-averaged data across all electrodes and across electrodes in the relevant regions of interest (Van der Donck et al., 2020; Xu, Liu-Shuang, Rossion, & Tanaka, 2017). We considered significant and relevant harmonics to be included as long as the Z-score for two consecutive harmonics was above 1.64 ($p < .05$, one-tailed) (Retter & Rossion, 2016; Van der Donck et al., 2020).

By applying this principle to the Baseline response, adults' harmonics in the occipital clusters proved to be significant up to the 4^{th} harmonic (i.e., 24 Hz), while infants' harmonics in the occipital clusters proved to be significant up to the 6^{th} harmonic (i.e., 36 Hz). Therefore, analyses on SNRs and BCAs were performed on the sum of these harmonics (Retter & Rossion, 2016).

For what concerns the Oddball frequency, adults' responses were significant from the eleventh to the thirteenth harmonic, therefore we analysed the aggregated response from 13.2 to 15.6 Hz. Infant's Oddball significant responses were observed from 14.4 Hz to 15.6 Hz. Therefore, we analysed the aggregated response of these harmonics.

Determination of ROIs

For the Baseline response the regions of interest (ROIs) for statistical analyses were selected a-priori based on all previous FPVS studies (left, medial and right occipital clusters). ROIs for the Oddball frequency were selected a-priori based on all previous FPVS studies (medial, left and right occipital clusters and two occipitotemporal clusters) (Barry-Anwar et al., 2018; de Heering & Rossion, 2015) and to include the area that incorporates the superior temporal sulcus, since this area show greater activation with High-Spatial frequencies (Leppänen & Nelson, 2009; Pessoa & Adolphs, 2010; Van den Boomen et al., 2019). Thus, for both adults and infants, the three occipital clusters (left, medial and right), two occipitotemporal clusters (left, right) and two temporal clusters (left, right) were selected (see Figure 4.3).

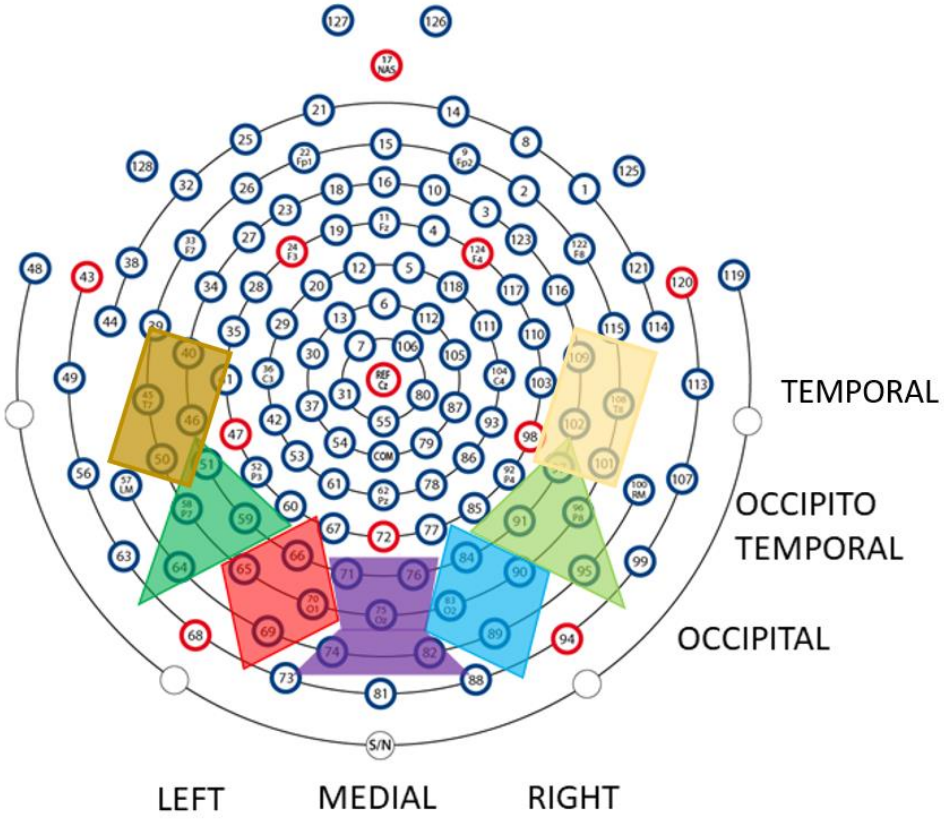

Figure 4.3. Regions of Interest (ROIs) for the Oddball frequency for both adults and 6-month-old infants.

As in previous studies (Dzhelyova, Jacques, & Rossion, 2017; Peykarjou, Hoehl, Pauen, & Rossion, 2017; Van der Donck et al., 2020), we used two different responses to avoid the problem of the reflection of the overall noise at a particular EEG frequency. We, therefore, computed Z-scores, calculated as the difference between the amplitude at the frequency of interest and mean amplitude of 6 surrounding bins divided by the standard deviation of the 6 surrounding bins, and baseline corrected amplitudes (BCAs), calculated as the amplitude at the frequency of interest minus the average of the 6 neighbouring frequency bins.

Grand-averages of the SNR (for data visualization - since the harmonic responses at high frequency ranges may be of small amplitude but with a high SNR-), Z-scores and BCAs were computed for each condition, each electrode separately and each pooled channels in ROIs.

Results

Statistical data analysis

Both Baseline and Oddball responses were analyzed through Z-scores of all occipital ROIs for the former and of the seven ROIs (see Figure 4.3) for the latter.

Moreover, to explore whether signal at the Baseline and Oddball frequency differed according to condition (High-Oddball or Low-Oddball), spatial filtering (High-pass faces or Low-pass faces) or ROIs, we conducted linear mixed-effects models (LMMs), performed using the GAMLj 2.3.0 module in the Jamovi software (Version.1.6.15; The jamovi project, 2021).

Following the recommendations of Meteyard and Davies (2020), we included conditions, spatial filtering and ROIs as fixed factors and random intercepts for the participants to control for potential between-subjects differences in performance. Degrees of freedom were calculated using the Satterthwaite method. Post-hoc contrasts were tested for significance using planned simple effects. All assumptions in terms of linearity, normality and constant variance of residuals were verified and met for all LMMs.

Infants

Baseline Frequency

The analysis proved to be significant in all occipital regions for all conditions, all *ps* < .001 (left Occipital: SNR *Low-Oddball;High-pass faces* = 1.188, Z = 3.906, *p* <.001; SNR *Low-Oddball;Low-pass faces* = 1.184, Z = 2.936, *p* <.001; SNR *High-Oddball;High-pass faces* = 1.251, Z = 4.580, *p* <.001; SNR *High-Oddball;Low-pass faces* = 1.323, Z = 4.953, *p* <.001; medial occipital: SNR *Low-Oddball;High-pass faces* = 1.478, Z = 8.319, *p* <.001; SNR *Low-Oddball;Low-pass faces* = 1.515, Z = 4.951, *p* <.001; SNR *High-Oddball;High-pass faces* = 1.493, Z = 8.798, *p* <.0001; SNR *High-Oddball;Low-pass faces* = 1.598, Z = 5.703, *p* <.0001; right Occipital: SNR *Low-Oddball;High-pass faces* = 1.403, Z = 6.989, *p* <.001; SNR *Low-Oddball;Low-pass faces* = 1.405, Z = 4.638, *p* <.001; SNR *High-Oddball;High-pass faces* = 1.447, Z = 7.744, *p* <.0001; SNR *High-Oddball;Low-pass faces* = 1.424, Z = 5.792, *p* <.0001), see Figure 4.4. When looking at individual data 100% of participants had a significant response and a SNR>1 in at least one ROI in all conditions.

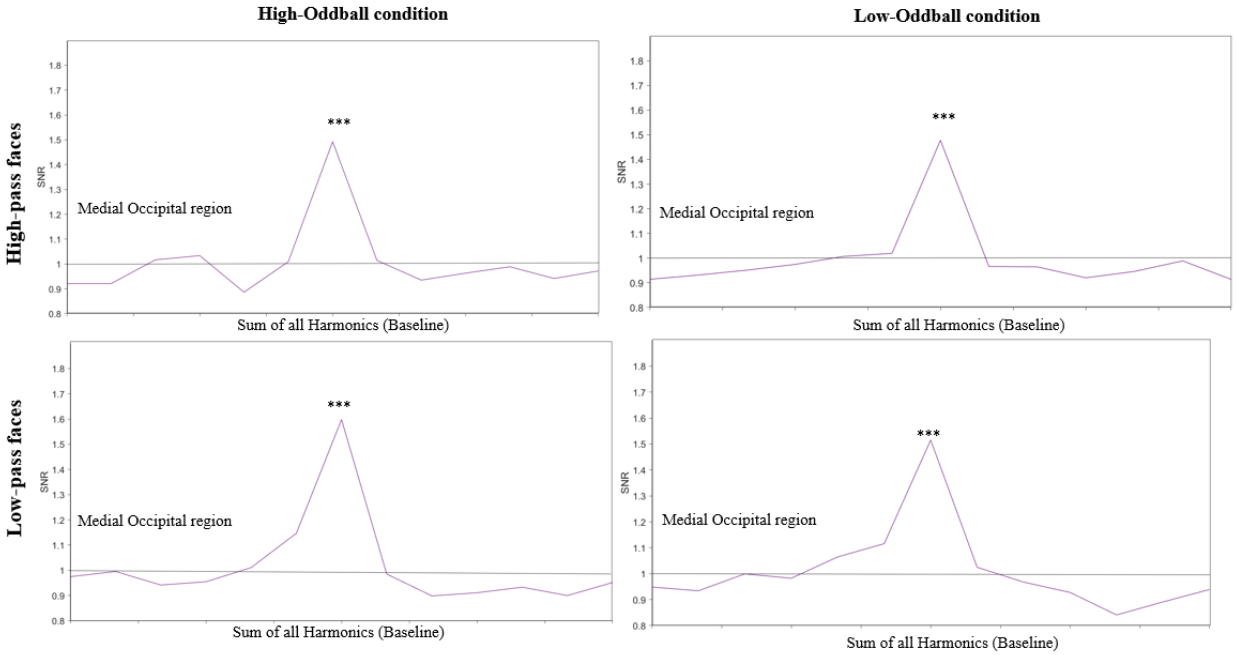

Figure 4.4. Infants' SNR at the Baseline frequency (sum of all harmonics of interest) for the High-Oddball condition and the Low-Oddball condition with both High-pass and Low-pass faces. The

*frequency graph represents the mean SNR in the medial occipital region, which peaked at the Baseline frequency (sum of harmonics of interest). * p < .05. ** p < .005. *** p < .001.*

The LMM analysis on BCAs with conditions, spatial filtering and ROIs as fixed factors revealed a significant main effect of ROIs, $F(2,9) = 13.35$, $p < .001$. Indeed, BCA in the medial occipital region proved to be significantly higher ($M = .715$, $C.I._{Lower} = .594$, $C.I._{Upper} = .837$) than both the left occipital ($M = .362$, $C.I._{Lower} = .240$, $C.I._{Upper} = .483$), $p < .001$, and the right occipital regions ($M = .567$, $C.I._{Lower} = .445$, $C.I._{Upper} = .689$), $p = .03$, independently of condition, see Figure 4.5.

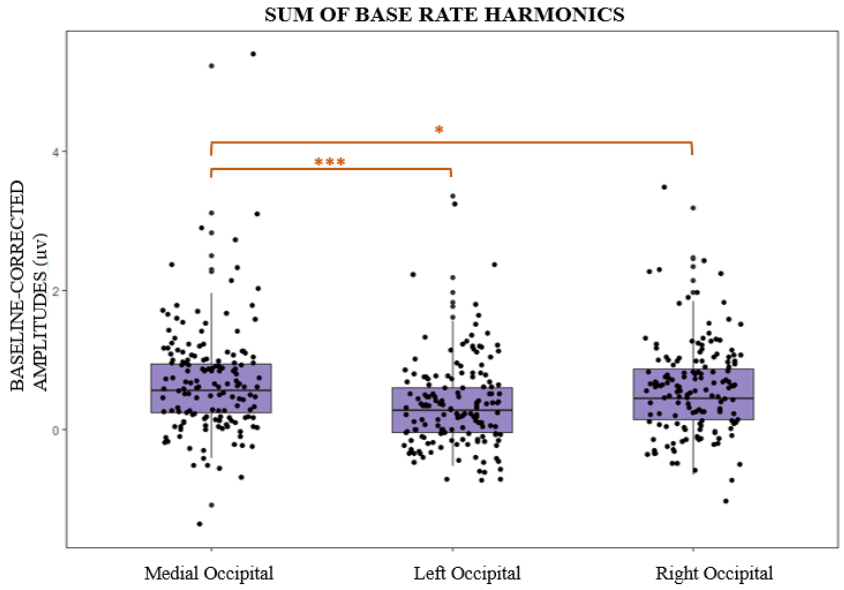

*Figure 4.5. Infants' summed baseline-corrected harmonics of the base rate for the medial occipital, left occipital and right occipital regions. Note that the response over the medial occipital is higher than both left and right occipital areas. * p < .05. ** p < .005. *** p < .001.*

Oddball Frequency

In the Low-Oddball condition SNR was significantly higher than noise only with High-pass faces in the Medial Occipital Cluster (SNR = 1.074, Z = 1.737, p = .0411), while in the High-Oddball condition SNR was significantly higher than noise only with Low-pass faces in the Left Temporal Cluster (SNR = 1.058, Z = 1.715, p = .0431), see Figure 4.6.

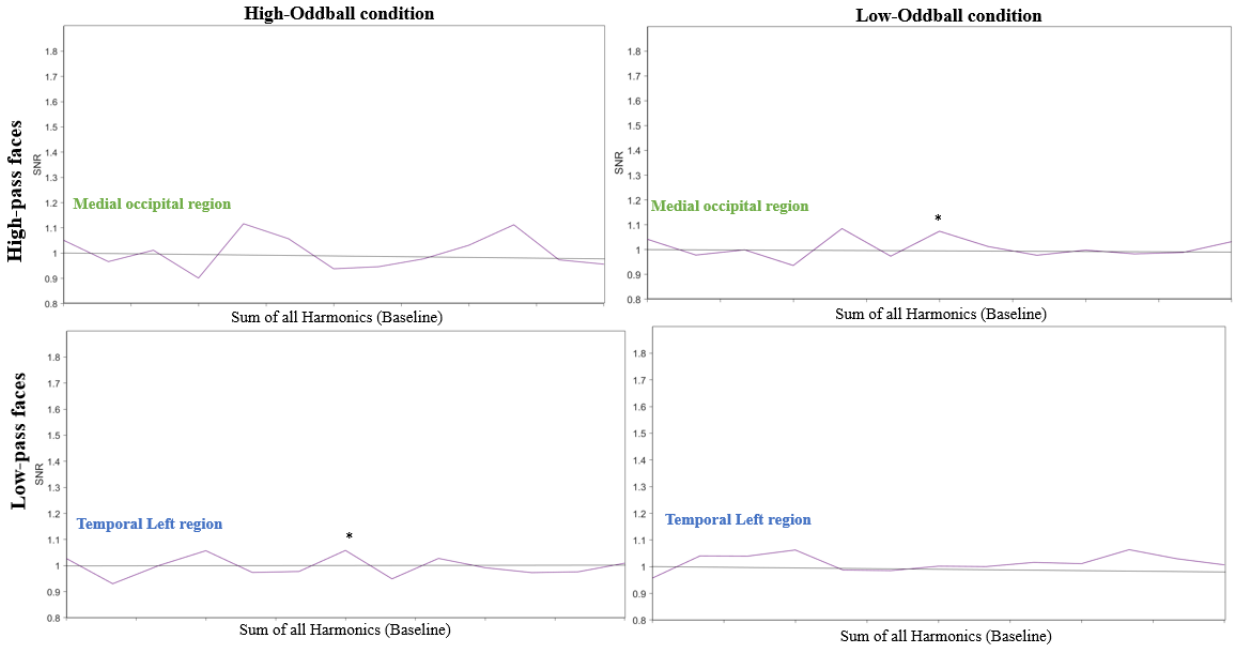

Figure 4.6. Infants' SNR at the Oddball frequency (sum of all harmonics of interest) for the High-Oddball condition and the Low-Oddball condition with both High-pass and Low-pass faces. The frequency graph represents the mean SNR in the medial occipital region when the oddball is Low

*Trustworthy with High-pass faces (top graphs) and in the Left Temporal Cluster when the oddball is High Trustworthy with Low-pass faces (bottom graphs). * p < .05. ** p < .005. *** p < .001.*

The LMM analysis on BCAs with conditions, spatial filtering and ROIs as fixed factors revealed no significant effect or interactions (all *ps* > .41).

Adults

Baseline Frequency

The analysis proved to be significant in all occipital regions for all conditions, all *ps* < .001 (left Occipital: $SNR_{Low\text{-}Oddball;High\text{-}pass\ faces}$ = 1.436, Z = 10.619, *p* <.001; $SNR_{Low\text{-}Oddball;Low\text{-}pass\ faces}$ = 1.539, Z = 4.545, *p* <.001; $SNR_{High\text{-}Oddball;High\text{-}pass\ faces}$ = 1.512, Z = 10.239, *p* <.001; $SNR_{High\text{-}Oddball;Low\text{-}pass\ faces}$ = 1.519, Z = 6.376, *p* <.001; medial occipital: $SNR_{Low\text{-}Oddball;High\text{-}pass\ faces}$ = 1.534, Z = 12.729, *p* <.001; $SNR_{Low\text{-}Oddball;Low\text{-}pass\ faces}$ = 1.812, Z = 8.309, *p* <.001; $SNR_{High\text{-}Oddball;High\text{-}pass\ face\ s}$= 1.764, Z = 14.673, *p* <.001; $SNR_{High\text{-}Oddball;Low\text{-}pass\ faces}$ = 1.782, Z = 10.591, *p* <.001; right Occipital: $SNR_{Low\text{-}Oddball;High\text{-}pass\ faces}$ = 1.505, Z = 11.975, *p* <.001; $SNR_{Low\text{-}Oddball;Low\text{-}pass\ faces}$ = 1.655, Z = 7.277, *p* <.001; $SNR_{High\text{-}Oddball;High\text{-}pass\ faces}$ = 1.644, Z = 10.833, *p* <.0001; $SNR_{High\text{-}Oddball;Low\text{-}pass\ faces}$ = 1.706, Z = 8.268, *p* <.0001), see Figure 4.7. When looking at individual data 100% of participants had a significant response and a SNR>1 in at least one ROI in all conditions.

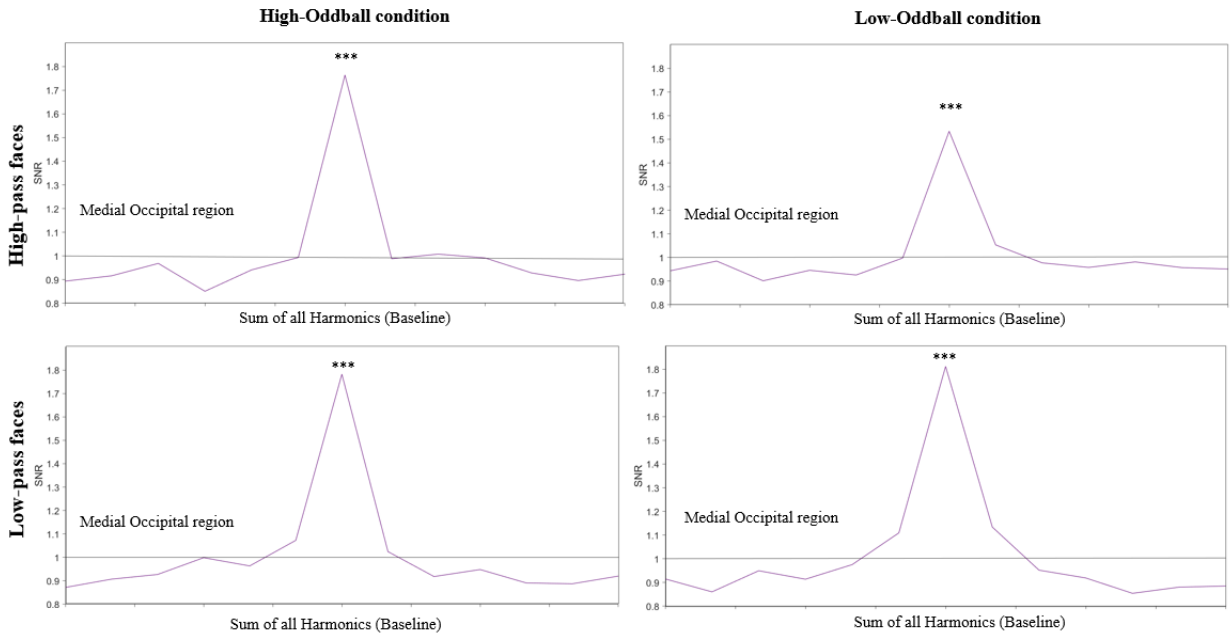

*Figure 4.7. Adults' SNR at the Baseline frequency (sum of all harmonics of interest) for the High-Oddball condition and the Low-Oddball condition with both High-pass and Low-pass faces. The frequency graph represents the mean SNR in the medial occipital region, which peaked at the Baseline frequency (sum of harmonics of interest). * p < .05. ** p < .005. *** p < .001.*

The LMM analysis on BCAs with conditions, spatial filtering and ROIs as fixed factors revealed a significant main effect of ROIs, $F(2,9) = 6.138$, $p = .002$. Indeed, BCA in the medial occipital region proved to be significantly higher ($M = .715$, $C.I._{Lower} = .594$, $C.I._{Upper} = .837$) than both the left occipital ($M = .362$, $C.I._{Lower} = .240$, $C.I._{Upper} = .483$), $p = .001$, and the right occipital regions ($M = .567$, $C.I._{Lower} = .445$, $C.I._{Upper} = .689$), $p = .006$, independently of condition (Figure 4.8, Panel A). Moreover, we found a significant main effect of spatial filtering, $F(1,9) = 7.991$, p

= .005, with higher BCA for Low-pass (*M* = .235, *C.I.*$_{Lower}$ = .181, *C.I.*$_{Upper}$ = .289) than High-pass faces (*M* = .188, *C.I.*$_{Lower}$ = .135, *C.I.*$_{Upper}$ = .242), see Figure 4.8 (Panel B).

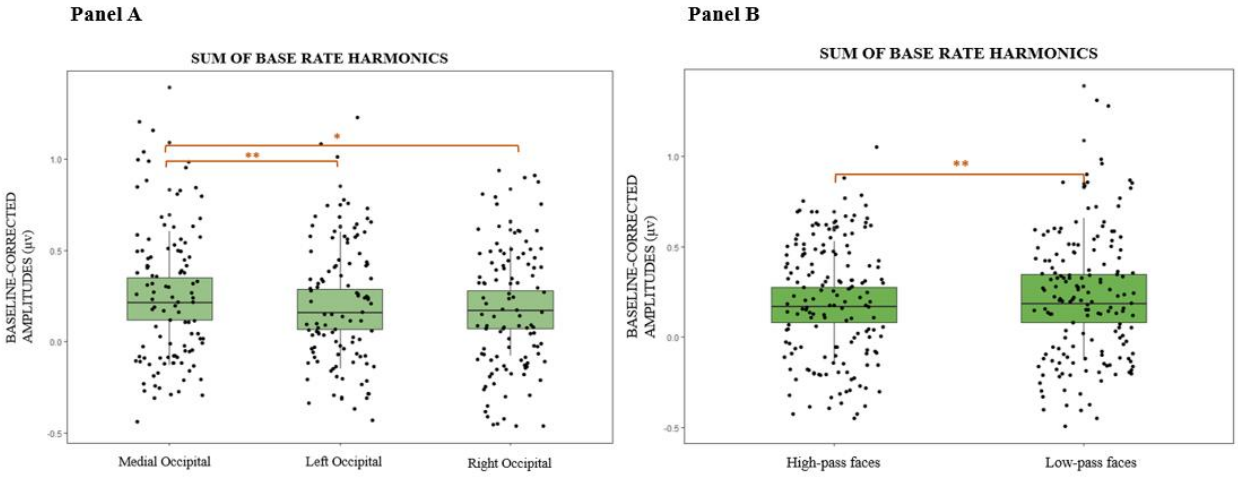

*Figure 4.8. Adults' summed baseline-corrected harmonics of the base rate for the medial occipital, left occipital and right occipital regions (Panel A). Note that the response over the medial occipital is higher than both left and right occipital areas. Adults' summed baseline-corrected harmonics of the base rate are higher with Low than High-pass faces (Panel B). * p < .05. ** p < .005. *** p < .001.*

Oddball Frequency

In the Low-Oddball condition SNR was significantly higher than noise only with High-pass faces in the Temporal Right Cluster (SNR = 1.110, Z = 3.079, *p* = .001). When the Oddball was High Trustworthy, SNR was significantly higher than noise with Low-pass faces in the Medial

Occipital (SNR = 1.110, Z = 1.767, p = .038) and Left Occipital (SNR = 1.135, Z = 1.924, p = .027) clusters, and with High-pass faces in the Medial Occipital (SNR = 1.162, Z = 2.674, p = .004), Left Occipital (SNR = 1.202, Z = 3.271, p = .0005), Right Occipital (SNR = 1.112, Z = 1.719, p = .042), Left Occipitotemporal (SNR = 1.157, Z = 2.897, p = .002), Left Temporal (SNR = 1.082, Z = 2.086, p = .018), and Right Temporal (SNR = 1.099, Z = 2.138, p = .016) clusters (Figure 4.9).

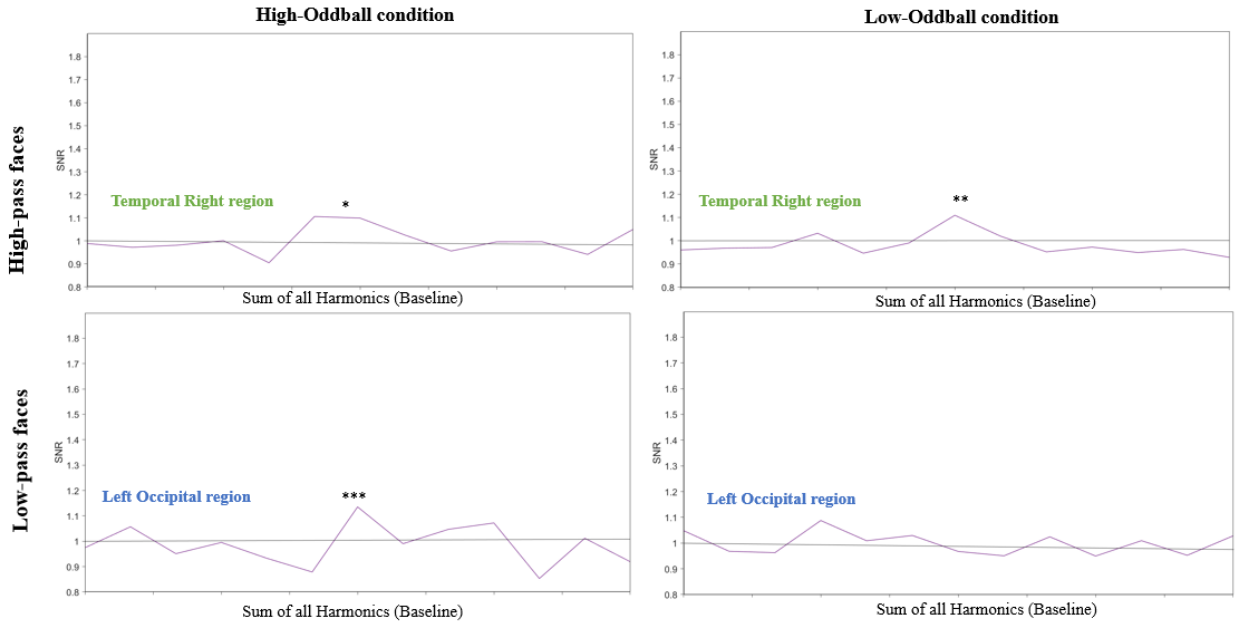

*Figure 4.9. Adults' SNR at the Oddball frequency (sum of all harmonics of interest) for the High-Oddball condition and the Low-Oddball condition. The frequency graph represents the mean SNR in the right temporal region with High-pass faces (top graphs) and in the left occipital region with Low-pass faces (bottom graphs). * p < .05. ** p < .005. *** p < .001.*

The LMM analysis on BCAs with conditions, spatial filtering and ROIs as fixed factors revealed a significant main effect of condition, $F(6,21) = 20.923$, $p < .001$, with higher BCA in High-Oddball ($M = .019$, $C.I._{Lower} = .012$, $C.I._{Upper} = .026$) than Low-Oddball condition ($M = .0003$, $C.I._{Lower} = -.006$, $C.I._{Upper} = .007$), see Figure 4.10 (Panel A). The analysis revealed a main effect of spatial filtering, $F(3,18) = 15.068$, $p < .001$, with higher BCA for High-pass ($M = .018$, $C.I._{Lower} = .011$, $C.I._{Upper} = .024$) than Low-pass faces ($M = .002$, $C.I._{Lower} = -.005$, $C.I._{Upper} = .008$), see Figure 4.10 (Panel B).

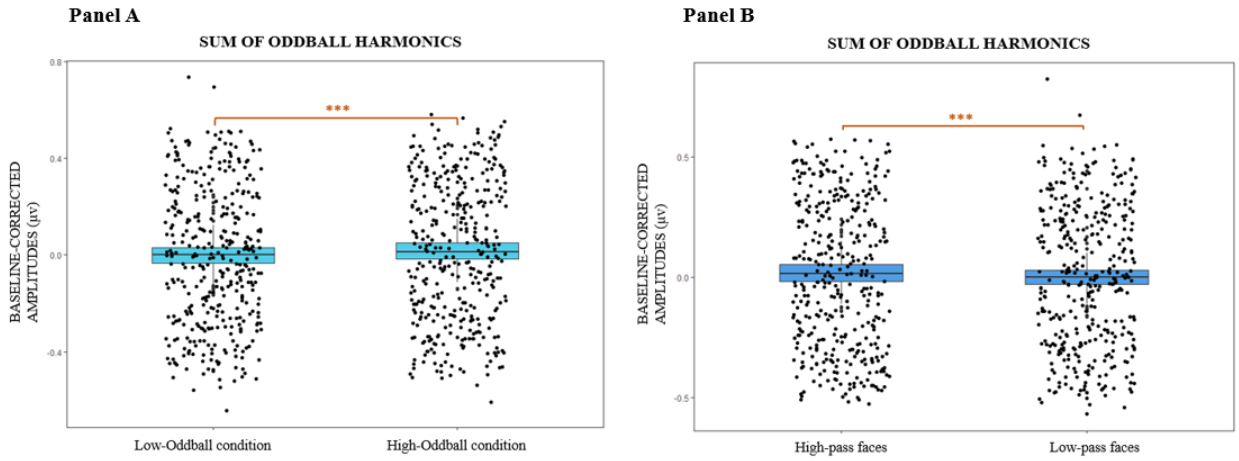

*Figure 4.10. Adults' summed baseline-corrected harmonics of the Oddball frequency are higher for the High-Oddball condition than the Low-Oddball condition (Panel A). Adults' summed baseline-corrected harmonics of the Oddball frequency are higher for High- than Low-pass faces (Panel B). * $p < .05$. ** $p < .005$. *** $p < .001$.*

Discussion

The present study investigated the nature of visual information infants use to discriminate between trustworthy and untrustworthy faces. To accomplish this aim we here used the FPVS paradigm, where the brain is stimulated repeatedly at a specific frequency and produces a response at that frequency that can be recorded using EEG (Norcia et al., 2015; Rossion, 2014). This paradigm has the advantage to precisely quantify the presence of a signal-to-noise ratio at the exact frequency of interest reflecting the discrimination of the oddball stimulus by the subjects without performing a particular behavioral task (Norcia et al., 2015; Rossion, 2014). For this reason, FPVS represents a suitable method to quickly detect implicit responses without collecting explicit judgments, as in the case of developmental populations (Swe et al., 2020; Verosky et al., 2020). We here adopted FPVS with 6-month-olds and adults using female face identities showing high or low levels of trustworthiness in two filtered conditions, High- and Low-pass.

Baseline frequency of infants indicated that the activity in the medial and occipital areas oscillated at the frequency of presentation of faces, regardless of the condition and spatial frequencies presented (i.e., whether the Oddball was a High or a Low Trustworthy face or whether faces were High- or Low-pass filtered).

Analysis on the Oddball frequency revealed that infants discriminate between the two extreme levels of trustworthiness. More specifically, Oddball frequency revealed a SNR higher than noise with High Trustworthy faces only with Low-pass faces in the temporal right region and a SNR higher than noise with Low Trustworthy faces only with High-pass faces in the medial region. Thus, infants were able to implicitly detect the changes of the level of trustworthiness with high trustworthy faces discriminated from low trustworthy ones only with low spatial information and low trustworthy faces discriminated from high trustworthy ones with high spatial information.

In such terms, the visual information infants use to disentangle between trustworthy and untrustworthy faces in the current study differs from the visual information infants uses in studies on emotional discrimination (Di Lorenzo et al., 2021; Jessen & Grossmann, 2017b; Munsters et al., 2017; van den Boomen et al., 2019). Specifically, in the study of van den Boomen and colleagues (2019) happy faces were discriminated from neutral and fearful ones at the Nc with both high- and low-spatial frequencies and at the level of N290 and P400 only with high spatial frequencies. In the same way, Jessen & Grossmann (2017b) found that infants discriminate between happy and fearful faces with only high spatial frequencies. Moreover, there was a difference at the level of the Nc between HSF and LSF only for happy but not for fearful faces, indicating a detection of fearful faces irrespectively of the spatial content. Similarly, even 5-month-old infants discriminate between fearful and neutral faces, regardless of the spatial content (van den Boomen et al., 2021). These results, taken together, pointed out that infants are more tuned to high spatial information in emotional discrimination but that under particular conditions of visual salience, even low spatial information is sufficient to allow infants to discriminate between fearful and neutral faces.

Thus, facial cues of emotion may be carried in finer visual information than face trustworthiness. Specifically, here, we found that in the case of face trustworthiness discrimination, the presence of coarse or fine visual information determines the discrimination of high- and low-trustworthy faces respectively.

It should be noted that the filtering cut-offs used in the present study are the same as those used in the Jessen & Grossmann's study (2017b). Thus, any difference on the nature of visual information that allow emotion and trustworthiness discrimination cannot be attributed to the spatial filtering approach.

Rather, the difference could be attributed to the different experimental paradigm used, ERP in studies on emotion perception and FPVS in the present study. To our knowledge, the only FPVS study on emotional discrimination and spatial frequencies focused on adult populations to pinpoint the optimal spatial frequency range to fear perception showed that the necessary visual information during neural fear discrimination is the higher spatial frequency (Dzhelyova et al., 2017). In the same vein, in the present study we found infants need HSF to detect low trustworthy faces. Therefore, detailed information seems necessary to negative valence facial cues perception (i.e., both fearful and low trustworthy faces).

Furthermore, the segregation of visual information supporting the valence of trustworthiness (i.e., negative and positive valence) is consistent with behavioral studies of emotional perception in adults (Kumar & Srinivasan, 2011).

The behavioral study of Kumar & Srinivasan (2011) showed that spatial frequency has an effect on emotion identification, with LSF content associated with happy expression identification and HSF content with sad expression identification. In the same way, perception of untrustworthy faces, as perception of sad expressions, relies on HSF, while perception of trustworthy faces, as perception of happy faces, depends on LSF. Consistent with the model of Kumar & Srinivasan (2011), the "global-trustworthy" and the "local-untrustworthy" imply that the global advantage might be applied to the identification of trustworthy faces (Johnson, 2005; LeDoux, 1996). LSF might activate the magnocellular pathway, the system that elicits fast processing of the arousing information in the amygdala and processes the global stimulus features and, only later, a slower process of fine discrimination, activating the parvocellular pathway by the HSF, occurs (LeDoux, 1996).

According to this model, the link between LSF and trustworthy faces indicate that exists a quickly need to identify high trustworthy faces, the most present in infants' social environment, and, only later, the presence of details support untrustworthy faces discrimination, with which infants have less experience. Future studies could deepen this conceptualization by investigating the temporal dynamics of trustworthiness perception in infants.

Moreover, the few FPVS studies on trustworthiness perception focused on adults' population (Swe et al., 2020; Verosky et al., 2020). These studies found a strong Oddball response in the medial and bilateral occipital areas (Swe et al., 2020; Verosky et al., 2020). According to Verosky and colleagues (2020), such a result could indirectly reflect the amygdala activity, which is consistent with Todorov & Engell's (2008) theory that the amygdala processes facial cues to trustworthiness and influences cortical brain activity.

In the present study, infants discriminated trustworthy faces in the temporal left region and untrustworthy faces in the medial area. Thus, in line with the model proposed by Verosky and colleagues (2020), it is plausible that this system is already active early in development. However, since subcortical structures are far from the scalp, they generate weak electrical activity that is barely detectable at the scalp level (Wadman & Da Silva, 2017). Thus, our study cannot provide evidence for the involvement of the subcortical route in trustworthiness perception.

The adults' sample was included to explore age-related differences in brain sensitivity to trustworthiness cues from filtered faces.

Adults' data on the Baseline frequency, like the infants' ones, showed that independently of the condition (i.e., whether the Oddball was a High or a Low Trustworthy face) or spatial filtering (i.e. whether faces were a High- or a Low-pass), the activity in the medial occipital areas

oscillated at the frequency of face's presentation. It should be noted that adults' baseline response was higher for Low-pass faces compared to High-pass ones. This could be explained by the higher attentional request of the Low-pass condition. Indeed, in this condition only a narrow band of low spatial frequency is available in the stimuli. Thus, the Low-pass condition represents a more challenging condition in respect to the High-pass condition in which almost the entire band of spatial frequencies remains. In line with the results of Study 1, in which a narrow band of low spatial frequency is sufficient to induce modulation of trustworthiness explicit judgments similar to that generated by the original images, here this condition represents the most attractive in attentional terms.

Analysis on the Oddball frequency revealed a SNR higher than noise with High Trustworthy faces with both Low- and High-pass faces. More specifically, with Low-pass faces in the medial and occipital left areas and with High-pass faces in the medial, left occipital and occipito-temporal, and bilateral temporal regions. An SNR higher than noise was found for Low Trustworthy faces only with HSF in the temporal right area. These results confirm adults' ability to discriminate between the two levels of trustworthiness even in detrimental conditions.

The discrimination of Low-Trustworthy faces only with HSF in right areas is in line with studies on emotion perception showing a right hemispheric advantage for negative valence emotion processing (Alpers, 2008; Baijal & Srinivasan, 2011; Kumar & Srinivasan, 2011; Smith & Bulman–Fleming, 2005). Moreover, in the study of Kumar & Srinivasan (2011) the right hemispheric bias for negative valence emotion is more pronounced with High-pass than Low-pass faces. Similarly, for Low Trustworthy faces, resembling negative valence emotion (Engell et al., 2007; Freeman et al., 2014), a right-hemispheric bias emerges and seems to be mediated by HSF content.

Even if this evidence would lead one to think that the perceptual mechanisms at the basis of emotional perception partially overlap with those at the basis of trustworthiness perception, any conclusion must be drawn with caution considering that these cut-offs are not based on adults' visual acuity.

Also, a higher oddball response for High- than Low-pass faces was found in the adults sample. Again, this result indicated a key role of HSF in adults' trustworthiness discrimination. However, it should be kept in mind that our filtering cut-offs are based on infants' visual acuity. Indeed, the key role of HSF does not represent a real advantage for detailed information in adults since HSF faces contain almost the entire spectrum of spatial frequencies (except for the frequency spectrum below 0.6 c/g). On the contrary, these results seem to confirm a need to implicitly identify trustworthy faces even in detrimental conditions (i.e., with a narrow band of low-SFs). In any case, to draw any precise conclusions on the visual information' role on trustworthiness perception in adults, future studies should use the cut-offs based on adults' visual acuity.

Lastly, adults' results indicated a higher oddball response for High- than Low-trustworthy faces. It is possible that adults, as infants (Sakuta et al., 2018) perceive the High Trustworthy face an appealing stimulus, signalling a friendly approach, and, thus, detected with both LSF and HSF. Thus, adults are more stucked to trustworthy faces for an attentional mechanism that drives to a higher saliency for positive valence faces (Kisley, Wood, & Burrows, 2007; Mather & Carstensen, 2005).

In conclusion, our study is the first that, through the spatial filtering approach, explores the perceptual mechanisms underpinning trustworthiness perception in infants pointing out the importance of both local and global information and the evolutionary necessity to detect trustworthiness cues from the first stage of development even in detrimental conditions.

Chapter 5

Study 5 - The role of visual spatial frequency information in newborns' discrimination of facial emotional expressions

If for a long time it was believed that newborns were equipped only with automatic response, it has now been shown that at birth newborns are endowed with a rich repertoire of specific skills that allow them to explore their environment and interact with it. As already described in the Introduction of this thesis, at birth humans possess a spontaneous preference for stimuli that also represent the human face in a simplified way, as an innate response evolving during the course of phylogeny according to its adaptive value (Buiatti et al., 2019; Goren et al., 1975; Macchi Cassia et al., 2004).

Newborns are sensitive not only to faces but also to the emotional cues generated by faces. Humans are, thus, programmed to communicate their internal states with facial expressions (Green & Wilson, 2006). Even before birth, the fetus in the womb starts to communicate with the facial movements (Reissland, Francis, Mason, & Lincoln, 2011). In these terms, emotional expression represents a congenital communicative tool with which the infant and the caregiver are endowed and which enables intrinsic communicative interaction to ensure survival (Rosenstein & Oster, 1988; Lundy, Field, & Pickens, 1996).

In addition to communicating emotions, newborns are able to recognize emotions expressed by faces, to adapt their behavior. However, only few studies have explored emotional recognition at birth with static (Farroni et al., 2007) and dynamic faces (Addabbo et al., 2018).

In particular, Farroni and collaborators (2007) found that newborns did not show a preference or discriminate between fearful and neutral expressions but preferred happy over fearful faces bilaterally presented. This evidence showed how newborns discriminate at least between some emotions and in particular prefer positive emotions, such as happiness (Farroni et al., 2007). It should be considered that emotional recognition is acquired through experience in daily life. It is, therefore, possible that experience with over-represented stimuli in the environment during the first hours of life, thus smiling and happy faces, drives the preference for positive valence emotions (Farroni et al., 2007; Quinn & Johnson, 1997). The absence of preference and discrimination between neutral and fearful faces could be explained by neurophysiological evidence showing infants and children to display the same amygdala activation for neutral and fearful stimuli (Thomas et al., 2001). Thus, since both faces activate the same subcortical pathway, they probably are categorized as similar stimuli by newborns who do not show any discrimination between the two stimuli and treat them as equivalent (Farroni et al., 2007).

Although interesting, this evidence is limited to not ecological static images of emotions. Nevertheless, in social interactions, emotions are the result of combinations of facial cues that change and unfold over time (Krumhuber, Kappas, & Manstead, 2013). In this sense, dynamic emotional faces represent more ecological stimuli. Moreover, dynamic stimuli evoke different neural activity in emotional neural networks, facilitating emotion discrimination, in respect to static stimuli (Arsalidou, Morris, & Taylor, 2011; Xiao et al., 2015). Using dynamic stimuli allows for a more accurate exploration of the underlying emotional neural networks (Krumhuber et al., 2013). Furthermore, at birth, it is even more crucial to investigate emotional perception with dynamic stimuli since the small visual experience of newborns is characterized by dynamic rather than static patterns.

The only study investigating whether newborns prefer or discriminate between dynamic emotions showed that 2-day-old newborns did not show a preference between two displays depicting a happy and a disgusted face. However, while newborns do not prefer one of the two emotions, they are able to detect the changes that take place during the unfolding of emotional expressions, thus, can discriminate between the two (Addabbo et al., 2018). It is plausible that both happy and disgusted faces are equally visually salient for newborns that do not prefer one over the other (Addabbo et al., 2018). It may be that the happy face attracts newborns' attention because it is the emotion they are most exposed to in the first hours of life and the disgusted face attracts in the same way their attention as an emotion they have never experienced (Addabbo et al., 2018).

If it is clear that newborns are able to discriminate at least between some emotional expressions, the visual mechanisms underlying emotion discrimination are still unclear. While the role of SF in adults is widely investigated (for a recent review see Jeantet, et al., 2018), little is known about the role of the visual information crucially involved in face processing in the early stages of development.

The only studies that explore the nature of visual information necessary for emotional identification, focused on infants. These electrophysiological studies converged to show that from 7 months of age, infants require more detailed information in emotion discrimination (Di Lorenzo et al., 2021; Jessen & Grossmann, 2017b; Munsters et al., 2016; van den Boomen et al., 2019; van den Boomen et al., 2021). Thus, infants discriminate between fearful and happy faces only when stimuli contain HSF but not when containing LSF, indicating that detailed information, linked to the involvement of the slow-responding parvocellular visual pathway, is necessary for discriminating between negative and positive valence emotions.

These findings appear intriguing in light of the early limitations of the visual system, which biases infants' perception towards the low-SF bands of visual images (Acerra et al., 2002). Accordingly, newborns rely on low-SF when discriminating between hierarchical stimuli (Macchi Cassia et al., 2002) and, also, neutral faces based on identity (de Heering et al., 2008)

Indeed, the only study focusing on younger infants explored the nature of the visual information newborns rely on in identity recognition (de Heering et al., 2008). They manipulated the band of spatial frequencies of static faces. Given the limited visual ability and immaturity of the cortical visual areas in newborns, they first verify the newborns' ability to extract visual information in the visible range of newborns (i.e. 0-1 cpd, cycle per degree). Subsequently, to explore the spatial frequencies that newborns use to discriminate face identity, they split the visible spectrum of the newborn considering the spatial frequencies below 0.5 cpd as LSF and the spatial frequencies above 0.5 cpd as HSF. They found that newborns discriminate face identity only with LSF but not with HSF. These results offered the first empirical support to the hypothesis that low spatial frequencies are necessary in detecting face identity for newborns. Thus, as for non-social hierarchical stimuli in which newborns seem to rely more on global information (Macchi Cassia et al., 2002), a *global bias* also emerged for social stimuli like faces.

Given the lack of evidence at birth, we intend to explore if emotional perception in newborns is driven by the global bias emerging in identity perception and non-social stimuli processing at birth or, on the contrary, mainly relies on detailed information as older infants.

Here we applied the spatial filtering approach to the investigation of emotion perception to explore whether 2-day-old newborns' emotional preference is mainly vehiculated by analytical or configural information using a visual preference task.

Given the scarcity of studies on emotion processing in newborns, our first aim was to generalize the preference for positive valence emotion on dynamic stimuli. Subsequently, we wanted to verify if the preference is maintained when only analytical or configural information remains.

Study 5a

In this first study, we used a visual preference task to explore whether newborns can manifest a visual preference when presented simultaneously with two different dynamic displays depicting a smiling face and a fearful one also when spatial frequencies were filtered out.

In the Full spectrum condition (Broad Spatial Frequency condition, BSF), we expect them to show a visual preference for the smiling face, as shown by previous studies with newborn and older infants (Farroni et al., 2007; Vaish, Grossmann, & Woodward, 2008; Wilcox & Clayton, 1968).

Given the lack of evidence at birth, we did not have expectations on the two filtered conditions (Low Spatial Frequency condition, LSF, and High Spatial Frequency condition, HSF) as we intend to explore if emotional perception in newborns is driven by the global bias emerging in identity perception and non-social stimuli processing in newborns or, on the contrary, mainly relies on detailed information as older infants.

Materials and methods

Participants

A total of 63, healthy, full-term newborn infants successfully completed the study (22 for BSF condition, 21 for LSF condition and 20 for HSF condition; 37 female; mean age = 44 hours; SD = 1.05 hours; range: 21–76 hours, mean birth weight: 3276 gr, range: 2400 g – 4120 g). Thirty-eight other newborns were recruited and tested but excluded for sleepiness (14), crying (12), experimenter error (5), mother interference (1) and position biased (i.e. looking towards the right or the left position for more than the 85% of the total looking time) (n = 1).

The sample was determined on an a priori power analysis, no sequential testing was performed and data were not analysed until data collection was completed. Indeed, a power analysis for a repeated measure ANOVA with two within factors (Emotion and Trial) and one between factor (Filter condition) revealed that 60 participants would be needed to have a 95% of chance to observe a significant effect with an alpha level of 0.05 and a medium effect size.

All infants had an Apgar score of 10 after 5 minutes and met the screening criteria for normal delivery (gestational age > 37 weeks). Infants were recruited inside the maternity ward, with the authorization of the director of the maternity department at Mangiagalli Hospital of Milan. All infants were tested in the presence of the mother. Parental written informed consent was obtained before testing began. 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

Newborns were presented simultaneously with two black and white videos of a woman's face performing a happy and a fearful expression on a black background. Both emotional

expressions were conveyed by the same Caucasian female face with direct gaze and visible ears, hair and neck.

Each video was 2000 ms long and consisted of 24 frames (24 fps, frames per second) each one of the duration of 83.3 ms. The first 6 frames represented the faces with neutral expression instead, in the following 18 frames, the expressions of happiness and fear were unfolded and the maximum peak of intensity was reached in frame 18. The two videos were proposed bilaterally, one on the right and one on the left, at a distance of 15°, and played in loop. At a distance of 30 cm from the screen the dimensions of the images of the faces were 20° high and 13° wide. Luminance, contrast, hue and saturation were kept constant between frames and stimuli.

To create the LSF and the HSF versions of each video, a spatial frequency filter was applied to all images using a Matlab script available online at https://psy.van-diepen.com/pvdmatl.html (see Dobkins & Harms, 2014). For LSF images, the filtering was done around a frequency cutoff of 0.5 cycles/°, so that these images contained frequencies primarily below 0.5 cycles/°. HSF images were similarly filtered with a high-pass cutoff of 0.6 cycles/°. Cut-off values were chosen after de Heering and colleagues (2008). Considering that we used a different type of filtering method in respect to de Heering et al. (2008), we choose the cut-off of 0.6 cycles/° for HSF to match their cut-off and maintain as little LSF as possible. Given that the visual acuity and contrast sensitivity of newborns are 40 times worse compared to those of adults (Macchi Cassia et al., 2002; de Heering et al., 2008), using these cut-offs it is possible to extreme the frequency portion space present in the image in visible spectrum of newborns (0-1 cpd).

The BSF, LSF and HSF images did not differ in terms of Root Mean Square (RMS) (BSF: 8.13 cd/m^2; LSF: 7.93 cd/m^2; HSF: 8.35 cd/m^2) contrast, a commonly used index for perceived contrast in natural images (Wilcoxon test, all $p > .125$).

Stimuli validation

Stimuli were validated by 50 adults (35 females, mean age = 25.7, SD = 4.8) who were asked to indicate the emotion expressed by the face and the intensity on the basis of a 10-point Likert scale (from -5 to +5). We presented adults participants two Caucasian identities (identity A and identity B) that express the two emotions and then selected only one identity to be presented in the visual preference task for newborns.

Participants provided their ratings through an online Questionnaire delivered on Qualtrics (Qualtrics, Provo, Utah, USA, https://www.qualtrics.com). The results showed that the happy face was judged as expressing happiness in both identities A (M = 76%, SD = 43%) and B (M = 80%, SD = 40%), with no differences in accuracy between the two identities, $p = .53$. Also, the fearful face was judged to express fear in both faces A (M = 62%, SD = 49%) and B (M = 70%, SD = 46%), with no significant differences in accuracy between the two identities ($p = .27$).

Moreover, the Wilcoxon test indicated that the accuracy for happy faces did not differ from the accuracy for fearful faces (Face A, $p = .06$ and Face B, $p = .24$). However, as in other studies on emotion perception (Addabbo et al., 2018), the Wilcoxon test indicated that there was a significant difference between the judgements of the emotional valence of the two stimuli, with higher intensity in both identities for fearful faces than happy ones (fearful vs happy Face A, $p < .001$ and fearful vs happy Face B, $p = .008$). Further, no significant difference was found between the ratings of the two happy faces (happy face A and happy face B, Wilcoxon test, $p = .15$) and between the two fearful faces (fearful face A and fearful face B, Wilcoxon test, $p = .92$).

Apparatus and Procedure

Newborns were placed on the lap of an experimenter in front of a monitor at a distance of about 30 cm from the screen on which the stimuli were presented (screen size: 27", resolution: 1920 X 1080, refresh rate: 60 Hz). Newborns' eyes were aligned to a central fixation point in the monitor, which also acted as an *attention getter*. Above the screen was placed a camera directed on the face of newborns that recorded eye movements, thus allowing another experimenter, unaware of the experimental condition presented, to code online newborn's visual behavior. To ensure that the experimenter holding the baby in her arms could make sure that the baby was aligned at the center of the screen, the image of the baby's face was shown on a monitor placed high above the screen.

Total looking times and number of orienting responses were measured within a preferential looking paradigm with an infant-control procedure. Each participant was presented with two trials in which the happy and fearful faces were shown simultaneously and bilaterally. Each trial began as soon as the newborns looked at a red flickering circle appearing in the center of the monitor. In the first trial, half of the newborns saw the happy faces on the left and the fearful one the right. The left or right position of the stimuli on the screen changed between the first and second trials (for an exemplification of the stimuli used in the three experimental conditions see Figure 5.1). The trial ended when participants looked at both stimuli at least once for at least ten consecutive seconds and looked away from one for more than ten seconds.

To avoid interference, the lights in the room were turned off and the windows covered with blackout panels. Black panels were also placed on the sides of the screen to avoid additional distractors. The parents were present during the entire experimental session and could interact with the child only in case of crying or manifestations of discomfort by the child.

Figure 5.1. The last frame of the video of each of the trials presented (Happy-Fear, H-F, or Fear-Happy, F-H) in the three experimental conditions (Broad Spatial Frequencies, BSF, Low-Pass Spatial Frequencies, LSF, and High-Pass Spatial Frequencies, HSF). In the first trial (a), the face expressing fear (F) is presented on the left and the one expressing happiness (H) is presented on the right. In the second trial (b), the face expressing fear is presented on the right and the happy face on the left.

Coding

All the video-recording of the eye movements were coded offline, from the video recording played at slow speed, by a second observer blind to the stimuli shown. As in other studies (Bonn, Netskou, Streri, & de Hevia, 2019), we here reported the analyses based on the average of the two closest measurements for each trial. Since the online coding is often permissive in order to not lose the trial (e.g., if infant sneezed the experimenter did not stop the trial) and newborns' looks are quite hard to code (e.g., if the eyes are not wide open or if look with one eye only), a third

experimenter coded looking times offline when the two first coders' judgments differed by more than 5 s (26% of all trials).

Thus, the final measure used in the analyses could be an average of the online coder and one offline coder, if no third coder was necessary, or, if a third coder was used, it could be either of the two possible pairs of coders, one online or both offline. The correlation between the two measurements, the inter-coder agreement (Pearson correlation), was .99 ($p < .001$) for total fixation time and .98 ($p < .001$) for number of orientations.

Results

Statistical models

Preliminary data inspection revealed that looking times (LT) recorded during the two trials were not normally distributed for all happy (happy 1, WS= .90; happy 2, WS= .85) and fearful (fearful 1, WS=.89; fearful 2, WS = .89) stimuli presented (all *p*s < 0.001). Thus, after Csibra et al. (2016), data were logarithmically transformed before performing all statistical analysis.

Since most studies of infant looking times usually report repeated-measures ANOVA with planned post-hoc comparisons, we here reported this analysis first and we then build similar models within a Bayesian Framework. Our aim was to strengthen our results and appropriately quantify the amount of uncertainty about group differences with Bayesian analysis that offers control over the range of possible effect sizes with weakly informative priors reducing overinterpretation of sampling error in a more principled way than *p*-value. Moreover, following the same logic, since random effects models are less readily interpretable for infant researchers

due to its scarcity in looking-time studies, we here prefer not to run this analysis but rather to compare frequentist and Bayesian approaches.

Thus, following recent recommendations on best practices in infant looking-time research (Oakes, 2017), we performed Bayesian analyses in JASP v0.12.2 (https://jasp-stats.org/) by using the default Cauchy prior (r = 0.707).

Frequentist analysis

The LT log-transformed responses were entered in a repeated measures ANOVA, with emotion (happy, fear) and trial (first, second) as within-subjects-factor, and filter group (BSF, LSF, HSF) as between-subjects-factor.

The analysis revealed a significant main effect of emotion, F (1, 60) = 10.17, p = 0.002, partial η^2 = 0.14, due to longer looking times for happy (M = 23.28 s, SD = 11.38 s) compared to fearful faces (M = 18.38 s, SD = 9.37 s). There was also a main effect of filter group, F(2, 60) = 7.71, p = 0.001, partial η^2 = 0.20, with shorter looking times for BSF (M = 13.35, SD = 7.23) compared to LSF (M = 22.18, SD = 6.08) and HSF (M = 24.34, SD = 9.51). These two main effects were qualified by a significant emotion × filter group interaction, F(2, 60) = 5.11, p = 0.009, partial η^2 = 0.15.

To further explore this interaction, we run planned comparisons exploring LT for happy and fearful faces with simple main effects, to address our experimental questions, namely whether a preference was present in the BSF condition and maintained also in conditions in which spatial frequencies were selectively removed.

We found higher LT for happy faces (M = 19.51, SD = 9.53) compared to fearful ones (M = 13.19, SD = 7.96) in BSF condition (p = 0.002) and between happy (M = 28.79, SD = 14.15) and fearful face (M = 19.88, SD = 1.33) in HSF condition (p = 0.02). However, no differences between happy (M = 21.97, SD = 8.27) and fearful (M = 22.39, SD = 7.44) faces were found in LSF condition (p = .43) (Figure 5.2).

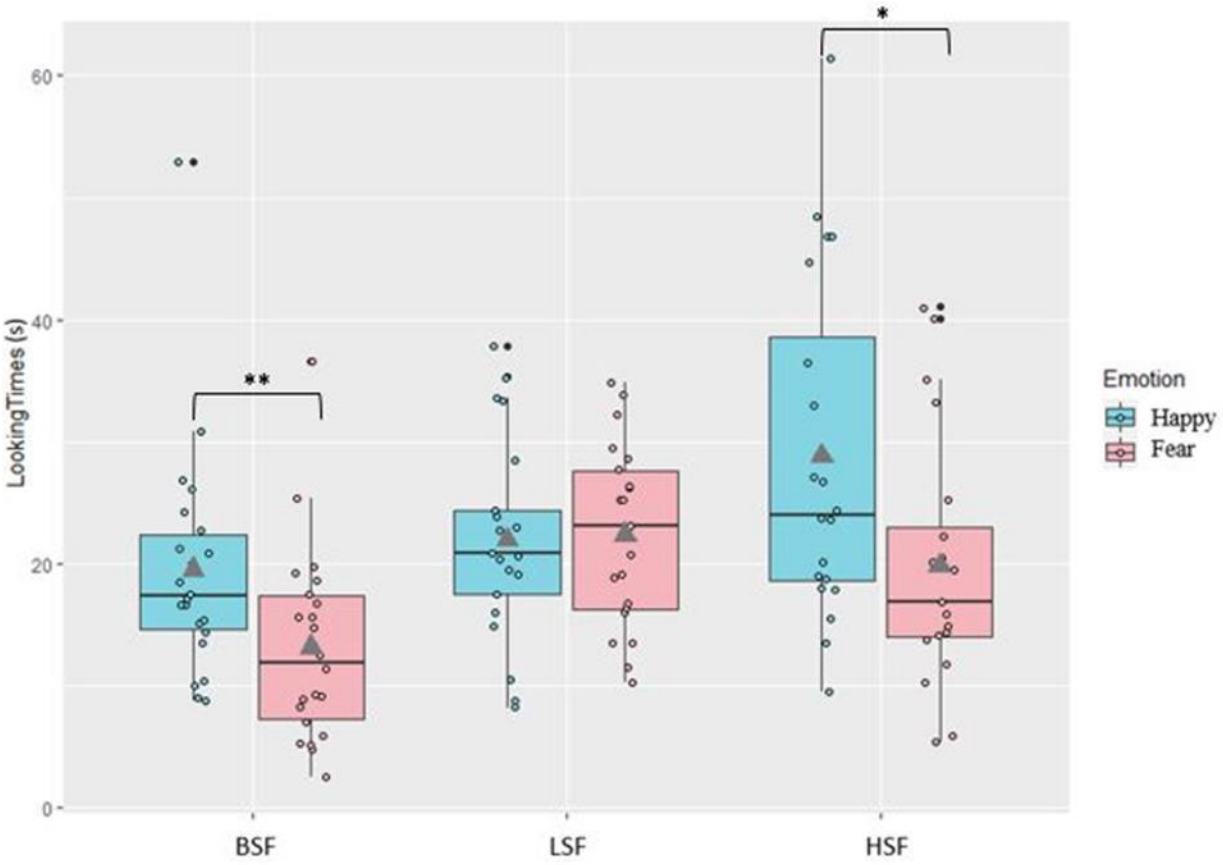

*Figure 5.2. Newborns' looking times towards the expression of happiness and fear in three experimental conditions (BSF, HSF and LSF). Means are represented by the gray triangles in the boxplots. * p < .05. ** p < .005. *** p < .001.*

Finally, to explore whether the number of newborns who looked at happy faces more than fearful faces was statistically significant, we ran three binomial tests, one for each filter condition. In the BSF condition, binomial tests indicated that 18 newborns out of 22 looked at happy faces significantly more than at fearful ones (p = .002). In LSF condition, among 21 newborns, 12 looked longer at happy expressions, while 9 looked longer at fearful one (p = .81). In the HSF condition, binomial tests indicated that 17 newborns out of 20 looked at happy faces significantly more than at fearful ones (p = .001).

The eye orienting responses were entered in a repeated measures ANOVA, with emotion (happy, fear) and Trial (first, second) as within-subjects-factor, and filter group (BSF, LSF, HSF) as between-subjects-factor. The analysis revealed a main effect of filter group, $F(2, 60) = 4.75$, $p = 0.012$, partial $\eta^2 = 0.14$, with less orienting responses for BSF (M = 6.53, SD = 2.69) compared to LSF (M = 8.69, SD = 2.96), $p = 0.04$, and HSF (M = 8.83, SD = 2.53), $p = 0.03$. No other main effects or interactions attained statistical significance (all ps > 0.24) (Figure 5.3).

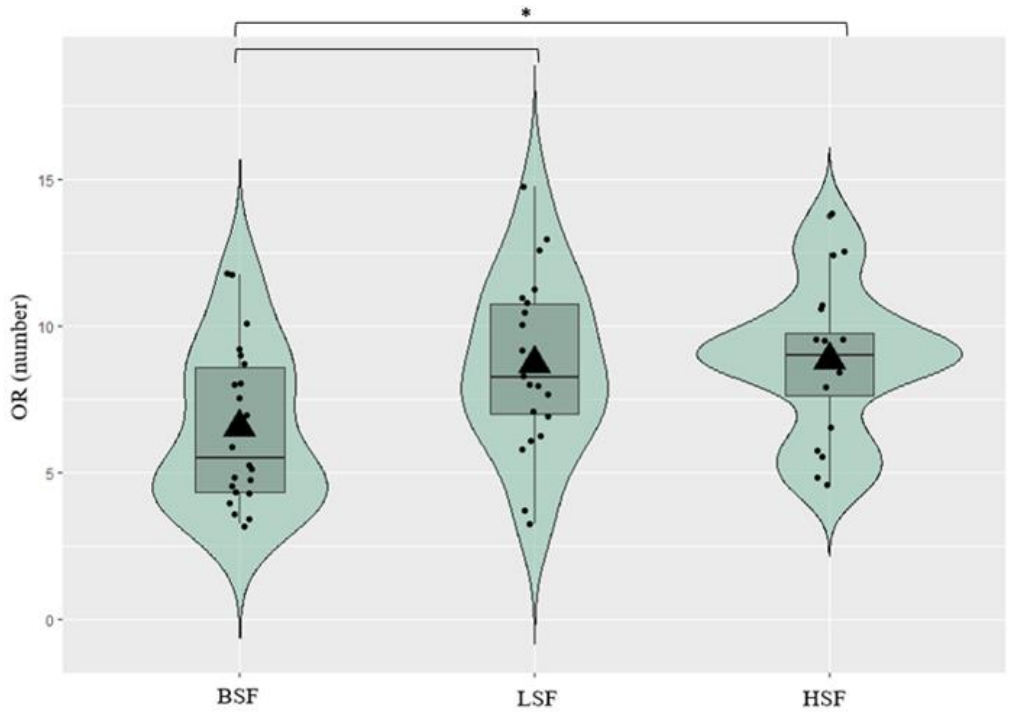

*Figure 5.3. Newborns' orienting responses (OR), regardless of emotions presented, in three experimental conditions (BSF, HSF and LSF). Means are represented by the black triangles in the boxplots. * $p < .05$. ** $p < .005$. *** $p < .001$.*

Bayesian analysis

We implemented analyses of variance for both looking times and orienting responses with emotion and trial as within subject factors and filter group as between subject factors. Examination of the Q-Q plots suggested that the assumption of normality was not violated.

A Bayesian mixed factor ANOVA on looking times determined that the data were best represented by a model that included emotion and group filters as main factors and the emotion x filter condition interaction. The Bayes factor (BF10) was 1237.50, indicating decisive evidence in favor of this model when compared to the null model. The BF10 in favor of indicating the interaction effect (on top of the two main effects) equaled 7.28.

Moreover, the analysis of effects revealed that there is stronger evidence for the inclusion of emotion than a model without this predictor (BFincl= 54.49). There is also decisive evidence for the inclusion of filter condition (BFincl=30.08) and the interaction between the two factors (BFincl=13.89) as predictors.

To explore the interaction and to investigate if newborns looked significantly longer to happy rather than fearful faces in each of the three conditions we ran three Bayesian paired t-tests. Shapiro-Wilk was not significant (all *ps* > .22) suggesting that the assumption of normality was not violated in any of the three conditions.

A two-sided analysis confirmed the results obtained from frequentist analysis, revealing strong evidence for a difference between happy and fearful faces in BSF condition (BF10 = 18.1). In LSF condition, the two-tailed paired sample Bayesian t-tests further confirmed the lack of significant results emerging from the frequentist analysis, showing anecdotal evidence for the lack of difference in LT between happy and fearful faces (BF10 = 0.23). In HSF condition, the two-tailed paired Bayesian t-test confirmed the results obtained from frequentist analysis, showing moderate evidence for a difference between happy and fearful faces (BF10 = 2.73).

The Bayesian mixed factor ANOVA on eye orienting responses confirmed results emerging from the frequentist ANOVA. Data were best represented by a model that included the filter group as a factor (BF10 = 4.29), indicating moderate evidence in favor of this model when compared to the null model. Post-hoc comparisons of BSF vs LSF and BFS vs HSF revealed posterior odds of 59.45 and 589.17 against the null hypothesis, which indicates decisive evidence in favor of the alternative hypothesis. When comparing LSF and HSF, the posterior odds of 0.102 indicated no evidence in favor of the alternative hypothesis.

Study 5b

The lack of preference only in the LSF condition shown by newborns in Study 5a doesn't directly imply that they weren't able to differentiate between happy and fearful faces. It is possible that newborns simply didn't prefer one emotion over the other when only LSF are presented in the stimulus, even if they were able to discriminate between them.

To ensure whether newborns were able to distinguish between the two dynamic expressions despite the null result revealed during the preference task, we conducted a second

experiment in which we used a visual habituation paradigm. We habituated newborns to happy or fearful facial expressions. Following the habituation phase, we tested their discriminative abilities presenting them the familiar expression along with the novel one. If newborns are able to discriminate between the two facial expressions, then we expect them to look longer and orient their gaze more frequently towards the novel stimulus in the test phase, regardless of the facial expression presented in the habituation phase.

If newborns recognized the difference between the two emotional faces, this would indicate that the LSF are sufficient to allow discrimination between the faces while not conveying the preference. On the contrary, this would indicate that removing HSF negatively impacts emotional recognition in newborns.

Materials and methods

Participants

The sample size was set in advance to match de Addabbo and colleagues (2018). Data from Experiment 2 reported in Addabbo and colleagues' study (2020) indicate that power to detect a main effect of novelty (novel vs. familiar) at the same effect size to be at .97 for a sample size of minimum 17 at $\alpha = 0.05$.

We recruited 22 full-term newborns at the maternal unit of Mangiagalli Hospital of Milan (13 girls; mean age = 43 hours; SD = 0.62 hours; range: 24–85 hours, mean birth weight: 3249 g, Apgar score: at least 9 after 5 minutes from birth) were tested when they were in an awake and alert state. Thirteen other newborns were recruited and tested but excluded for sleepiness (7), crying (5) and mother interference (1). Although power analysis indicated a minimum sample size

of 17, no sequential testing was performed and data were only analyzed once all the data were collected.

Parental written informed consent was obtained before testing began. 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 were the same as in Study 5a. Here, we employed the second identity that expressed the two emotions to avoid the possibility that newborns' discrimination could be ascribed to the salient features of one single identity. Thus, two faces of different Caucasian women were used (face A and face B). Half of the newborns saw face A and the other half saw face B, randomly assigned. Also, in the second identity woman had a direct gaze. As in face A, used in Study 5a, each video was 2000 ms long and consisted of 24 frames (24 fps, frames per second) each one of the duration of 83.3 ms. The first 6 frames represented the faces with neutral expression instead, in the following 18 frames, the expressions of happiness and fear were unfolded and the maximum peak of intensity was reached in frame 18. The same procedure of Study 5a for filtering out HSF was used here. The two videos were shown bilaterally at a distance of 15°, and played continuously, in a loop. At a distance of 30 cm from the screen, both faces A and B were 13° wide and 20° high. The Luminance, contrast, and hue, as well as saturation, were kept constant between the frames and the stimuli.

Apparatus and Procedure

Newborns were tested using a visual habituation paradigm and total looking times and orienting responses were measured. The habituation phase started when the newborn oriented towards a red flickering circle appearing in the center of the screen. During the habituation phase, newborns viewed bilaterally two videos of a face expressing the same emotion (happy or fearful). Half of the newborns were habituated to the happy faces, the other half to the fearful faces. Two identities were used (face A and face B). In each habituation trial, videos were shown continuously in a loop until newborns shifted their gaze away for more than 2 s. Habituation phase ended when the newborn reached the habituation criterion which was a 50% decline in looking time on the last three consecutive trials, relative to the looking time on the first three trials. Following habituation, newborns were presented with two test trials in which a novel facial expression (happy for newborns habituated to fearful facial expressions and *viceversa*) and a familiar facial expression were displayed simultaneously and bilaterally on the screen. Each test trial began as soon as the newborns looked at a red flickering circle appearing in the center of the monitor. The left/right position of the stimuli was reversed between the first and the second trial. In the first trial half of the newborns saw the happy face on their right and the other half on their left. Each test trial continued in a loop until newborns looked for a minimum of 20 s, each stimulus was watched at least once and newborns' gaze was shifted away for more than 2 s.

This procedure has previously been used in several studies with newborn infants (Addabbo et al., 2018; Valenza & Bulf, 2007). The same procedure of coding of Study 5a was used. The correlation between the two measurements, the inter-coder agreement (Pearson correlation) was .99 ($p < .001$) for total fixation time and .87 ($p < .001$) for number of orientations.

Results

Frequentist analysis

Preliminary data inspection revealed that looking times (LT) recorded during the two trials were not normally distributed for all familiar (familiar 1, WS= .85; familiar 2, WS= .91; all *ps* < .05) stimuli and for novel stimuli only during the second trial but not in the first one (novel 1, WS=.95, *p* =.37; novel 2, WS=.90, *p* = .03).

Thus, after Csibra et al. (2016), data were logarithmically transformed before performing all statistical analysis.

Analyses on habituation showed that all newborns reached the habituation criterion. The rmANOVAs on total looking times with habituation condition (happy vs. fear) as the between-subjects factor, and habituation trials (first three vs. last three) as the within-subjects factor revealed a significant effect of habituation trials, $F(1,21) = 174.2$, $p < .001$, partial $\eta^2 = .72$, with average looking times on the first three habituation trials (M = 45.9 s, SD = 12.6) significantly longer that the average looking times on the last three (M = 15.9 s, SD = 4.4). No other effects attained statistical significance (all *p*s > .62).

To investigate if newborns are able to discriminate between happy and fearful faces with only LSF, the log-transformed data, fulfilling the assumption of homogeneity ($p > 0.2$), were entered in a repeated-measures Analyses of Variance with trial (first vs. second) and novelty (novel vs. familiar) as within-subjects factors and habituation condition (happy vs. fear) as between-subjects factor.

The analysis revealed a significant main effect of novelty, $F(1,21) = 41.1$, $p < .001$, partial $\eta^2 = .16$, with newborns looked significantly longer at the novel (M = 20.2 s, SD = 8.1) than the

familiar (M = 11.7 s, SD = 5.0) facial expression during test phase (Figure 5.4). No other significant effect and interaction emerged from this analysis (all *ps* > .08). Moreover, 22 out of 21 newborns in the sample looked longer at the novel stimulus than at the familiar one (binomial test, $p < .001$).

Last, rmANOVAs on eye orienting responses with trial (first vs. second) and novelty (novel vs. familiar) as within-subjects factors and habituation condition (happy vs. fear) as between-subjects factor revealed a main effect of novelty, $F(1,21) = 4.59$, $p = .04$, with newborns oriented more frequently towards the novel (M= 5.4, SD = 1.8) than towards the familiar (M= 4.8, SD = 1.4) facial expression during test phase (Figure 5.4). The other factors and interactions were not significant (all *p*s > .07).

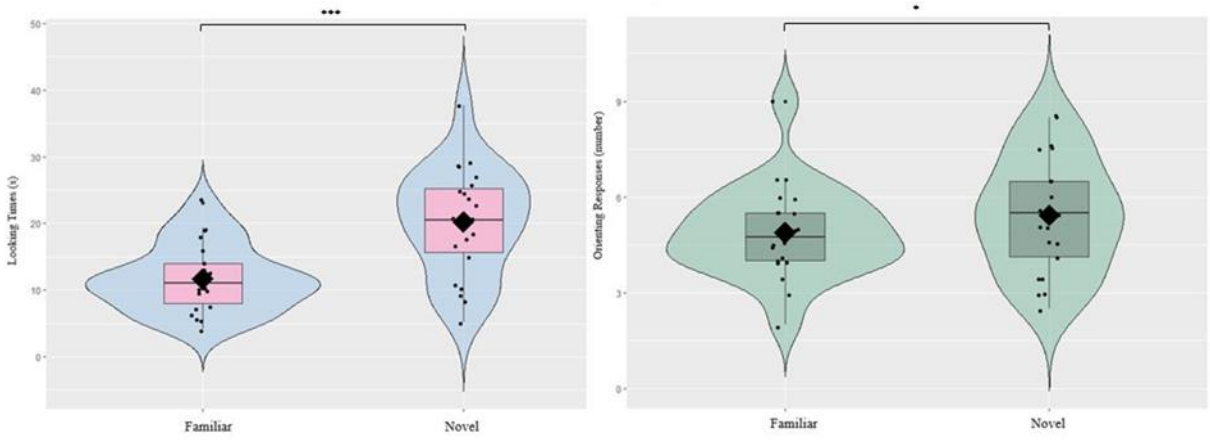

*Figure 5.4. Newborns' looking times (left) and orienting responses (right) towards the novel and familiar stimulus. Means are represented by the black diamonds in the boxplots. * p < .05. ** p < .005. *** p < .001.*

Bayesian analysis

For both looking times and orienting responses, the Bayesian mixed factor ANOVA partially confirmed the relevance of the novelty factor emerging from the frequentist analysis.

Looking at the inclusion BF for novelty effect, there was strong evidence in the data for including it in the looking times model (BFincl looking times =242.5). Hence, the BF10 in favor of indicating the main effect of novelty for looking times equaled 1043.9, providing strong evidence in favor of this model when compared to the null model.

Looking at the inclusion BF for novelty effect, there was no evidence (compared to other factors) for including it in the orienting responses model (BFincl orienting responses= .07). The BF10 in favor of indicating the main effect of novelty for orienting responses equaled to .39, revealing no evidence in favor of this model when compared to the null model.

Discussion

Study 5 investigated the nature of visual information that newborns rely on to perform facial emotion recognition using the spatial filtering approach by manipulating the spatial frequency bands of naturalistic dynamic face stimuli.

In Study 5a, to explore if the visual preference manifested by newborns for happy faces (Farroni et al., 2007) is mainly vehiculated by analytical or configural information, we selectively removed high or low spatial frequencies contained in the images.

We found a series of findings, the most important of which regards newborns' preference for happy faces only when configural information, conveyed by low spatial frequencies, is removed from the image. Thus, newborns seem to prefer happy rather than fearful faces in dynamic

conditions both when no spatial frequencies and low spatial frequencies are filtered out (i.e. HSF condition).

First, the preference for happy faces is in line with previous studies (Farroni et al., 2007) showing that few-days-old infants prefer happy expressions compared to fearful ones. Therefore, not only with static stimuli but even more with naturalistic ones, thus in motion, newborns prefer emotion with a positive valence over expression with a negative valence. Taking into consideration that the small visual experience of newborns is characterized by dynamic rather than static motor patterns, it could be that adding the movement has favored the preference for happy faces that already emerges with static faces in newborns (Farroni et al., 2007). This preference for the happy over fearful faces can be explained by the experience that newborns have with faces more represented in their social environment (Quinn & Johnson, 1997; Quinn et al., 2011). The positive interactions with humans in the initial days and months after birth may explain young infants' early visual preference for smiling faces over other expressions (Rigato et al., 2011; Vaish et al., 2008). In the first few hours of life, infants pay more attention to visual cues in the environment that are relevant to social interactions and that maximize the chances of social connections with conspecifics (i.e., happy faces with direct gaze, see Reid & Striano, 2007; Rigato et al., 2011). An attentive response to negative valence emotions, on the other hand, may not be meaningful to infants until they begin to crawl or walk (Hoehl, 2014). Indeed, gradually during the development, different emotional expressions are discovered and used to differentiate inputs and orient behavioral responses accordingly (Quinn & Johnson, 1997). Thus, only between 5 and 7 months of age, fearful expressions are preferred to happy ones (Ludemann & Nelson, 1988; Nelson & Dolgin, 1985; Peltola et al., 2008; 2009).

Moreover, removing low spatial frequencies does not impact the preference for happy faces. On the contrary, removing high spatial frequencies negatively impacts the preference for happy faces. It seems that only in the condition in which the details of the image conveyed by high spatial frequencies are removed, newborns do not show a preference for any of the two emotional faces. As in older infants' evidence (Jessen & Grossmann, 2017; van den Boomen et al., 2019), high spatial frequency, related to local information, are sufficient but also necessary to allow discrimination between emotional faces. Thus, 7- to 10-month-old infants discriminate between happy and neutral or fearful faces when images contained high but not low spatial frequencies at the neural level. Our result showed that early in the first hours of life, humans need detailed information to prefer happy over fearful expressions. This led to the consideration that the preference for happy faces is driven by detailed information probably vehiculated by analytic facial cues such as the region of the eyes or the mouth.

We found that while newborns looked longer to happy faces in both unfiltered and high-pass filtered conditions, orienting responses are not modulated by the emotional content of the image. Newborns did not orient more frequently to the happy stimulus in any of the three conditions, but they performed more orientation, regardless of the emotion presented, in the two filtered conditions. Thus, the number of orienting responses is higher in high- and low-pass conditions in respect to the full-spectrum one.

Orienting responses (OR), like heart rate, pupil dilatation, and skin resistance, reflect the activation of the parasympathetic nervous system elicited for the detection of salient and relevant stimuli (Colombo & Mitchell, 2009). Thus, the registration of OR in eye movement studies is commonly used to investigate the facial cues processing in infants (Colombo & Mitchell, 2009). It should be further considered that OR are mostly activated by the subcortical pathway reflecting

its activity (Johnson, 2005). The subcortical route, already active from birth, has connections with the cortical route and could enhance its activity recruiting specific cortical areas (such as lateral occipital, fusiform, and orbitofrontal cortices), resulting in involvement in face processing of both routes early in development (Johnson, 2005). From this perspective, one could speculate that removing spatial frequencies makes the stimuli more salient and the higher number of OR in those two conditions could reflect the greater engagement of these systems for filtered faces. This aspect should be better investigated in future studies comparing filtered stimuli presented in the nasal and temporal visual field, allowing to differentiate the contribution of the cortical and subcortical visual route.

However, during the first stage of development, OR should be interpreted with caution as in many studies are not totally in line with looking times responses (Gava, Valenza, Turati, & Schonen, 2008) since they could depend on other factors (such as the stimulus position in the visual field or the stimulus salience). To date, in many studies, only fixation times are used as the dependent variable (Bulf, Johnson, & Valenza, 2011; de Heering et al., 2008; de Hevia, Cassia, Veggiotti, & Netskou, 2020; de Hevia, Izard, Coubart, Spelke, & Streri, 2014; Simion, Regolin, & Bulf, 2008).

Anyhow, one of the most important findings in the present study regards the absence of newborns' preference for happy faces when analytic information is not available in the image (and only configural information of the blurred faces remains). It should be considered that the absence of preference in the low-pass condition does not directly imply that newborns are not able to discriminate between the two emotional faces in that condition.

Indeed, Study 5b indicated that newborns are able to distinguish between unfolding happy and fearful faces with low spatial information. Not only did newborns look more at the novel

stimulus than the familiar one, but they also oriented more to the novel than the familiar stimulus. We have already discussed how conclusions about results concerning OR are tricky. Moreover, even though we found newborns orienting more to the novel in respect to the familiar stimulus in the frequentist analysis, we did not find the same probable results with the Bayesian analysis. Thus, even though we decided to present the interesting results of OR, we here considered looking times as a more realistic and reliable measure of newborns' behavioral responses.

To conclude, newborns can discriminate between happy and fearful faces with both global, vehiculated by low-spatial frequencies, and local, represented by high-spatial frequencies, information. However, it seems that detailed information highlights the facial cues that lead newborns to prefer happy faces, the ones they probably have more experience with. On the contrary, global information leads to a "non-preference" for happy faces making fearful faces as salient as the happy ones. Thus, even if the *global bias*, present from the first hours of life for non-social (Macchi Cassia et al., 2002) and non-emotional social stimuli (i.e., in identity recognition, de Heering et al., 2008), is not present for emotional faces, it still plays a crucial role in emotional discrimination by making more salient a stimulus of which newborns have little experience but which is ontogenetically and evolutionarily important to detect, fearful faces (Peltola et al. 2008). Thus, the visual information present in the image modulates the salience of the facial cues to emotions from the first hours of life.

Chapter 6

Conclusion and General Discussion

6.1 Tracing the red thread

The present doctoral dissertation aimed to explore the nature of the visual information involved in perception of facial cues to trustworthiness and emotional expressions. As discussed in the Introduction, the investigation of the basic visual mechanisms involved in the perception of these facial cues allows us to understand more about the ontogeny of sensitivity to facial cues to trustworthiness and emotion. Moreover, the manipulation of the spatial frequencies (SF) content of the stimuli corresponding to featural or configural information represents a viable tool to the investigation of the underlying visual mechanisms that support face processing. A large number of studies highlighted the associations between high spatial frequencies (HSF) and the processing of the fine-scale local details of the original face image, and between low spatial frequencies (LSF) and the processing of the large-scale global shape of the face (Goffaux et al., 2005; 2006). On this basis, spatial filtering (i.e., the selective removal of portions of the SF information contained in the image) can be used to assess the contribution of local and/or global information to participants' performance in any face-processing task. In the present dissertation, we adopted the spatial filtering approach to investigate the nature of the visual information used in the trustworthiness and emotion perception from faces.

Specifically, the five studies reported in the thesis aimed to address the five questions anticipated in Chapter 1: (1) Is trustworthiness perception mediated by the same bands of visual

SF information across development, i.e. in adults (Study 1 and 2), children (Study 3), and preverbal infants (Study 4)? (2) Does trustworthiness perception generalize across face ethnicity in adults (Study 2) and children (Study 3), and is it mediated by the same SF information in own-race and other-race faces? (3) What SF information supports discrimination of facial emotional expressions at birth (Study 5)?

Evidence from **Study 1 and 2** suggests that both LSF and HSF visual information are sufficient to allow explicit judgments **(Study 1)** and perceptual discrimination **(Study 2)** of trustworthiness intensity in adults. Nonetheless, results also showed that selective removal of the LSF content of the stimuli negatively impacted trustworthiness ratings **(Study 1),** and decreased performance accuracy when adults were asked to choose the more trustworthy face in a pair **(Study 2)**. This indicates that detection of facial cues to trustworthiness relies more heavily on the LSF content of the images than on the HSF bands.

Critically, **Study 2** showed that, in adults, trustworthiness perception, and its reliance on LSF information, generalize across face ethnicity, as participants' discrimination performance did not differ for unfiltered Caucasian and Asian faces, and the selective removal of LSF had negative effects on discrimination accuracy for both face categories. Nonetheless, participants also showed more fine-grained sensitivity to variations in trustworthiness intensity in own-race faces compared to other-race faces, and an own-race discrimination advantage when only LSF information was available in the stimuli. This is indicative of greater sensitivity to facial cues to trustworthiness in own-race versus other-race faces, and, again, of the critical contribution of LSF information to trustworthiness perception.

Children' data from **Study 3** showed an opposite pattern, as children relied more on HSF information when discriminating trustworthiness intensity from own-race faces and on LSF information for other-race faces.

Indeed, in preschool years children are building and refining their perception of trustworthiness from faces. According to the face-trait mapping model proposed by Over and Cook (2018), this is the time when they build their representational "trait-space" through exposure to trustworthy and untrustworthy faces in their social environment. This process is centered on the face categories that are more frequent in the child's social environment, which typically include own-race faces. Also, because we know that people rely on localized cues to infer trustworthiness from faces (i.e., wrinkling nose, up/downturned eyebrows and mouth; see e.g., Garrod, Jack, & Schyns, 2014), it is possible that, at the time when a prototypical representation of trustworthiness is being built, local/featural information mediated by HSF bands enjoys an advantage in perceptual processing. That is, children may rely heavily on details when they discriminate trustworthiness in own-race faces because these are the faces that are feeding the perceptual representation they are building in memory. Later in development, once this representation is refined, global/holistic information mediated by LSF would become more relevant for trustworthiness discrimination.

It should be noted that the inclusion of participants from one single ethnic group is an aspect that may limit the generalizability of the current findings. Indeed, it is frequently argued that the absence of cross-cultural comparison limits the interpretation of the observed face-race effects as being driven by perceptual expertise for own-race faces, as those same effects might well be driven by differences in low-level stimulus characteristics rather than race *per se*. Moreover, the inclusion of only one ethnic group prevented us from determining whether the source of visual information mediating trustworthiness perception was influenced by the

participants' cultural background. Thus, future studies should test whether differences across cultures could influence the nature of visual information trustworthiness perception relies on.

Study 4 expanded the evidence of the visual information involved in trustworthiness perception in preverbal infants. Here, the nature of visual information that triggers neural discrimination of facial cues to trustworthiness in 6-month-old infants was investigated by adopting a recently developed Electroencephalographic (EEG) visual discrimination paradigm, the Fast Periodic Visual Stimulation, (Norcia et al., 2015). FPVS is based on the tendency of endogenous neural oscillations to align with an ongoing periodic stimulus in the external environment. Specifically, when exposed to a rapid stimulus presentation at a constant frequency, the voltage amplitudes in the brain's electrical activity oscillate at the same frequency. Based on this neural propriety, the FPVS paradigm is particularly suitable to measure the discrimination between base and oddball stimuli, differing on a dimension of interest (i.e., the trustworthiness level) presented at two different periodicities within the same sequence. A discrimination response can be measured at the frequency at which there is a change in face category (i.e., the Oddball frequency) expressed in terms of Signal to Noise Ratio (SNR).

To conduct a qualitative investigation of age-related differences in brain sensitivity to trustworthiness from filtered faces, a group of adults was also tested using the same paradigm. Data from this adult sample showed that brain activity in the occipital regions oscillated at the frequency of presentation, independently of the condition (i.e., whether the Oddball was a High or a Low Trustworthy face) and spatial filtering (i.e., whether faces contained LSF or HSF). More importantly, the fact that SNR was significantly higher than noise when the Oddball was High Trustworthy in both the LSF and HSF conditions, and when the Oddball was Low Trustworthy in the HSF condition only confirms adults' ability to discriminate between the two levels of

trustworthiness even in subliminal detrimental (i.e., filtered faces) conditions. Indeed, it should be kept in mind that the filtering cut-offs were calibrated on infants' visual acuity. Thus, the significant Oddball response for the Low Trustworthy faces in the HSF has not to be taken as indicative of an actual selective reliance on detailed information, since HSF condition almost contained the entire spectrum of spatial frequencies. On the contrary, LSF condition contained only a narrow band of low spatial frequency, calibrated on infants' visual acuity. Thus, our results on the adults' group pointed out the necessity to identify trustworthy faces even with a narrow band of LSF. The crucial role of LSF in the discrimination of perceptual cues to trustworthiness in own-race faces founded in Study 1 and Study 2 also emerged in subliminal and neural trustworthiness discrimination.

Like adults, infants' brain activity in the occipital regions as well oscillated at the frequency of stimulus presentation, independently of the condition and spatial filtering. However, the Oddball responses revealed that infants discriminated the change in trustworthiness intensity in LSF condition when the Oddball stimulus was High-trustworthy, while they succeeded in the HSF condition when the Oddball stimulus was Low-trustworthy. This suggests that both LSF and HSF information is relevant for infants' perception of trustworthiness, even if the infants' brain discriminated between high-trustworthy and low-trustworthy faces based on LSF and HSF visual information, respectively. Infants' reliance on LSF to detect trustworthy faces may reflect infants' familiarity with this positively valenced type of faces, that are likely the most frequent in the infant's social environment. Only later in processing, the presence of details support untrustworthy faces discrimination, with which infants have less experience. The specialization of perceptual processes, thus, does not seem to be a unitary phenomenon but rather modulated by the type of task or the type of information individuals are motivated to extract from those faces.

Finally, in **Study 5a** and **5b** the nature of visual information that newborns rely on in emotion perception was investigated. Study 5a and 5b explored if at birth emotion perception is influenced by the global bias that emerges in identity perception and non-social stimuli processing or if it relies on detailed information as older infants. Study 5a' results confirmed previous evidence of newborns' visual preference for happy faces with dynamic stimuli. The preference for happy faces was maintained when only analytical information, conveyed by HSF, remained in the image. In Study 5b we investigate if low spatial frequencies, while not conveying the preference for happy faces, are at least sufficient to allow discrimination between happy and fearful faces. Study 5b' results showed that newborns are able to discriminate between happy and fearful faces with LSF. Overall, our findings suggest that newborns discriminate between happy and fearful facial expressions with both high and low spatial frequency information, but they prefer happy faces when only high spatial frequencies remain. The visual information present in the image modulates the perceived salience of facial cues for emotions at birth, with low-SF contributing critically to the salience of threat-related cues.

The studies presented in this dissertation have some limits. First, all studies used one or two female face identities as stimulus material. Female faces were used based on evidence showing that infants are better at discriminating female than male faces since are the most frequent faces in infants' social environment (Quinn et al., 2002). This choice may have limited the results' generalizability and, thus, future research shall investigate whether our findings apply to other face identities, such as male faces.

Nonetheless, it should be considered that trustworthy and untrustworthy faces used in studies 1-4 were created by merging three/four different identities. This approach has the advantage of achieving control over idiosyncratic information while preserving category-

specifying information. Nevertheless, in the light of the current debate concerning whether computer-generated faces are appropriate to explore face processing expertise (Crookes et al., 2015), future studies may investigate the generalizability of the current results to real face images.

Another limit of the studies concerns the approach used to create the experimental stimuli. The filtering method used in all studies has the merits of maximizing the naturalistic appearance of the images. Moreover, to preserve the natural distribution of contrast energy across spatial frequencies, the contrast of the images in all studies was not normalized. Thus, one could claim that differences in contrast between filtering conditions might have affected participants' perception of the filtered images, thus constraining conclusions about the mere influence of spatial frequencies on the obtained results. We believe this was not the case, as recent studies (Munsters et al., 2016; van den Boomen et al., 2019) revealed that the effects of spatial filtering on the discrimination of social cues from faces are not accounted for contrast differences. Still, future studies could use normalized images to replicate the current findings in absence of any confounding between the SF and the power content of the filtered images.

In conclusion, results from studies 1-5 provide evidence that both the high and the low spatial frequency content of face images provide **sufficient** visual information to allow emotion and trustworthiness perception in newborns, preverbal infants, children and adults. Thus, emotion and trustworthiness information are carried by both coarse and fine resolution visual signals across development. Nevertheless, the visual information that **more heavily contributes** to trustworthiness and emotion perception changes over the course of development as a result of accumulating experience with faces in the individual's social environment: newborns and children rely more heavily on high-SFs, while adults rely more on low-SFs. Moreover, the nature of the visual information more heavily involved in trustworthiness perception differs as a function of

face familiarity across development, with a shift from heavier reliance on HSF to LSF with increasing experience with the more familiar face categories: children rely more on HSF while adults rely more on LSF information when discriminating trustworthiness of own-race faces.

Altogether, the evidence gathered from the current studies adds to the existing literature suggesting that emotion and trustworthiness perception are based on an adaptive and evolutionary sensitivity early in life that is refined over the course of development as a result of the quantity and quality of facial experience in the social environment.

6.2 Practical implications for developmental and social neuroscience

A better understanding of the origins and contextual factors influencing trustworthiness and emotion perception and developmental changes underlying these processes provides a starting point for tracing typical developmental trajectories. Here, we aimed (1) to provide insights into perceptual processes and neural bases underlying trustworthiness perception in infancy and adulthood, and (2) to explore the impact of experience on the processing of facial trustworthiness.

First, different studies have shown that people with Autism Spectrum Disorder (ASD) and Williams syndrome rely more than typically developing populations on detailed information, which drives their processing of emotion cues (D'Souza, Booth, Connolly, Happé, & Karmiloff-Smith, 2016; Leonard, Annaz, Karmiloff-Smith, & Johnson, 2011; Simmons et al., 2009; Vlamings, Jonkman, van Daalen, van der Gaag, & Kemner, 2010b). As mentioned in the Introduction, altered visual processing of low-level features in face perception might have cascading effects on multiple domains during development (D'Souza & Karmiloff-Smith, 2017). More specifically, since both global and detailed information play critical roles in emotional and

trustworthiness face processing throughout development, abnormalities in visual information processing likely affect the development of face processing. Thus, research in infancy and across development may offer a starting point for intervention in circumstances when social development goes awry.

Furthermore, the results of the present dissertation are critical not only for tracing typical developmental trajectories and identify early markers of atypical development of socio-cognitive abilities, but have fundamental implications for the field of eyewitness testimony (Meissner, Sporer, & Schooler, 2007). Indeed, individuals with untrustworthy face traits are subjected to harsh judgments, which have a significant impact on how others treat them and are more likely to be found guilty of a crime and face longer jail terms (Porter, ten Brinke, & Gustaw, 2010; Wilson & Rule, 2015). Different studies showed that, in both US and other nations, Black people are more commonly falsely convicted of crimes as a result of eyewitness identification, and their penalties are more severe (Blair, Judd, & Chapleau, 2004; Smith, Stinson, & Prosser, 2004). Our results provide interesting considerations in this area by showing that trustworthiness judgments are universal and not modulated by face ethnicity. Rather, the nature of visual information involved in trustworthiness perception differs in own- and other-race faces. This might have practical repercussions in circumstances where one should make a quick decision about whether or not trust someone. Future studies could investigate how the nature of visual information involved in trustworthiness judgments varies across different minority ethnic group members to develop precise theoretical models for application in judicial contexts.

A final consideration concerns the online nature of some of the studies reported in this dissertation. The facts that these studies were successful is a proof of the effectiveness of home testing in children and adults. This technique offers the advantages of making scientific research

more accessible to children and their families. While laboratory-based developmental research is often accused of suffering from sampling biases, online data collection pushes research closer to the statistical assumption for random sampling, allowing access to more diverse samples and thus more reliable effect estimates, as participation through devices is more cost- and time-effective than in-lab testing. Results gathered within the current project thus provide a methodological contribution to the field by testing the feasibility of collecting reliable response accuracy and preference data in young children through online tasks.

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