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Infants' early representation of faces: the role of dynamic cues.

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Abstract

The general aim of the current dissertation is to investigate whether the semi-rigid movement of a face might affect the encoding and the processing of socially relevant information retrievable from faces, such as identity and emotions, in the first year of life. In particular, the research project is aimed, on one hand, at testing whether facial motion promotes the construction of the face representation, which, in turn, might facilitate identity recognition in newborns and categorization of facial expressions in young infants; on the other hand, the current work is aimed at investigating whether infants are able to process facial motion information alone, when other pictorial cues, such as forms, colors, etc. are unavailable.

In the first study, I investigated how the movement of a happy facial expression could impact few-day-old infants' identity recognition. Previous studies have shown that, when newborns have to recognize a face that changed in some characteristics (such as profile view), the recognition of identity is inhibited (e.g., Turati et al., 2008). It has been demonstrated that both rigid and non-rigid facial motion could promote face recognition at birth (Bulf & Turati, 2010; Leo et al., in prep.). Four experiments have been carried out to test whether the beneficial effect of facial motion might be due to a facial representation more robust and less linked to the image stored in newborns' memory. Results have demonstrated that the benefits fail when the perceptual distance between the memorized face and the face newborns have to recognize increased (Experiment 1). Accordingly, when the perceptual distance is minimized, newborns are able to recognize the same identity despite the subtle changes even when habituated to a static face (Experiment 2). The third study showed that a biologically impossible facial motion hinders newborns' face recognition (Experiment 3). Finally, when the quantity of pictorial information is equated, the static presentation does not lead to a successful recognition (Experiment 4). Overall, it seems that non-rigid facial motion could promote a face representation less image-constrained, but only in a condition where the degrees of visual discrepancy between the habituated and the test face images have been minimized.

The second study investigated whether emotions expressed dynamically might facilitate the ability to categorize facial expressions at 3 months of age. According to the infants' literature on the perception of static emotional expressions, categorization starts to appear only between 5 and 7 months of age (e.g., deHaan & Nelson, 1998). Findings coming from naturalistic studies of mother-infant interactions (e.g., Nadel et al., 2005), as well as intermodal preference tasks (e.g., Kahana-Kalman & Walker-Andrews, 2001), suggest that infants' ability to process facial expressions might have been underestimated. In a within-subject design, 3-month-old infants were familiarized to four different identities posing four different intensities of a happy and a fearful expression, presented sequentially in loop in order to convey the dynamic information. Results have shown that 3-month-old infants are able to categorize the emotion of happiness, whereas they do not show this ability when they are familiarized with the emotion of fear. Such difference is likely due to the different degree of familiarity of happy and fear expressions (Malatesta & Havildand, 1982). Thus, the presentation of dynamic emotional expressions enhances infants' ability to categorize facial expressions.

The purpose of the third study was to analyze infants' ability to process the dynamicity embedded in a face when other pictorial cues are unavailable, as demonstrated in adults (e.g., Bassili, 1978). To this end, point-light displays (Johansson, 1973) of happy and fear expressions were created. In experiment 1, in a habituation procedure, the ability to discriminate between happy and fear only on the basis of motion cues has been investigated in 3-, 6- and 9-month-old infants. Point-light displays of a face were presented both upright and inverted, to test whether infants were able to organize the motion pattern according to a face-schema. Results have shown an inversion effect at all the three age groups, suggesting that infants process the motion patterns as facial motions. Importantly, when habituated to the happy expression, all the three age groups show successful discrimination ability. In contrast, when habituated to the fear PLD, only 3-month-olds show a successful discrimination, whereas 6- and 9-month olds seem to loose such capability. Experiment 2 ruled out the possibility that a spontaneous preference for the fearful face might have affected infants' looking behavior. These results seem to indicate that the ability to process facial expressions by relying on motion cues follows a developmental trajectory that starts with an early processing of the lower-level facial attributes, in which motion patterns are processed in a face-related way, and then evolves in the capacity to process the higher-level facial attributes, in which face movements are processed as facial expressions.

Overall, the results of the present dissertation suggest that, already within the first months of life, the semi-rigid facial motion might promote the processing of the socially relevant information conveyed by faces by means of an enhanced facial representation. Moreover, the current data reveal that infants are able to process facial expressions from facial motion cues alone starting from 6 and 9 months of age.

Riassunto

Il presente lavoro di tesi si propone di indagare come il movimento semi-rigido del volto influenzi la codifica e la elaborazione di alcune informazioni socialmente rilevanti estraibili dal volto stesso, come l'identità e le espressioni emotive, in bambini al di sotto del primo anno di vita. In particolare, l'ipotesi è che il movimento facciale possa promuovere la costruzione di una rappresentazione mentale che, a sua volta, faciliti il riconoscimento degli stimoli in compiti di abituazione e familiarizzazione visiva. Inoltre, è stata analizzata la capacità degli infanti di processare l'informazione cinetica del volto quando altre informazioni pittoriche, come le forme, i colori, ecc., non sono presenti.

Nel primo studio è stato indagato come il movimento facciale veicolato dall'espressione facciale di felicità possa influenzare sulla costruzione della rappresentazione del volto in bambini con un massimo di 3 giorni di vita). Precedenti studi alla nascita hanno dimostrato che quando alcune caratteristiche facciali del volto da riconoscere cambiano, la capacità di riconoscimento dell'identità di un volto viene inibita (e.g., Turati et al., 2008). In questi casi, è stato dimostrato come sia il movimento rigido che quello non-rigido del volto facilitino il riconoscimento dell'identità alla nascita (Bulf & Turati, 2010; Leo et al., in prep.). Attraverso quattro esperimenti, si è voluta verificare l'ipotesi che l'effetto di beneficio del movimento semi-rigido sia legato alla costruzione di una rappresentazione del volto meno legata all'immagine pittorica immagazzinata in memoria. Anzitutto, i dati dimostrano che il movimento facciale non favorisce il riconoscimento quando viene aumentata la distanza percettiva tra il volto memorizzato e quello da riconoscere (Esperimento 1). Coerentemente, quando tale distanza percettiva è minima, i neonati sono in grado di riconoscere lo stesso volto anche in condizioni statiche (Esperimento 2). Il terzo studio mostra che un movimento biologicamente impossibile ostacola il riconoscimento dell'identità alla nascita (Esperimento 3). Infine, è stato dimostrato come le stesse informazioni pittoriche presentate staticamente in sequenza non portano ad alcun beneficio nel riconoscimento (Esperimento 4). Nel

complesso, il movimento non-rigido sembra promuovere una rappresentazione del volto resiliente ai cambiamenti, ma soltanto quando la differenza percettiva tra le diverse immagini dello stesso volto è limitata.

Il secondo studio ha indagato se l'utilizzo di stimoli facciali emotivi dinamici consenta l'astrazione di caratteristiche comuni permettendo la categorizzazione delle espressioni facciali di felicità e paura già a 3 mesi di vita. La letteratura sulla capacità di categorizzazione negli infanti, infatti, indica che tale abilità si sviluppi soltanto tra i 5 e i 7 mesi di vita (e.g., deHaan & Nelson, 1998). Tuttavia, nella quasi totalità degli studi sono stati utilizzati stimoli statici. Dati provenienti dalle osservazioni naturalistiche delle interazioni madre-bambino (e.g., Nadel et al., 2005) , nonché da studi che utilizzano altri paradigmi sperimentali, come preferenze di tipo intermodale (e.g., Kahana-Kalman & Walker-Andrews, 2001), in cui gli stimoli facciali sono dinamici, suggeriscono una sensibilità al tono emotivo delle espressioni facciali (in particolare, quella di felicità) ben più precoce di quella indicata dagli studi di laboratorio. In un disegno *within-subjects*, bambini di 3 mesi sono stati familiarizzati a 4 differenti identità che mostravano 4 differenti intensità di felicità e paura presentate sequenzialmente in modo da creare una percezione di dinamicità. I risultati hanno mostrato come l'espressione di felicità viene categorizzata già a tre mesi di vita, mentre questo non succede per quella di paura. Tale differenza è riconducibile al diverso grado di familiarità delle due espressioni (Malatesta & Haviland, 1982). Questi risultati supportano l'ipotesi che il movimento facciale promuova l'astrazione di caratteristiche invarianti del volto, facilitando la categorizzazione delle espressioni facciali.

Il terzo studio si è proposto di analizzare la capacità di processare la sola informazione cinetica del volto, scorporata dagli altri indici pittorici. A tal fine, sono stati creati stimoli facciali di tipo *point-light* (Johansson, 1973) raffigurati la dinamicità delle espressioni di felicità e paura. Nell'esperimento 1, tramite abituazione visiva, è stata indagata la capacità di infanti di 3, 6 e 9 mesi di vita di discriminare queste due espressioni facciali sulla base del solo movimento del volto, come precedentemente dimostrato negli adulti (e.g., Bassili, 1978). Gli stimoli sono stati presentati sia dritti che invertiti, al fine di verificare che il movimento fosse processato come un movimento del volto. I risultati hanno mostrato anzitutto un effetto inversione, che indica che l'insieme dei punti in movimento viene organizzato secondo lo schema volto. Inoltre, quando abituati all'espressione di felicità, i bambini di tutte le tre età dimostrano capacità di discriminazione. Al contrario, quando abituati alla paura, solo i bambini di 3 mesi mostrano capacità di discriminazione, mentre a 6 e 9 mesi questa abilità sembra scomparire. L'esperimento 2 ha escluso la possibilità che una preferenza a priori per l'espressione paura possa aver causato questo andamento. I risultati sembrano indicare che la capacità di processare le espressioni facciali sulla sola base cinetica si evolvi secondo una traiettoria di sviluppo che prevede una iniziale elaborazione di attributi del volto "low-level", in cui i movimenti vengono processati come movimenti del volto, verso una più sofisticata elaborazione di attributi del volto "high-level", in cui il movimento è processato come espressione facciale.

Nel complesso, i dati di questo lavoro di tesi sembrano suggerire che il movimento facciale possa promuovere l'elaborazione delle informazioni sociali trasmissibili dal volto fin dai primi mesi di vita, attraverso un rafforzamento della costruzione di una rappresentazione del volto. Inoltre, i dati hanno mostrato che la capacità di processare le espressioni facciali sulla sola base del movimento emerge tra i 6 e i 9 mesi di vita.

Introduction

The concept of "biological motion" is commonly associated with Gunnar Johansson's pioneer study (Johansson, 1973), even if in that circumstance he never formalized its specific meaning. What Johansson called "biological motion" seemed rather a tool to explore the role of motion in perceptual organization, the real purpose of his investigations. Nowadays, research on biological motion perception has deviated in different ways from his original question and sometimes the term itself has been used to comprehend different aspects. For example, while several authors refer to human movements (whole body, body parts and face) as biological ones (e.g., Grosbras et al., 2012), others (e.g., Moore, 2010) consider as biological all forms of animal motion, even the invertebrates, naming instead human motion as "biomechanical motion". Troje (Troje, 2013) utilizes a more general term, "life motion" in order to include "*any kind of visual stimulus that evokes the impression that something is alive, independently from the specific depiction is being used and what aspect of the motion is being emphasized*" (Troje, pp.17). In this broader sense, any research and stimulus that efforts to isolate the motion component from other sources of information about animals and people, is suitable for studying how such motion is perceived and what kind of information can be extracted from it. Troje's "life motion" extended sense could be overlapped, at least for some aspects, with "animated motion", which however refers specifically to the capability of an object to have self-propelled motion (a characteristic not possessed by non-living objects). Perceive an entity as animate means to be able, on the basis on kinematic cues, to attribute intentions and motivations, even if this entity is a rigid geometric shape (e.g., Heider & Simmel, 1944).

Aside the terms and the different purposes of the existing studies in this research field, what it can be inferred is that the characteristic movement patterns of a living being not only determine to be recognized as a social agent, but also communicate socially relevant information to other conspecifics. Indeed, social information such as identity, emotions, intentions, and many others, is transmitted through the way the agent moves. It is not surprising, thus, that humans possess both an intrinsic sensitivity to others' humans movements, the propensity to seek social information and, together, the astonishing ability to derive such information from visual motion. Since social behaviors occur almost always in dynamic conditions, it becomes relevant to understand the origin of such sensitivity and how it develops into a sophisticated ability to infer social meaning from motion signals.

Make use of motion as a cue for detect socially relevant information might be an evolutionary ancient resource we share with other animals. Some authors (e.g., Leslie, 1984; Johnson, 2006) hypothesized the existence of mechanisms that precociously bias humans toward socially relevant moving stimuli in the environment. For example, Johnson (Johnson, 2006) proposed an inborn *Life Detector*, which allows living creatures to detect and preferentially attend to other conspecifics, making the social world be processed differently from that of inanimate objects.

An inborn predisposition to attend to social agents that rapidly develops within the first year of life is not only proved by infants' response to human motion that differ from the way they respond to object motion (e.g., Lloyd-Fox, Blasi, Volein, Everdell, Elwell & Johnson, 2009; Mahajan & Woodward, 2009; Falck-Ytter, Gredeback, & von Hofsten, 2006), but, also and importantly, by the available evidence proving that very young infants are already well equipped to respond to different types of human movements: whole body, body parts and facial motion (e.g., Christie & Slaughter, 2010; Craighero, Leo, Umiltà & Simion, 2011; Farroni et al., 2013; Galazka Roché, Nyström, & Falck-Ytter, 2014; Ichikawa, Kanazawa, Yamaguchi, & Kakigi, 2010; Ichikawa, Kanazawa & Yamaguchi, 2011; Longhi et al., 2014; Missana, Atkinson & Grossmann, 2015; Moore, Goodwin, George, Axelsson & Braddick, 2007; Poulin-Dubois, Crivello & Wright, 2015; Reid, Hoehl & Striano, 2005; Spencer, O'Brien, Johnston & Hill, 2006; Stucki, Kaufmann-Hayoz & Kaufmann, 1987; Xiao et al., 2015; Zieber, Kangas, Hock & Bhatt, 2014).

For example, Longhi and colleagues (2014) presented newborns with two whole-hand closure movements differing only in their anatomical plausibility. Neonates manifested a preference for impossible over the possible hand movements. In another study, Craighero and collaborators (2011) found that, when presented with a video of an arm grasping a ball, neonates looked longer at the goal-directed action, i.e., an arm moving forward to the ball, than when the arm moved away from it. These findings suggest that the ability to detect relevant social aspects of a movement, such as actions with a purpose, may origin from an innate capacity to discriminate simple motions of limbs and extremities.

Another interesting NIRS (near infrared spectroscopy) study (Farroni et al., 2013) analyzed newborns' brain hemodynamic responses to a dynamic social stimulus (a woman showing a peek-a-boo gesture) and to a non-social dynamic stimulus (moving cog wheels and pistons). The authors observed an activation selective to the social stimulus over bilateral posterior temporal cortex, a location consistent with the findings of fMRI adult studies on STS activity in response to social stimuli (for a review, see Grossman, 2013). Newborns' brain is also equipped with a functioning subcortical circuit, which rapidly detects face-like stimuli thanks to a specific sensitivity to salient visual cues that resemble faces, providing a developmental ground for the adult "social brain" (for a review, see Johnson, Senju & Tomalski, 2015). These studies hint that visual sensitivity to human features and human motions reflects some innate neural mechanisms.

Together, these results support the existence of some innate biases that direct attention towards the motion components of the human social behavior. At the earliest stages of development, these predispositions might be driven by low-level perceptual motion cues, which the immature, but functioning, human visual system is attuned to attend at and to prefer since the first days of life (for a discussion, see Simion, Bardi, Mascalzoni & Regolin, 2013). It is reasonable, therefore, that motion cues might significantly impact the way in which faces are processed from very early on.

Moreover, since these predispositions imply a preferential processing of the social aspects of the visual world, they might constitute the basis for the later-developing skill to perceive socially relevant information from patterns of human movement, like identity and expressions. Indeed, discerning the identity, the intentions and the emotional states of others from their characteristic movements is an essential ability that needs to be developed very early in life in order to promote social communication and interaction.

The present dissertation will deal with the effect of facial motion cues in face processing. More specifically, the experimental work will be devoted to answer the question about how infants utilize the dynamic cues embedded in a face during face processing. While there are a number of adults' studies exploring both the role of facial motion in face recognition (for reviews, Krumhuber, Kappas & Manstead, 2013; Xiao et al., 2014) and the processing of socially relevant information from human motion cues only (e.g., Troje, 2008), the current knowledge regarding these issues in infants' development is very limited.

Chapter 1

Face in motion: adults' studies

Faces convey a variety of socially relevant information, such as identity, emotions, age, gender and race. The human being possess the incredible capacity to detect such information and to recognize a potentially infinity number of faces in milliseconds without efforts. Consequently, a significant number of studies have investigated the complexity and diversity of the information available from pictorial facial features and their configurations. Most of what we know about face processing derives from studies that have exclusively used static face images. However, dynamicity is one of the key features of facial behavior: faces tilt, nod, look away, laugh, grimace, speak. Social communication information is embedded in each of these facial motions. Such social signals permeate most kinds of facial motions and thus, visual processing of the movements should yield information useful for everyday human interactions (Allison, Puce, & McCarthy, 2000). Only in the last two decades researchers have begun to wonder whether the results of experiments on static face recognition could generalize to more naturalistic contexts, examining the role of facial motion on face processing to obtain a more realistic and comprehensive description of face perception.

The sensitivity of humans to moving faces is also described by a relevant number of neuroimaging studies proving that dynamic versions of faces lead to different neural activities and different brain network as opposed to static faces and other moving controls (e.g., Buccino et al., 2001; Calvert & Campbell, 2003; Fox, Iaria & Barton, 2009; Kilts, Egan, Gideon, Ely & Hoffman, 2003; Pitcher, Dilks, Saxe, Triantafyllou & Kanwisher, 2011). For example, Kilts and collaborators (2003), in a PET study, found increased activation in STS in response to dynamic compared to static facial stimuli. Pitcher and colleagues (2011), in an fMRI study, found similar results in the same brain region when participants were presented with facial motion compared to the motion of non-face objects. These data suggest not only a special sensitivity to the dynamic component of facial information, but also demonstrate that static and dynamic faces are processed differently.

In the dynamic face processing literature, facial movements have been divided artificially into two typologies: rigid and elastic (or non-rigid) facial movement. Rigid facial movement refers to the rigid rotations of the head while facial structure does not deform itself (e.g., head turning and nodding, Figure 1.1). In other words, it refers to the translation of the head providing continually changing perspective of the face. In contrast, elastic facial motion refers to the deformations of the face shape and the relative locations of the facial features (e.g., speech, facial expressions, eye gaze changes).

Figure 1.1. Rigid head rotations examples

Despite this classification, in real life situations rigid and non-rigid motions occur simultaneously in moving faces. Several studies have focused on faces depicting elastic facial movement, and very few have reported substantial differences between elastic and rigid facial movements in their influence on face processing (e.g., Lander & Bruce, 2003).

1.1 Facial motion on identity processing

In general, researchers have consistently observed that processing famous faces, familiar faces, and unfamiliar faces in motion leads to better recognition performances than processing faces from static pictures (Bruce, Henderson, Newman & Burton, 2001; Knight & Johnston, 1997; Lander & Bruce, 2000, 2003, 2004; Lander & Chuang, 2005, Lander & Davies, 2007; Lander, Christie & Bruce, 1999; Lander, Chuang & Wickham, 2006; Thornton & Kourtzi, 2002; Pike, Kemp, Towell & Phillips, 1997; Pilz, Thornton & Bülthoff, 2006; Xiao, Quinn, Ge & Lee, 2012, 2013; for reviews, see O'Toole & Roark, 2010; O'Toole, Roark & Abdi, 2002; Roark, Barrett, Spence, Abdi, & O'Toole, 2003; Xiao et al., 2014). Some authors named such phenomenon the *facial motion beneficial effect* (e.g., O'Toole et al., 2002).

Two main hypotheses regarding the facial motion beneficial effect on face recognition have been proposed, even though the existing studies did not test systematically such hypotheses. The first one, the *supplementary information hypothesis*, suggests that facial movement provides idiosyncratic facial information in addition to the invariant structure of the face. The second hypothesis, the *representation enhancement hypothesis*, posits that facial movements enhance the perception of the three-dimensional facial structure, producing a more robust and flexible face representation and, in turn, improving face recognition. I will discuss each of the two hypotheses more in details in the next sections, providing evidences directly or indirectly supporting each of them. As it will be shown, these hypotheses are non-exclusive, in the sense that the validity of one hypothesis does not exclude the validity of the other. In fact, their mechanisms apply to different parts of the process of perceiving, encoding and recognizing a face. Because recognition of a moving face occurs in different situations (i.e., different facial motions, various viewing conditions, and either newly-learned or familiar faces), the contribution of each hypothesis is determined by the characteristics of the recognition task (Xiao et al., 2014).

1.1.1 The supplementary information hypothesis

The supplementary information hypothesis maintains that perceivers can recognize a moving face based on both static facial features and their spatial configurations, and idiosyncratic motion information, i.e., the characteristic way in which individuals move their faces. In other words, in addition to processing the invariant facial structure, humans also process identity-specific facial signatures embedded in facial movements. Therefore, the supplemental information hypothesis seems most relevant for processing familiar faces, since it is unlikely that one can learn such identity-specific facial signatures the first time he/she encounters someone. Importantly, a consequence of this idea is that such identity-specific facial signatures may form a part of our representation of an individual's identity (Roark et al., 2003). In other words, such hypothesis supports the existence of an inherently dynamic visual representation of a face: a "mental video clip" in the brain.

There are two main lines of evidence supporting the supplemental information hypothesis. The first one comes from experiments demonstrating how facial motion could convey the facial identity (Hill & Johnston, 2001; Knappmeyer, Thornton & Bülthoff, 2001, 2003).

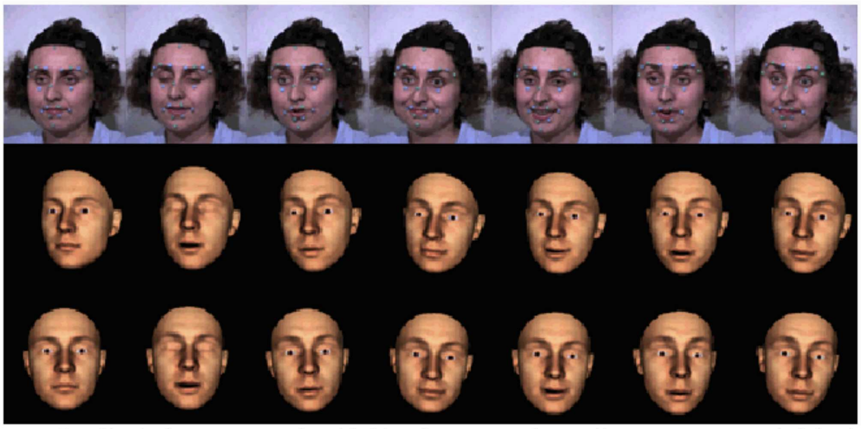


Figure 1.2. Projections of human facial movements in synthetic heads (Hill & Johnston, 2001).

For example, employing 3D computer faces, i.e., facial stimuli on which facial motion patterns are projected, maintaining the same facial structure (called synthetic head, see Figure 1.2).

Hill and Johnston (2001) demonstrated that adults could discriminate among individuals based only on the facial motion patterns. These data further support the beneficial effects of dynamic identity signatures for recognition.

The second line of evidence comes from studies showing that people could use facial motion information to recognize someone when viewing conditions are non-optimal (e.g., Knight & Johnston, 1997; Lander et al., 1999). As shown in Figure 1.3, such non-optimal viewing conditions could comprise image blurring, pixelation, negation (dark-light intensity reversed), and thresholding (i.e., converting a gray scale image to a one-bit-per-pixel pure black and white image, thus, only black or white). The aim of these manipulations is a shift of reliance from the pictorial information to the motion information. The underlying idea is that when both static and dynamic identity information is present, adults usually rely more on the static information because it provides a more reliable marker of facial identity (O'Toole & Roark, 2010).

Fig 1.3 Examples of experimental manipulations to degrade the image quality.

However, when pictorial information is unavailable or difficult to access, recognition accuracy gets worse. For example, recognition of facial images becomes difficult from photographic negatives, even for highly familiar faces (Galper & Hochberg, 1971). Even minor changes in viewpoint (e.g., O'Toole, Edelman & Bülthoff, 1998) and illumination condition (e.g., Hill & Bruce, 1996) result in a decrease in performance when people are asked to remember, or even to match, pictures of newly learned faces (e.g., Henderson, Bruce & Burton, 2001). In such cases, facial movements may supply the visual system with additional facial information to assist in recognition. Consistent with this idea, researchers have reported that dynamic facial information boosts recognition performance in degraded viewing conditions (e.g., Burton, Wilson, Cowan & Bruce, 1999; Knight & Johnston, 1997; Lander & Chuang, 2005; Lander et al., 1999). For example, Knight and Johnston (1997) tested recognition ability for famous faces when either a video or a static picture was presented in negative contrast. Participants were better in identifying the famous face in the motion condition compared to the static one.

While the supplemental information hypothesis involves a direct encoding of the dynamic visual information inherent in a face, the mechanism at the basis of the representation enhancement hypothesis differs substantially. In this latter case, facial motion information helps to encode the invariant structure of the face. Thus, such mechanism should be equally relevant for both familiar and unfamiliar faces.

1.1.2 The representation enhancement hypothesis

According to the representation enhancement hypothesis, dynamic facial information assists in creating a mental representation that is more accurate and more resilient to facial changes than that created only from static images. Such face representation, in turn, leads to an enhanced face recognition performance. Support for the representation enhancement hypothesis comes from two main lines of evidence. The first one concerns all the studies showing that faces are recognized more accurately when they are learned in motion rather than from single or multiple static face images (e.g., Lander & Bruce, 2003; Lander et al., 1999; Pike et al., 1997; Xiao et al., 2012). Indeed, the facial motion beneficial effect may be also explainable by the fact that in a dynamic presentation of a face, more pictorial information is available, compared to a single static picture. To verify this possibility, in several studies moving sequences have been compared to static sequences matched for the number of views presented (for example, the static frames composing a movie). Thus, participants are shown with two situations equated for the number of pictorial information and differing only for the presence of motion. With this method, several studies have demonstrated that recognition is significantly more accurate when participants learn a face in motion than from multiple images (e.g., Lander & Bruce, 2003; Lander et al., 1999; Pike et al., 1997; Xiao et al., 2012). These results indicate that motion per se, and not the quantity of pictorial information, leads to better recognition performance.

A second brunch of studies supporting the representation enhancement hypothesis has shown how recognition is most enhanced when the observed facial motion is natural, compared to when some temporal or spatial characteristics are altered (e.g., Hill & Johnston, 2001; Lander & Bruce, 2000, 2004; Lander et al., 1999, 2006; Pike et al., 1997; Schultz, Brockhaus, Bülthoff & Pilz, 2012). For example, Lander and Bruce (2000) reported that randomly ordered video frames leaded to less accurate recognition than a natural video sequence. The same authors, in a successive experiment (2004), demonstrated how slowing down the motion speed yielded to worse the performance than the normal speed. In another interesting study, Lander and collaborators (2006) demonstrated that recognition of familiar faces was significantly better when the faces were shown smiling naturally than when they were shown smiling in an artificial way. Moreover, speeding up the motion impaired identification from the natural smile, but did not from the morphed artificial smile. All these data demonstrate that the naturalness of the facial dynamicity, which includes both temporal and spatial characteristics, plays a fundamental role in determining the recognition advantage associate with moving faces. Importantly, the results suggest that dynamic information becomes part of the face representation stored in memory (e.g., Lander & Bruce, 2000). The facilitation effect might be related to such facial representation: when the characteristics of a particular facial motion diverge from the characteristics of the facial movements usually perceived, recognition performance is prevented (Xiao et al., 2014).

In summary, both the supplementary information hypothesis and the representation enhancement hypothesis have tried to explain the critical role of facial motion in learning new/unfamiliar faces and recognizing familiar faces. On one hand, facial motion offers information about a face, by means of a formation of an enhanced face representation. On the other hand, the idiosyncratic facial signatures inherent in facial motion patterns can serve as a cue to facilitate identity recognition, especially when facial static information becomes uninformative under non-optimal viewing conditions. Importantly, the two hypotheses suggest two intriguing ideas. First, that facial motion can be processed separately from the static facial information, as a separate visual cue that conveys socially relevant information, such as identity. Second, that the representation of face stored in memory is inherently dynamic, at least in part.

1.1.3 Other studies

The beneficial effect of facial motion suggests that the mechanisms underlying face motion processing may differ from those underlying static face processing (Xiao et al., 2014). Recently, some researchers have tried to clarify the nature of such mechanisms, investigating the influence of facial motion on face processing and testing the hypothesis that the encoding strategies employed when processing a moving face might be different from those employed when processing a static face (e.g., Rigby, Stoesz & Jakobson, 2013; Stoesz & Jakobson, 2013; Xiao et al., 2012, 2013). In particular, it has been suggested that facial motion promotes processing strategies appropriate for the specific task demands compared to static images (Xiao et al., 2014). In other words, when presented with moving faces, individuals increase the flexibility of the face processing according to the requirements of a specific situation more than they would do if presented with static pictures of faces. The following experiments attempted to support this idea.

Typically, faces are processed holistically, so that the facial information is processed as a gestalt (e.g., Maurer, Le Grand & Mondloch, 2002; Tanaka & Farah, 1993). One demonstration of such global processing strategy is the composite face effect (e.g., Young, Hellawell & Hay, 1987), in which participants are slower and less accurate in recognizing one half of a face when it is aligned with the other half of another face, compared to when the two halves are misaligned (i.e., the two halves are offset laterally). This manipulation is thought to disrupt the holistic face processing. In this composite face task, an optimal strategy would be to utilize a part-based processing method, in which the facial information is processed feature by feature. It has been demonstrated that the composite face effect becomes weaker, or even disappears when moving faces instead of static pictures are employed, both with rigid motion (Xiao et al., 2012) and elastic motion (Xiao et al., 2013). These results indicate that facial motion promoted a shift in processing strategies, from the holistic manner, to the part-based processing manner.

The facial motion effect is not limited to promote of a part-based processing strategy. Rather, it seems to increase the flexibility of face processing strategies according to the task requirements. Previous studies have shown that the processing of facial identity and facial expression might interfere with each other (e.g., Gallegos & Tranel, 2005; Lander & Metcalfe, 2007; Schweinberger & Soukup, 1998; Schweinberger, Burton & Kelly, 1999). However, when moving faces are employed, no such double interferences are found (Rigby et al., 2013; Stoesz & Jakobson, 2013).

Together, these data indicate that, when a moving face is presented, the flexibility of face processing strategies increases as a function of the task demands, leading to a more accurate recognition performance.

In sum, dynamic faces are processed differently from static faces. First, they lead to better recognition performances. Second, they increase the flexibility of face processing strategies. Third, they enhance neural activity and activate different brain-networks. Moreover, the naturalness of the motion characteristics plays a significant role in face processing. These effects are not merely due to additional pictorial information, and are more effective when the viewing conditions are non-optimal. All these data highlight the importance to study the role of the motion component in face processing and raise some doubts about the generalizability of the available findings coming from studies where static faces have been employed.

1.2 Facial motion on facial expression processing

A facial expression is a dynamic change in the facial features and in the facial configuration as a consequence of the underlying facial muscle activations. A facial expression is, therefore, intrinsically dynamic. It involves different types of changes: the shape of individual facial features (such as mouth and eyes); the facial configuration (i.e., the spatial relations among the facial features) and, finally, a particular type of facial motion when all these changes unfold over time (Leppänen & Nelson, 2006). To date, researchers have focused almost exclusively on the first two types of changes and facial expressions have been historically studied as static snapshots, frozen in time and typically modeled at the peak point, ignoring the fundamental component of the motion information. Such stereotypes of emotion, portrayed in a static way, are nonetheless sufficient to be recognized as, at least, the basic facial expressions (i.e., happiness, fear, sadness, anger, surprise and disgust), even across cultural boundaries (e.g., Ekman, Friesen & Wallace, 1971; Ekman, Friesen & Ellsworth, 1972). However, it is becoming increasingly evident that dynamic facial stimuli lead to a more ecological validity, more generalizable experimental data and a more comprehensive view of facial expressions processing.

Even though there are no explicit hypotheses regarding the role of facial motion on facial expressions recognition, several lines of evidences show that the processing of facial expressions from static pictures differs from the processing of facial expressions from moving displays (e.g., Ambadar, Schooler & Cohn, 2005; Bould & Morris, 2008; Bould, Morris & Wink, 2008; Ehrlich, Schiano & Sheridan, 2000; Fiorentini & Viviani, 2011; Kamachi et al., 2001; Kätsyri & Sams, 2008; Sato, Fujimura & Suzuki, 2008; Sato & Yoshikawa, 2007; Wallraven, Breidt, Cunningham & Bülthoff, 2008; Wehrle, Kaiser, Schmidt, & Scherer, 2000; Weyers Mühlberger, Hefele & Pauli, 2006; for a review, see Krumhuber et al., 2013). Moreover, the available data from facial expression recognition under dynamic conditions resemble some of the data obtained from identity recognition under dynamic conditions. Thus, despite the absence of explicit hypotheses, similar conclusions could be formulated.

Dynamic expressive behaviors strongly impact the perception of the underlying emotion, not only in terms of recognition accuracy, but also to what concerns the intensity and authenticity.

1.2.1 Emotion recognition

Research using motion displays, line drawings, schematic and computer-animated faces suggests that facial motion enhances the identification of specific emotional states (e.g, Ambadar et al., 2005; Bould & Morris, 2008; Ehrlich et al., 2000; Fiorentini & Viviani, 2011; Kamachi et al., 2001; Kätsyri & Sams, 2008; Wallraven et al., 2008; Wehrle et al., 2000).

Similarly to the findings in the recognition of facial identity (see previous sections), several studies have demonstrated a beneficial effect for emotion recognition, particularly when the viewing conditions are non-optimal, i.e., when static pictorial information is limited or difficult to access (e.g., Ehrlich et al., 2000; Fiorentini & Viviani, 2011; Kamachi et al., 2001; Kätsyri & Sams, 2008). For example, it has been shown that participants better identify a specific emotional state in dynamic displays compared to static displays only when the facial stimuli were modified as schematic or synthetic (i.e., computer-animated; Ehrlich et al., 2000; Kätsyri & Sams, 2008). Thus, when the pictorial facial information is available, facial motion information seems to be a less relevant cue for recognition, suggesting a compensating role played by dynamic facial information compared to the static information. Remind that data suggesting the supplemental role of dynamic cues support the supplemental information hypothesis.

Another brunch of studies that could support the supplemental information hypothesis in the field of emotional expression recognition are studies using experimental stimuli that convey only the motion information, hiding the pictorial facial information (e.g., point-light displays). These studies have demonstrated how the human perceptual system is endowed with a high sensitivity to motion information incorporated into emotional expression movements (e.g., Atkinson, Vuong & Smithson, 2012; Bassili, 1978, 1979; Doi, Kato, Hashimoto & Masataka, 2008; Pollick, Hill, Calder & Paterson, 2003). For example, it has been shown that adults are able to discriminate the six basic emotional expressions from point-light displays (e.g., Bassili, 1978, 1979). These results demonstrate how the facial motion component of facial expression alone could be used as cue for recognition.

Data that overlap studies supporting the representation enhancement hypothesis in face identity recognition are twofold: first, those proving that the facial motion beneficial effect on expression recognition is not merely a consequence of the extra static information contained in moving stimuli, in a similar way as shown with identity recognition tasks (e.g., Ambadar et al., 2005; Bould & Morris, 2008). For example, Ambadar and colleagues (2005), matching the quantity of static information by means of multiple static views presented without motion, showed that recognition of subtle facial expressions was better only when stimuli were depicted in a kinetic condition. These data support the idea that facial motion benefit is not attributable only to additional static cues. Interestingly, it seems that the motion benefit for dynamic as compared to multi-static presentations is reduced for intense expressions (Bould & Morris, 2008), suggesting that static displays of faces shown at the peak point of their intensity already contain diagnostic information to identify the conveyed emotion. In contrast, when the facial expression is depicted at lower degrees of intensity, facial motion might provide additional cues. Again, all these data indicate that, when static pictorial cues are present, individuals preferentially rely upon these cues to process facial expressions, suggesting a supplemental and secondary role of dynamic facial information in facial expression processing compared to the static facial information.

The second line of evidence supporting the representation enhancement hypothesis in face identity recognition shows that the naturalness of facial motion plays a fundamental role in the facial motion recognition benefit. For example, some researchers have investigated the possibility that facial motion benefit might stem from the fact that a dynamic facial expression enables perceivers to observe how an expression changes over time (Bould et al., 2008). In particular, a dynamic facial expression provides perceivers with the temporal unfolding, which shows the direction in which facial configurations change. Bould and collaborators (2008) demonstrated that recognition performance was greater with moving faces compared to the apparent facial motion created by the first and the final frame of an expression sequence. This result hints that the motion advantage might derive from the facial information embedded in the temporal unfolding of an expression.

Consistently, other evidence shows that different manipulations in the temporal unfolding of an emotional expression affects recognition performance (e.g., Wallraven et al., 2008; Hess & Kleck, 1994; Hill, Troje, & Johnston, 2005; Kamachi et al., 2001; Krumhuber & Manstead, 2009; Pollick et al., 2003; Sato & Yoshikawa, 2004; Weiss, Blum & Gleberman, 1987). For example, speeding up or slowing down the motion rate could impair or benefit recognition accuracy and velocity (e.g., Hill et al., 2005; Pollick et al., 2003; Sato & Yoshikawa, 2004). Several findings also reported that there are different variables related to the temporal characteristics of facial expressions (such as the speed of changes, the offset time, the apex and others) that differ among emotional categories and that have an impact on the capacity to discriminate between facial expressions modeled in a natural way (emotion-elicited), or in an artificial way (posed expressions; e.g., Hess & Kleck, 1994; Krumhuber & Manstead, 2009; Weiss et al., 1987). For example, spontaneous smiles could be discriminated from posed smiles on the basis of dynamic displays, but not static ones (Krumhuber & Manstead, 2009). All these findings suggest that motion characteristics, such as the direction and speed of motion, are important components of the dynamic facial information that could enhance or hinder the identification of the underlying emotion.

The speed rate at which a facial expression is depicted not only affects recognition performance, but also influences the naturalness judgment of the expression itself (e.g., Sato & Yoshikawa, 2004; Pollick et al., 2003). Moreover, the effect of temporal manipulations is specific to the particular emotion: for example, fear expression is identified more accurately and judged most natural at the slowest speed (e.g., Sato & Yoshikawa, 2004).

1.2.2 Other studies

Aside the beneficial effect in recognition performances, moving facial expressions have been shown to contribute to various aspects of emotion judgments.

For example, dynamic expressions are perceived as more intense, realistic and authentic than static expressions (e.g., Ambadar, Cohn & Reed, 2009; Biele & Grabowska, 2006; Cunningham & Wallraven, 2009; Krumhuber & Kappas, 2005; Weyers, Mühlberger, Hefele & Pauli, 2006).

Other studies have reported emotion-specific reactions to dynamic as opposed to static expressions (Sato et al., 2008; Sato & Yoshikawa, 2007; Weyers et al., 2006). These imitative responses, interpretable as facial mimicry, occur spontaneously and rapidly, stronger and more frequent compared to static expressions (e.g., Vinter, 1986). Facial mimicry is thought to play a fundamental role in facial expressions processing. For example, Niedenthal and colleagues (Niedenthal, Brauer, Halberstadt & Innes-Ker, 2001) have shown that impeding participants to imitate facial expressions implicates longer reactions to detect the point at which a facial expression changed to a categorically different emotion (e.g., happiness changing into sadness), by comparison with when they were allowed to mimic. Vice versa, authentic (i.e., spontaneous) versus posed happy expressions could be discriminated each other only when participants could freely mimic the expressions (Maringer, Krumhuber, Fischer, & Niedenthal, 2011). All these findings suggest that temporal dynamics convey unique information that is not available in static displays. Such temporal information not only is used for judging emotional expressions, but also drives behavior-specific responses in the perceiver (Kruhumber et al., 2013).

Another relevant brunch of studies regards the neuroimaging studies investigating the neural activation difference between the processing of dynamic and static facial expressions stimuli. Several studies have indeed shown different brain activity in regions associated with the processing of social-relevant information, such as the STS (i.e., superior temporal sulcus) and regions associated with the processing of emotion-relevant information, such as the amygdala (e.g., Arsalidou, Morris & Taylor, 2011; Foley, Rippon, Thai, Longe & Senior, 2012; Furl, Henson, Friston & Calder, 2014; Kessler et al., 2011; Kilts et al., 2003; Sato et al., 2004). For example, Kilts and colleagues (2003) carried out a PET study comparing dynamic and static face stimuli and found increased activation in the STS area in response to dynamic compared with static face stimuli, as well as a greater activation in the amygdala and the hippocampus. In a fMRI study, Sato and collaborators (2004) demonstrated increased activation in different brain areas, among which the inferior occipital gyrus (IOG) and STS, to dynamic happy and fearful facial expressions compared with static and dynamic scrambled faces controls. Interestingly, Foley and collaborators (2012) have recently found that, whereas the STS seems to be specifically sensitive to the facial motion information regardless the emotion conveyed (a result in line with other studies supporting a central role of STS in biological motion processing in general; e.g., Grossman, 2013), the amygdala seems more sensitive to the facial affect, independently from the motion information (a result in line with previous studies showing a significant role of amygdala in emotional expressions processing; e.g., Morris et al., 1998). All these results not only indicate that different brain regions are involved in the facial expressions processing, but also and importantly, that static and dynamic facial cues are processed by different underlying brain areas.

In sum, dynamic emotional facial displays are processed differently from static snapshots of facial expressions. First, they lead to better recognition performances, in which the conveyed emotion is identified more accurately. Second, they enhance emotional judgments in terms of intensity, authenticity and naturalness. Third, they enhance brain activity and activate a spreader brain-network. Moreover, the temporal characteristics of the motion speed have shown to play a significant role in facial expressions' processing. These effects are not merely due to additional pictorial information, and are more effective then the viewing conditions are non-optimal. All these data further highlight the necessity to consider the motion component of facial expressions and raise some doubts about the generalizability of the available findings coming from studies employing static facial experimental stimuli.

To conclude, there are overlapping points in the evidence concerning the recognition of both facial identity and facial expressions under dynamic conditions. The main idea is that dynamic facial motion might be a cue for recognition per se. On one side, dynamic facial motion adds additional information and, on the other side, it enhances the recognition of the socially relevant aspects embedded in the face. Overall, the reported lines of evidence support the idea that, in order to recognize a face and a facial expression, both static and dynamic cues could be used. As said, the most intriguing idea of the supplemental information hypothesis is the suggestion not only that the dynamic facial information can be directly processed, but also that such information alone could convey identity-specific and emotion-specific information. This idea represents a fundamental difference from the classic assumptions that 1) the identity of faces is encoded only via feature sets that capture the invariant structure and configuration of a face, and 2) the facial expression is encoded only via features sets that capture the changeable facial aspects (Roark et al., 2003; Xiao et al., 2014). Even though there is no direct evidence that the visual system retains memory traces of moving faces, the reported evidence strongly supports this idea, hinting the hypothesis that the visual representation of faces may be also inherently dynamic. Based on the reported studies, some authors have proposed that the dynamic facial information 1) might require more time and experience and 2) is nonetheless less reliable for the identity and expression recognition, compared to the static facial information (Bassili, 1978, 1979; Roark et al., 2003; Xiao et al., 2014).

The idea that the dynamic aspect of facial information is stored independently of static facial information is also supported by some neurological disorders cases showing that deficits in static facial information processing are not linked to impairments in facial movement processing. Some prosopagnosic cases have been reported, in which the ability to use static facial cues for face recognition was impaired, whereas the ability to use facial motion cues to identify faces was maintained (Longmore & Tree, 2013; Steede, Tree & Hole, 2007). Comparable benefits have been found in facial expression recognition, in which some brain damages patients were better in attributing the right emotion category label only if presented with moving displays and not if presented with static pictures of facial expressions (e.g., Back, Ropar & Mitchell, 2007; Harwood, Hall & Shinkfield, 1999; Humphreys, Donnelly, & Riddoch, 1993). These results support the idea that different neural pathways underlie the processing of moving and static facial stimuli that could lead to a dissociation between static and dynamic aspects of facial information processing.

1.3 Neural systems frameworks for processing moving faces

A general framework in the study of face identity and facial expression processing was first provided by the pioneering model of Bruce and Young, in 1986, based mainly on behavioral findings. The main idea underlying this model of face recognition is that, after an initial stage of structural encoding, the identity and expression are processed independently from each other. This independency is proved, for example, by some cases of prosopagnosic patients, who corroborated this functional independency by showing a recognition of facial expressions together with an inability to recognize familiar faces (e.g., Humphreys et al., 1993).

Haxby, Hoffman, and Gobbini (2000, 2002) successively updated this model, providing also the neurological bases of face perception (Figure 1.4). Alike the preceding model, Haxby and collaborators conceived distinct pathways for the visual analysis of identity and expression information. Their “distributed neural system for face perception” considers two reciprocally linked main systems: the core system, which represents the visual analysis of both the invariant and changeable aspects of faces, and the extended system, which incorporates additional brain regions to further support face processing, such as emotion recognition.

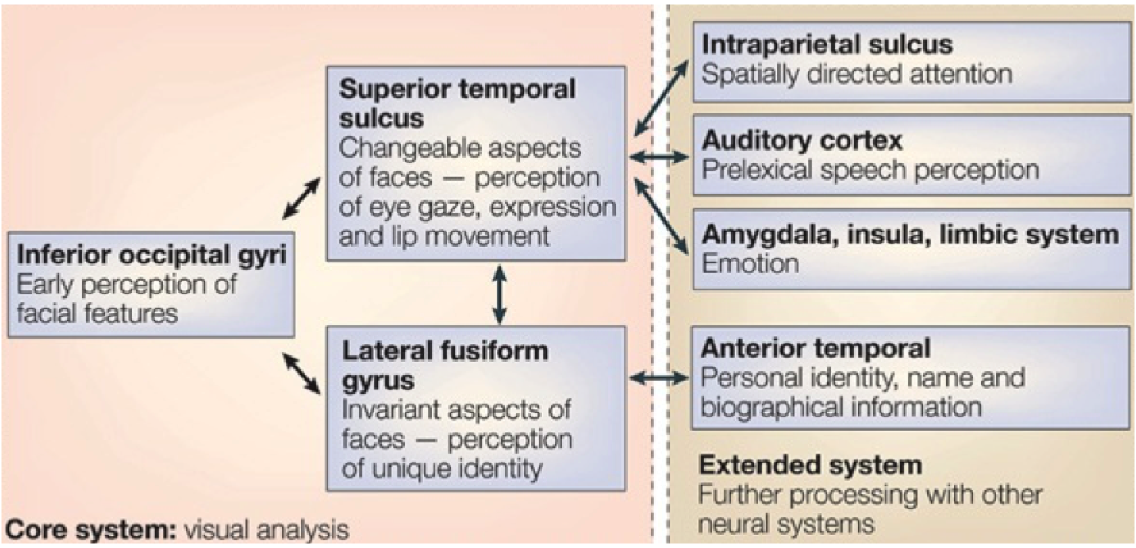


Figure 1.4. The distributed neural system of face perception (Haxby et al., 2000, 2002).

In this model, the perception of the identity (that is, the invariant aspect of a face) occurs via the lateral fusiform gyrus (including the fusiform face area, FFA; Kanwisher, McDermott, & Chun, 1997), to the anterior temporal regions that are involved in the recalling of the personal biographical information. The perception of the changeable aspects of faces (that is, expressions, eye gaze and speech) is mediated by the superior temporal sulcus (STS) and proceeds to other brain regions, such as the auditory cortex (for lip reading), parietal areas (i.e., for spatial attention to changeable features), and the amygdala (AMG, for emotions).

In another model, Adolphs (2002) focused on the perception of facial expressions in particular, extending the model of Haxby et al. (2000, 2002) by adding a temporal dimension (Figure 1.5). This model shows how perceiving and recognizing facial expressions involves an aggregate of different and partially independent neural structures. Specifically, an early processing of the facial expression is achieved by the AMG and other areas, which automatically and coarsely encode the perceptual structures of the salient emotional stimuli (equivalent to the core system of Haxby's model, 2000). Facial expression processing proceeds then with a pathway in which a more detailed perceptual analysis is conducted, necessary to make fine discriminations between facial expressions. Successively, other emotion recognition modules (equivalent to the extended system of the distributed model), comprising the FFA, again the AMG and the orbitofrontal cortex (OFC), enter in the running.

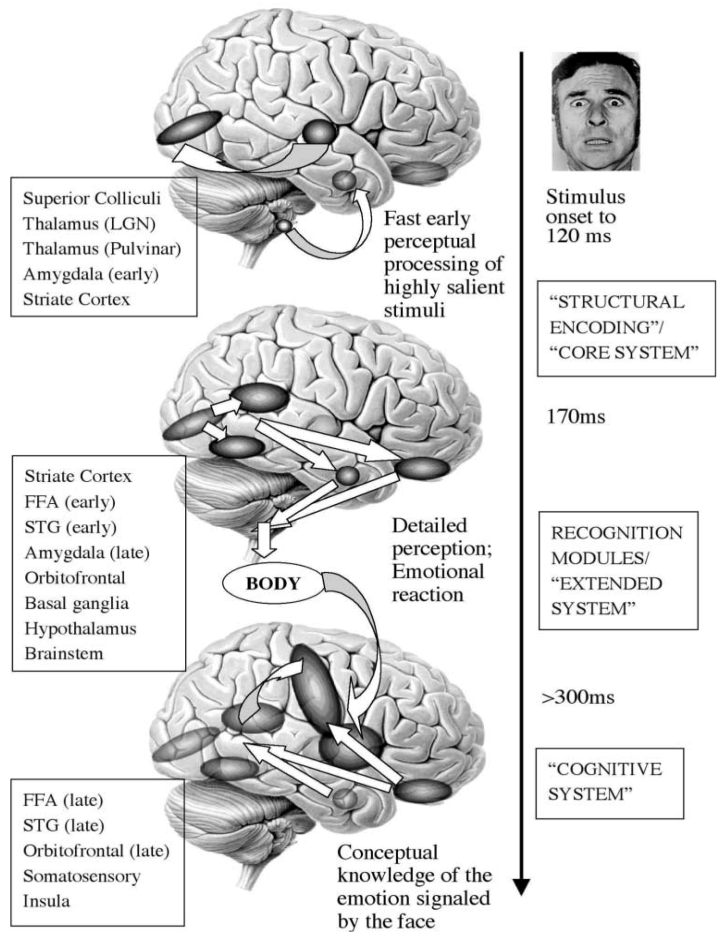


Figure 1.5. The perception of facial expressions as a function of time (Adolphs, 2002).

More recently, other face processing models have tried to fit the available data on recognition of moving faces with the distributed face processing model of Haxby (2000), considering that facial motion can be processed as a separate visual cue that conveys socially relevant information, and that the representation of face stored in memory might be inherently dynamic, at least in part (O'Toole & Roark, 2010; O'Toole et al., 2002; Roark et al., 2003; Xiao et al., 2014). In brief, according to Haxby's model, the FFA system is responsible for the invariant, high-resolution analysis of facial features from the ventral stream input, and the STS is responsible for the facial motion analysis from the dorsal stream input. Based on the findings supporting from identity and facial expressions' recognition under dynamic conditions, some speculative modifications were proposed to the distributed model of face perception.

The first one comes from the facts that facial motion cues could be directly encoded and could convey emotion-specific and identity-specific information. Thus, it has been hypothesized that the STS system may act as a supplementary system (in addition to the IT system) for face recognition, based on solely facial motion information (see Figure 1.6; O'Toole et al., 2002; Roark et al., 2003). Thus, the model suggested that the STS stream has the additional role to recognize a face via the processing of motion cues. This idea stems from the supplemental information hypothesis.

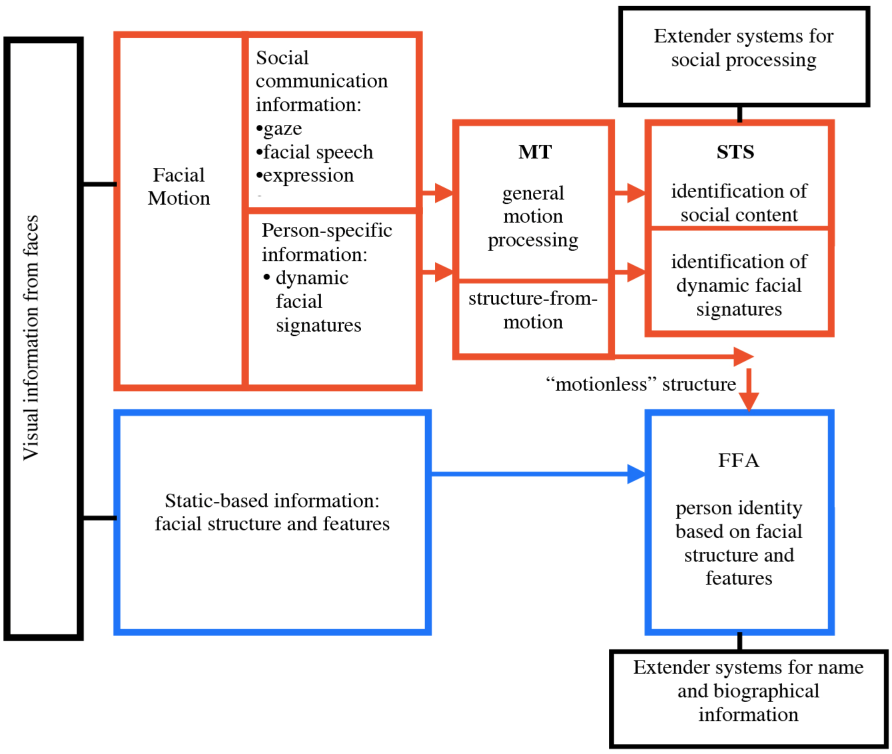


Figure 1.6. Based on Haxby et al., model (2000, 2002), an updated face processing model that accounts for the psychological findings regarding the effects of facial motion on face processing (O'Toole et al., 2002; Roark et al., 2003).

The second modification of Haxby's model (2000) stems from the representation enhancement hypothesis, according to which motion cues are used to extract a more accurate representation of the invariant structure of a face. It has been proposed a structure-from-motion analysis in MT (medial-temporal cortex) that projects to IT as static form information (named “motionless structure”, see Figure 1.6). In this way, facial motion could bootstrap the encoding of static (motionless) facial information, improving the perceptual quality of the static-related facial representation (O’Toole & Roark, 2010; O’Toole et al., 2002; Roark et al., 2003).

Chapter 2

Face in motion: infants' studies

In the previous half century and particularly in the last two decades, a great and relevant knowledge about the development of face processing in infancy has emerged (for reviews, see Hoehl & Peykarjou, 2012; Anzures, Quinn, Pascalis, Slater & Lee, 2013; Simion & Di Giorgio, 2015).

Shortly after birth, newborns demonstrate to prefer to look longer at faces and face-like stimuli as opposed to other objects equated for visual complexity (Goren, Sarty & Wu, 1975; Johnson & Morton, 1991; Johnson, Dziurawiec, Ellis & Morton, 1991; Macchi Cassia, Turati & Simion, 2004; Mondloch et al., 1999; Valenza, Simion, Macchi-Cassia & Umiltà, 1996). Few-hours-old infants also show to prefer their mother's face to a unfamiliar female face (Bushnell, 2001; Bushnell, Sai, & Mullin, 1989; Field, Cohen, Garcia, & Greenberg, 1984; Pascalis & de Schonen, 1994). Moreover, newborns can learn about the identity of an unfamiliar face to which they are repeatedly exposed, recognizing it as familiar when compared to a new unfamiliar face, although under certain visual conditions (e.g., when the images to recognize do not excessively differ from each other; de Heering et al., 2008; Gava, Valenza, Turati & de Schonen, 2008; Pascalis, de Schonen, Morton, Deruelle & Fabre-Grenet, 1995; Turati, Macchi-Cassia, Simion & Leo, 2006; Turati, Bulf & Simion, 2008). Newborns' face processing system, initially broadly tuned and flexible, rapidly develops in the following months, and, particularly starting from 3 months of life, face processing abilities become increasingly specialized and adult-like form. For example, at 3 months of age infants, but not 1-month-olds, are able to form a prototypical representation of faces (de Haan, Johnson, Maurer & Perrett, 2001). Between 3 and 10 months of age, infants evolve their face processing strategies from a more part-based way (i.e., processing the facial features independently) to a more global, holistic way (i.e., integrating the facial features; Cashon & Cohen, 2004; Cohen & Cashon, 2001; Schwarzer, Zauner & Jovanovic, 2007). Moreover, between 3 and 9 months of age, the ability to recognize faces refines and narrows according to the face typology infants are mostly exposed to, leading to phenomena such as the *other-race effect* (ORE; e.g., Kelly et al., 2005, 2007) and the *other-species effect* (OSE; e.g., Pascalis, de Haan & Nelson, 2002; Pascalis et al., 2005).

Despite the impressive amount of studies on the detection, discrimination and recognition of faces in the first year of life, few studies have employed moving facial stimuli. However, infants' face experience mostly occurs from face to face interactions in real-life situations, where faces are definitely moving. In particular, they style of infant-caregivers' interactions is characterized by exaggerated, repeated and slowed facial behaviors, in which the particularly salient facial movements maintain and engage infants' attention (e.g., Papousek & Papousek, 1989; Stern, 1974; Werker & McLeod, 1989). Moreover, it has been demonstrated that facial motion affects adult's face processing particularly when the pictorial information is unavailable or difficult to access (see previous sections). Given that such non-optimal viewing conditions may be comparable to the immature visual system in the first months of life, it is likely that infants might rely on facial motion cues even more than adults do, in that motion may help to sustain the visual analysis of the environment in young infants (Roark et al., 2003). After these considerations, one may wonder to what extent the available findings obtained with static faces could be generalized.

It is quite evident that motion plays a key role in infants' ability to process general visual inputs (e.g., Gibson & Pick, 2000). Given that the visual system evolves under dynamic visual conditions, it seems reasonable to assume that human beings are highly attuned to motion signals from the very early on. Already J. J. Gibson, a half century ago, proposed the hypothesis that the temporal transformations in the visual moving configurations provide richer information in the projection on the retina compared to single static images, making therefore infants' discrimination of multimodal stimuli easier and more meaningful (Gibson, 1966). Accordingly, starting from the first days of life, infants show a sensitivity for the dynamic information: for example, newborns prefer to look at a moving stimulus compared to a stationary one (Slater, Morison, Town, & Rose,

1985) and can perceive an occluded object only if presented in motion (Valenza & Bulf, 2007; Valenza, Leo, Gava & Simion, 2006).

In the next paragraphs, I will first report some infants' studies employing moving facial stimuli that demonstrate infants' sensitivity to the facial motion information in general. These studies differ for the facial movement employed (i.e., rigid and/or elastic), for the investigated age, for the aims of the study, as well as for the method. This may explain, at least in part, the mixed obtained results and the difficulty to make clear conclusions.

Even though there are no explicit hypotheses regarding the effect of motion on infants face processing, with the exception of the *heightened internal features hypothesis* posited by Roark and collaborators (2003), which will be examined more in depth in the next paragraphs, I will nevertheless report some evidences showing that facial motion could affect infants' face processing in manners that are in some ways similar to those discussed in the adults' sections and, in particular, data consistent with both the representation enhancement hypothesis and the supplemental information hypothesis in the context of face identity recognition.

Finally, the few existing studies regarding the role of facial motion in facial expression recognition in infants will be reported.

2.1 Role of facial motion in infants' face recognition

Evidence of an early sensitivity to facial motion has been shown since the first weeks of life. The imitation of different facial movements (e.g., Meltzoff & Moore, 1977), for example, could be taken as a marker of newborns' attention to moving faces. Newborns show differential tracking of moving face (and face-like) stimuli compared to other equally complex stimuli (Goren et al., 1975; Johnson et al., 1991). One-month-old infants prefer moving to static faces (Sherrod, 1979) and, starting from 2 months of life, infants engage more likely and in a more structured way when faces are animated compared to when they are static, such as in the Still Face paradigm (e.g., Cohn &

Tronick, 1983). Three- and 4-month-old infants prefer the upright over the inverted Mooney Face stimuli (i.e., two-toned face-like images, usually employed to examine the holistic face processing; Mooney, 1957), only when stimuli were presented in motion (rotating), but not when presented statically (Otsuka, Hill, Kanazawa, Yamaguchi & Spehar, 2012). Similarly, Johnson, Dziurawiec, Bartrip, and Morton (1992) found that 5-month-old infants show spontaneous preferences for schematic versus scrambled faces only when the internal features were moving. In addition, Hunnius and Geuze (2004) compared 6- to 26-week-old infants' eye movement patterns with two different moving stimuli: a video of their mothers (talking) and a video of the same moving face, only scrambled. They found differences between the two stimuli in several parameters (for example, average looking durations and fixation distributions) emerging in 10- and 14-week-old infants. Finally, 3-month-olds show different recognition performances according to the facial movement depicted by the model: a happy facial expression leads to better recognition compared to neutral facial motion (Turati, Montirosso, Brenna, Ferrara & Borgatti, 2011) and to negative facial expressions (Brenna, Proietti, Montirosso & Turati, 2013), as it happens with adults (e.g., Lander & Metcalfe, 2007). All these studies indicate that young infants are sensitive to the motion information embedded in faces from very early on.

A more direct evidence of the role of facial motion in face processing comes from studies demonstrating a differential response to moving than static faces. For example, few-day-old babies show different recognition performances when familiarized to a static, or a dynamic face (Coulon, Guellaï & Streri, 2011; Guellaï, Coulon & Streri, 2011). In particular, they show a novelty preference when habituated to a static face, and familiarity preference when habituated to a talking face. This difference in newborns' response is likely be related to different levels of face representations: in newborns' studies, the familiarity preference is taken as an evidence of a partial recognition, likely caused by a partially formed face representation (e.g., Cohen, 2004). I will come back on this specific issue in the first chapter of the present dissertation. Note that, in these studies, facial motion is related to a worse recognition performance compared to static face condition. This might be due to the fact that facial stimuli were presented in audio-visual conditions, i.e., when also the person's voice was audible: especially at birth, multimodal stimulation could lead to different stimulus' processing compared to the unimodal, visual stimulation (for a discussion, see Bahrick, Lickliter, & Castellanos, 2012). For example, Sai (2005) reported that when newborns are prevented from hearing their mother's voice, the preference for the mother's face disappears. Nonetheless, these studies demonstrate not only that moving faces are processed differently from static faces, but also that processing static or dynamic faces leads to construction of a different face representation.

In some self-recognition studies, 5-month-old infants show the ability to discriminate a display of an other peer over the self-display, only when the displays were presented in motion and not if presented statically, whereas 8-month-old achieve the task also in the static condition (Bahrick & Moss, 1996; Legerstee, Anderson & Schaffer, 1998). In another set of experiments, however, it has been shown that motion information might interfere with face recognition in infants of the same age (Bahrick & Newell, 2008; Bahrick, Gogate & Ruiz, 2002). Specifically, 5-month-olds were impaired in face recognition when familiarized to videos in which actress performed actions involving face and hand motions (such as brushing teeth and brushing hair). Interestingly, they showed recognition for the action. By contrast, when they were familiarized to a static snapshot of the same video, face recognition performance was achieved (Bahrick & Newell, 2008; Bahrick et al., 2002). These studies suggest that the effect of facial motion on infants' face processing might stem from an attention-based mechanism, in which motion cues drive infants' attention, which, in turn, affects (enhancing or inhibiting) the acquisition of information from faces. This idea is on the basis of the heightened internal feature hypothesis (Roark et al., 2003).

2.1.1 The heightened internal feature hypothesis

According to this hypothesis, the extent to which a particular facial motion benefits infants' face recognition may be a function of the focus of attention. In particular, it has been proposed that the elastic movements of the internal facial features (during speech, eye gaze shifting and facial expressions) increase le likelihood that attention will be focused on the inner portion of face, thereby providing infants with more quality views of the face configuration (Roark et al., 2003) and overcoming very young infants' tendency to focus in the outer face contours (e.g., Hainline, 1978; Haith, Bergman & Moore, 1977; Turati et al., 2006). Thus, elastic facial movements might enhance face processing by drawing infants' attention away from the external face edges and towards the inner face part. For example and Haith collaborators (1977), showed that 2- and 3-month-old infants focus more on the eyes when face are talking, compared to when they pose a rigid head motion, or when they are static. Consistently, it has been suggested that animated faces lead infants to switch from encoding strategies mainly based on external contours, to different strategies based on a more global scanning style (Sherrod, 1981).

One recent study supports the idea that facial motion leads infants to adopt different face processing strategies compared to those adopted with static faces (Xiao et al., 2015). Specifically, in this experiment, 3-, 6- and 9-month-old infants were familiarized to a chewing and blinking face, or to a static snapshot of the same face. The eye movement patterns were recorded. Different eye movement patterns (i.e., accumulative looking time in the eyes, nose and mouth areas, as well as fixation shifts between these areas) were found for static versus dynamic condition. In particular, 9 month olds showed longer looking at the mouth area and less at the eye area, as well as more frequent fixation shifts, in the dynamic condition relative to the static condition. Moreover, from 6 months onward, a positive correlation between number of fixation shifts and recognition performance was found: the more frequent shifts, the better recognition performance. Importantly, such significant correlation has emerged only in the dynamic condition. These findings not only prove a distinctive eye movement pattern for moving faces compared to static faces, but also that this pattern modulates face recognition ability, enhancing or inhibiting it. These data are in line with the previous reported adult studies (Xiao et al., 2012, 2013) and suggest that the facial motion effect derives from an attention-based mechanism, as posited by the heightened featural hypothesis, in terms of an impact on the encoding strategies that infants adopt during the processing of moving faces, compared to those adopted during the processing of static faces.

Other studies have attempted to investigate the role of motion cues in infants face processing. Though often not explicitly, these studies either support the supplemental information hypothesis, or the representation enhancement hypothesis.

2.1.2 The supplemental information hypothesis: infants' studies

Recall that the supplemental information hypothesis posits that adults can process both the invariant facial structure from pictorial cues, and the identity-specific (and, as shown, also emotion-specific) information from motion cues (e.g., Roark et al., 2003). Thus, facial motion information can be processed separately from the static facial information, as well as the pictorial static facial information can be processed separately from the dynamic facial information. In the available adults' literature, evidences supporting this hypothesis are twofold: first, that facial motion alone could convey identity and emotion information (e.g., Bassili, 1978; Hill & Johnston, 2001); second, that facial movements particularly enhance identity and facial expression recognition under non-optimal viewing conditions (e.g., Ehrlich et al., 2000; Knight & Johnston, 1997).

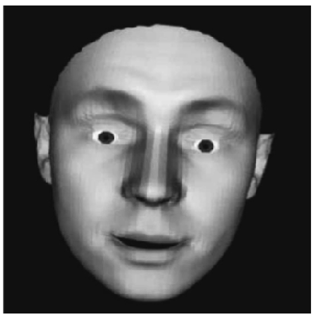


Figure 2.1. 3D face avatar (Spencer et al., 2006).

As for the first line of evidence, Spencer and collaborators (2006) demonstrated infants' ability to use facial motion cues as a source of information to recognize identity. By means of 3D animated computer-averaged faces (that is facial stimuli in which the face shape remains constant, varying only for motion patterns, see Figure 2.1), they familiarized 4- to 8-month-old infants to the facial motion pattern of one actor telling a joke. Then infants were presented with two face avatars both telling the same, new joke:

one avatar displayed the facial motion of the familiarized actor, the other one displayed the facial motion of a new actor. The rationale behind this design is that, if infants are able to perceive the generic invariants of an individual's identity from motion cues only, they will recognize the facial motion of the familiar actor, despite the fact that a different facial motion pattern is displayed (i.e., a different joke not displayed during familiarization) and will direct their attention toward the facial motion of the new actor. The results revealed a significant preference for the new actor's facial movements, clearly demonstrating that infants as young as 4 months of age can use dynamic facial identity signature motions to differentiate individuals. This study provides direct evidence for infants' use of facial motion in a way that in consistent with the supplemental information hypothesis.

As for the role of facial motion in the recognition of the identity in non-optimal viewing conditions, Layton and Rochat (2007) have provided supporting data. In particular, they investigated whether 4- and 8-month-old infants' recognition of their own mother's face could benefit of motion information when the pictorial facial cues are difficult to access. The faces were shown either static or dynamic (talking face), in a normal positive contrast (normal viewing condition) or in a negative contrast presentation (non-optimal viewing condition; see Figure 2.2). As predictable, in normal viewing condition, 4- and 8-month-old infants recognized their own mothers in both static and dynamic conditions. However, when faces were presented in negative contrast, 8-month-olds, but not 4-month-olds, could benefit of motion information to recognize their mothers' face. In contrast, they did not manifest a recognition ability

Figure 2.2. Example of stimuli employed in Layton and Rochat's study (2007). On the left, the normal viewing condition, on the right, the non-optimal viewing condition.

when faces were presented statically. These results demonstrate that, like in adults, motion information contributes to the discrimination of faces in non-optimal viewing conditions, compensating the unavailability of the facial pictorial cues. The authors speculated that the information embedded in facial motion requires some representational template of the invariant ways in which a person's face moves.

These are the only two studies that directly support the supplemental information hypothesis in infants. Other two studies endorse this hypothesis, even if more indirectly, since they both demonstrate how facial motion information alone can be processed by infants. In the first one, Stucki and collaborators (1987) presented 3-month-old infants with a point-light display (PLD) either of a face pretending to interact with a baby, or of a rubber mask animated by a hand, both in an upright and inverted condition. Results showed that infants as young as 3 months can distinguish facial motion from the mask motion on the basis of kinetic information alone. Moreover, when the stimuli are shown in their canonical orientation, the discrimination performance was much better compared to the inverted orientation, indicating that infants organized movement patterns in a face-like coherent structure. Similar results were reported in the second study: by using near-infrared spectroscopy (NIRS) with 7- to 8-month-old-infants, Ichikawa and collaborators (2010) demonstrated that a facial point-light display depicting a surprised facial expression induces different brain responses in the right temporal brain area for upright, but not for inverted PLD. Since the right hemisphere is reported to be involved in face processing by other NIRS infants' studies (e.g., Otsuka et al., 2007), these results suggest that babies were processing the PLD stimuli in a face-related manner. This study demonstrates that infants' brain activity is sensitive to a facial expression motion pattern conveyed by a PLD stimulus, as well as to its orientation.

Combined, these findings prove 1) the ability of infants to process the pure facial motion signals, even when other pictorial facial cues are absent; 2) the ability of infants to specify an individual's identity based only on the facial motion characteristics; 3) that facial motion cues can help the processing of the facial structure, supporting the ability to recognize a face, when the pictorial cues are difficult to access. Thus, it seems that, even in the first year of life, facial movements have an impact on face processing abilities in a manner consistent with the supplemental information hypothesis. It remains to analyze the effect of facial motion on infants' face processing in the light of the representation enhancement hypothesis.

2.1.3 The representation enhancement hypothesis: infants' studies

According to this hypothesis, facial motion information helps to encode the invariant structure of the face. Two lines of evidences support this idea: first, studies demonstrating how both identity and facial expression learned in motion are better recognized than those learned from multiple static face images (e.g., Ambadar et al., 2005; Pike et al., 1997). Second, studies showing how recognition performance is affected by the naturalness of the facial movements (e.g., Lander et al., 1999; Pollick et al., 2003). Thus, the representation of face stored in memory seems to be inherently dynamic, at least in part.

As for the first line of evidences, Otsuka and colleagues (2009) compared 3- to 4-month-old infants' recognition of faces learned from 30 seconds of either moving displays (happy face), or static displays (a snapshot of the same video). Infants had to recognize the familiarized face with a changed expression, i.e., neutral. Results showed that infants recognized the familiarized face only in the dynamic condition, and not in the static one. They showed successfully recognition only when the duration of the familiarization time was extended from 30 s to 90 s. This suggests that motion promotes infants' learning of face, since infants learn faster in the moving condition than in the static one. Importantly, such better performance was not merely explained by the presentation of a greater number of static information contained in the moving display, compared to the image display. Specifically, even when presented with the same number of static images as in the moving condition, infants did not show any recognition ability.

Similar results have been obtained with newborn babies (Bulf & Turati, 2010). In particular, few-day-old infants were able to recognize a face in its profile pose only if they had been previously familiarized with the same face undergoing a head rigid rotation (from one viewpoint to another, see Figure 2.3, Exp. 1). In contrast, they failed to discriminate the new and the familiar faces when familiarized to the same frames of the moving condition, but presented statically (Figure 2.3, Exp. 2).

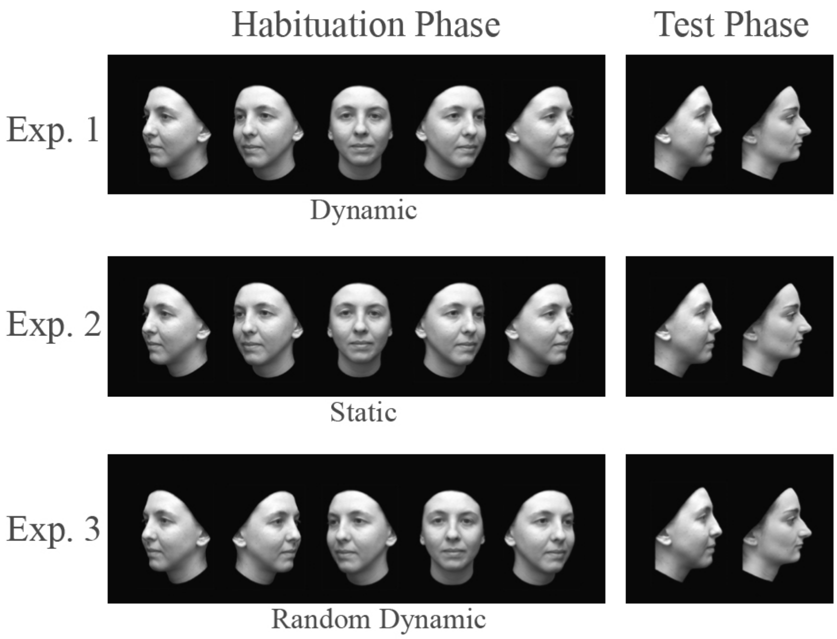


Figure 2.3. The three experiments in Bulf and Turati's study (2010) investigating the role of rigid head motion in newborns' face recognition.

This study suggests that the rigid head motion leads to a face representation that is more resilient to the depth head rotation than the face representation constructed from multiple, static face poses.

These data together demonstrate that infants' face recognition is better when faces are learned in dynamic than in static conditions. Importantly, they also prove that this better performance in the moving condition is due to the presence of motion per se, rather than to a mere difference in the static information.

In their third experiment, Bulf and Turati have also investigated whether, habituating newborns with the same different face poses showed in a random sequence instead of in a correct rotational motion (see Figure 2.3, Exp. 3), lead to the same results. Results revealed that the random head rigid motion leads to a familiarity preference instead of the classic novelty preference typically showed when recognition performance is successful. As previously mentioned, the familiarity preference is taken as an evidence of a partial recognition, caused by a partially formed face representation (e.g., Cohen, 2004; Hunter & Ames, 1988). What is relevant here is that the random motion was not effective as the ordered motion in allowing face recognition at birth. This result is in line with adults' studies (e.g., Pike et al., 1997) and indicates that the characteristics of the facial motion pattern is a fundamental aspect of the facial motion effect on face processing, even in infants. This agrees with the second line of evidence supporting the representation enhancement hypothesis, i.e., those providing evidence of a sensitivity to some characteristics of the natural facial motion.

The second study supporting this hypothesis comes from Ichikawa and collaborators (2011), who investigated 5- to 6- and 7- to 8-month-old infants' preference for abstract, biologically possible over biologically impossible, facial movements. The abstract faces consisted in a head-shaped line containing three back circles placed to represent the eyes and the mouth. In the biologically possible movement condition, the black circles moved vertically, emulating the eye blinking and mouth closing. In the biologically impossible movement condition, the same movement was shown, but in a horizontal direction (see Figure 2.4). Results showed that 7- to 8-month-olds, but not 5- to 6-month olds, significantly prefer the biologically possible over the

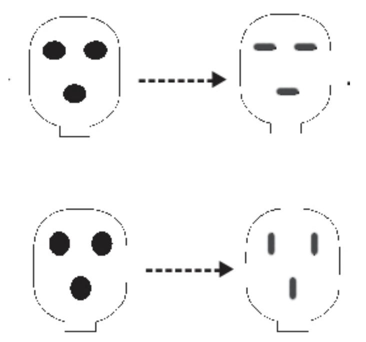


Figure 2.4. Stimuli employed in Ichikawa's et al.'s study. On the top, the impossible movement, on the bottom, the possible one.

impossible movement. Since the possible and impossible movements were identical in terms of motion characteristics, except for the vertical/horizontal direction, the authors speculated that this task required infants to associate the abstract face movement patterns with a facial movement representation stored in memory.

Another study reported an earlier sensitivity for naturally versus artificially moving patterns (Xiao et al., 2014). The authors investigated, in 3- to 5- and 6- to 9-month-old infants, the left visual field (LFV) bias, i.e., a tendency of individuals to asymmetrically process a face in which longer looking time are dedicated to the left side of the face compared to the right side (for the observer's point of view). This bias is commonly linked to the right hemispheric lateralization of face processing (e.g., Gilbert & Bakan, 1973). Two different stimuli were used: the naturally and the artificially moving faces. The natural movement represented a face counting, whereas the artificial movement represented the same stimulus, but mirrored (i.e., the natural video horizontally flipped). Results showed face-specific eye movement pattern only in the naturally moving and not artificially moving faces. Specifically, younger infants showed LVF bias in the lower face half and oldest infants showed LVF bias in the entire face half, but only when presented with the naturally moving face and not with the artificial moving face. The earlier sensitivity to the movements' naturalness found in this study compared to that found in Ichikawa's study (2001) might be due to the fact that, in the latter study, facial stimuli were abstract face-like shapes. Therefore, it is likely that the employment of more ecological faces let Xiao and colleagues to provide this sensitivity at an earlier age.

These studies demonstrate that the sensitivity specific to some characteristic of facial motion (sequence order, possible versus impossible, naturalness) develops already within the first months of age, suggesting the existence in very young infants of a facial representation that is inherently dynamic.

Overall, these findings suggest a role for motion in infants' face processing in a way consistent with the representation enhancement hypothesis. They indeed indicate that 1) face learned in motion are better recognized that face learned from the same pictorial information showed statically; 2) there is an early sensitivity to certain characteristics of the natural facial motion; 3) facial motion impacts the construction of the face representation, by enhancing the encoding of the facial structure, useful for recognition.

2.2 Role of facial motion in infants' recognition of facial expressions

Several adult studies suggest that dynamic facial expressions are processed differently from static stimuli (e.g., Krumhuber et al., 2013). Given the crucial role of facial motion in face processing, it is reasonable to assume that moving facial expressions are processed in a different way than facial expressions depicted in a static picture. Despite these considerations, a surprisingly limited number of studies have addressed how infants process dynamic facial expressions.

Most of the existing infants studies have utilized moving faces in intermodal preference tasks, in which faces and voices are presented simultaneously to investigate infants' ability to match the sound with the congruent visual stimulus in visual-auditory conditions (e.g., Caron, Caron, & MacLean, 1988; Soken & Pick, 1992; Walker-Andrews, 1986; for a review, see Walker-Andrews, 1997). For example, Caron and collaborators (1988) tested 5- and 7-month-old infants in an intermodal preference procedure: babies were shown with two simultaneous videos of happy and angry face and heard a single vocalization characteristic of one of the facial expressions. Infants looked longer at the facial motion affectively congruent to the auditory stimuli, than at the incongruent one. Soken and Pick (1992) reported similar results with point-light displays stimuli, where only the facial motion information is available. These results show that, in visual-auditory conditions, infants are able to match an angry or happy audio-expression with the coherent facial animation. More generally, they also prove that infants are sensitive to the dynamic cues inherent in facial expressions.

There are very few studies investigating the ability to process dynamic facial expressions in visual conditions only. Biringer (1987) tested 3-month-olds' preference for facial expressions in three conditions: static, elastic motion and head rigid motion conditions. Infants discriminated facial expressions both in the static and the elastic motion conditions, but not in the head motion condition. This finding suggests that rigid head and non-rigid (elastic) motions may have different impact on infant face processing. Rigid motion promotes the perception of the 3D structure of the face by means of a structure-from-motion analysis, whereas the movement of the internal portion of the face mostly supports the social interactions (Roark et al., 2003). Another recent study reported that the apparent motion of a facial expression (i.e., two frames shown in sequence creating the illusion of a facial movement) facilitates the discrimination of a subtle happy expression in 6- to 7-month-old infants, but not in 4- to 5-month old infants (Ichikawa, Kanazawa & Yamaguchi, 2014). This finding, however, was not replicated when the angry expression was showed (Ichikawa & Yamaguchi, 2014). Such "happy specificity" for moving faces is in line with other findings showing how happy facial expressions, but not negative ones, facilitate face recognition in 3-month-old infants (Brenna et al., 2013), as well as in adults (e.g., Lander & Metcalfe, 2007). I will further examine in depth this specific aspect of infants' processing of facial expressions in the third chapter of the current dissertation.

Overall, these data suggest that motion information might affect infants' encoding strategies of facial expression, leading to different recognition performances compared to those obtained with static pictures of emotions, as it happens with adults (e.g., Ambadar et al., 2005).

2.3 Aims of this work

To summarize, it seems that facial motion affects infants' face processing in ways that are similar to those reported in adults. Infants are sensitive to the facial motion component from the first days of life. Facial movements drive infants' processing strategies, supporting the processing of the facial invariant structure and, in turn, the construction of a more reliable face representation, useful for recognition. Moreover, infants are able to process the facial motion information alone, when other pictorial cues are not available. Infants are also capable to process socially relevant information from facial motion cues only, such as the identity. More studies are needed to analyze in depth the role of motion cues in infants' processing of facial expressions. It seems reasonable to predict that facial motion might affect infants' processing of facial expressions in similar ways as it affects identity recognition: for example, by enhancing the recognition of facial expressions.

The current work is aimed at investigating the role of motion in both identity and expressions recognition in early infancy.

The first study will investigate the role of the elastic facial motion in newborns' face recognition. Previous studies have demonstrated that newborns have difficulties in recognizing a face to which they have been habituated if it changes for some characteristics (e.g., Gava et al., 2008; Turati et al., 2008). In this case, rigid head motion can enhance newborns' face recognition (Bulf & Turati, 2010). Here, four experiments investigate whether the elastic motion of a face that changes facial expression might affect newborns' face recognition and, in particular, what specific dynamic cues newborns rely on during identity recognition.

The second study will investigate 3-monht-old infants' ability to categorize facial expressions when moving faces are presented. Categorization ability is considered an essential precursor of the recognition of facial expressions (e.g., Bornstein, 1984), because it serves to recognize that a facial expression remains the same even if modeled by different persons and with different intensities. Previous studies employing static pictures indicate that this ability develops between 5 and 7 months of life as a function of experience (e.g., de Haan & Nelson, 1998). However, other experimental settings (e.g., intermodal tasks and naturalistic observations) seem to indicate an earlier sensitivity to emotional expressions (for a discussion, see Bornstein & Arterberry, 2003). Given the hypothesis that facial motion might benefit facial expression recognition, we tested the ability of 3-month-old infants to categorize happy and fear emotional expressions by using moving facial stimuli.

The third study will examine infants' ability to process the motion information alone by using facial point-light stimuli (PLD). Given that infants as young as 4 months of age are able to process facial identity information from facial PLDs (Spencer et al., 2006), here we specifically examined the development of the ability to process facial expressions from facial motion signals. In particular, in the first experiment, we tested 3-, 6-, and 9-month-olds ability to discriminate happy versus fear PLDs. Stimuli were presented both in an upright and an inverted orientation condition in order to verify if infants process the motion patterns in a face-related manner. To exclude the possibility that a possible *a priori* preference for the fearful expression (e.g., Peltola, Hietanen, Forssman & Leppänen, 2013) could affect infants' looking behaviour, a second experiment will be reported where the spontaneous preference between happy and fear PLDs was tested in 6- and 9-month-olds.

Chapter 3

Study 1: The role of non-rigid motion in identity recognition at birth

The majority of the available literature about newborns' face perception comes from studies that have employed static and black-and-white pictures of faces posing a neutral expression. Given the considerations developed in the Introduction of the current dissertation, one may wonder to what extent we should generalize the available data. Nonetheless, the existing literature on newborns' face detection, discrimination and recognition provides a quite clear and thorough overview of few-day-old babies' ability to process faces from static images (for reviews, see Simion & Di Giorgio, 2015; Simion, Turati, Valenza & Dalla Barba, 2007).

1.1 Face recognition at birth

Shortly after birth, newborns show a special sensitivity to faces. They prefer to look longer towards face-like configurations and real face images, compared to other configurations paired for visual complexity (Goren et al., 1975; Johnson & Morton, 1991; Johnson et al., 1991; Macchi Cassia et al., 2004; Mondloch et al., 1999; Valenza et al., 1996). Some authors argued that such sensitivity might stem from an innate subcortical mechanism specific dedicated to faces (e.g., Johnson, 2005; Johnson & Morton, 1991); others prosed that it derives from a sensitivity towards some more general perceptual properties that faces share with other visual stimuli, such as the top-heaviness of the inner face elements (e.g., Simion, Macchi Cassia, Turati, & Valenza, 2003; Turati, 2004; for a discussion, see Simion et al., 2007). This debate is still under discussion and the current work does not aim to disentangle it.

From an evolutionary point of view, this sensitivity has the fundamental function to trigger newborns' attention toward faces, fitting with visual inputs the under-development cortical structures (e.g., Johnson, 2005; Leppänen & Nelson, 2009). Thanks to this mechanism, few-day-old infants acquire relevant visual information embedded in faces, allowing face discrimination and recognition. Indeed, newborns are able to learn a face to which they are repeatedly exposed (e.g., Bushnell, 2001; Bushnell et al., 1989; Field et al., 1984; Gava et al., 2008; de Heering et al., 2008; Pascalis & de Schoenen, 1994; Pascalis et al., 1995; Turati et al., 2006, 2008). In particular, newborns show a preference for their mothers' face to an unfamiliar female face (Bushnell, 2001; Bushnell et al., 1989; Field et al., 1984; Pascalis & de Schoenen, 1994). Thus, newborns are able to recognize their mother's face in a controlled, experimental setting, in which audible (voice), tactile (skin) and smell cues are removed. Moreover, neonates can learn the identity of a face never seen before (de Heering et al., 2008; Turati et al., 2006; Pascalis & de Schonen, 1994). For example, Pascalis and de Schonen (1994) habituated few-day-old infants to a picture of a stranger face. In the test phase, the habituated face and a new face were shown: newborns directed their attention towards the new identity, showing the ability to identify the habituated face as familiar.

The habituation procedure (Slater, Morison & Rose, 1985) employed to investigate the recognition abilities in infancy is based on the theoretical model of Sokolov (1963). In particular, according to this model, during the repeated presentation of the same stimulus in the habituation phase, the infant constructs a mental representation of that stimulus, a sort of template. This template increasingly becomes similar to the external stimulus as a function of the exposure to the stimulus itself: during the repeated exposure, the infant confronts the mental representation stored in memory with the external stimulus. The more the representation becomes similar to the real stimulus, the more infants' attention decreases, until the habituation criterion is reached and the habituation phase ends. Typically, in newborns' recognition tasks, in the subsequent test phase the same stimulus along with a new stimulus is presented. To successfully recognize the familiar stimulus, newborns have to match the representation stored in memory with the habituated stimulus: if they correspond, then newborns direct their attention significantly more towards the new, different stimulus and recognition is achieved. Thus, when the same visual stimulus is presented across habituation and test phase, newborns may just overlap the mental representation to the corresponding external stimulus, in an image-matching process. What does it happen if the stimulus presented in the test phase changes for some visual characteristics?

3.2 Newborns' face recognition over changes in visual characteristics

Overall, the reported studies prove the capability to recognize the identity of a face from a static picture in the first days of life. However, in all these studies, newborns' face recognition was tested by using the same picture both in the learning and the test phase (Fig 3.1). In other words, newborns had to recognize the same, identical image to which they were previously habituated. Theoretically, to be able to recognize when the faces in the habituated and the test phase are similar, newborns could just overlap the stored face representation and the perceived face image presented in the test phase, in an image-matching process, as shown in Sokolov' model (1963). However, one of the fundamental aspects of faces in natural environment is the fact that faces constantly change. Especially in infancy, the interactions with the caregivers are characterized by exaggerated and salient facial movements (e.g., Stern, 1974). Therefore, it becomes necessary to recognize a face even if presented in different aspects, such as different profile views, different facial configurations, different facial expressions and so on. To do so, newborns cannot simply match the stored representation to the perceived face stimulus, rather, they have to detect and extract the perceptual invariances across stimuli, being able to treat different versions of the same face as the same stimulus despite the perceptual differences. This ability is strictly related to the nature of the face representation on which newborns' face recognition relies

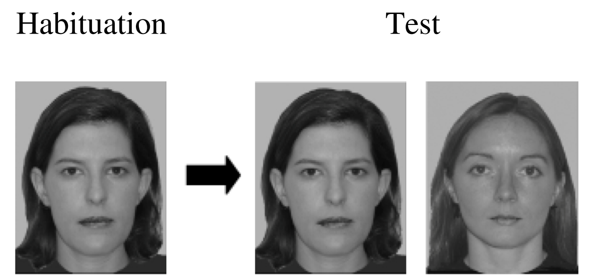


Figure 3.1. The classic stimuli employed in face recognition tasks at birth. The same picture of the face is presented both in the habituation and test phase (from Turati et al., 2006).

on. Specifically, newborns may be able to extract the invariant aspects of a face and construct a robust face representation, in the sense of being resilient to a variety of spatial transformations; by contrast, newborns may learn each version of a face individually, being not able to relate to each other the visual information they perceive (e.g., de Haan et al., 2001; Johnson & de Haan, 2001). In this case, the face representation would be more image-constrained and this representation would not be useful when the task requires to recognize the habituated face and the test face in a condition when the two faces differ for some perceptual characteristics. Thus, by means of manipulating the perceptual differences between facial stimuli, the nature of the underlying face representation could be inferred.

Models explaining the development of the neural basis underpinning learning and memory processes might shed some light on this issue. In particular, some authors have argued that the recognition of any visual stimulus, comprised faces, is mediated at birth by a hippocampal-based, pre-explicit memory. The term “pre-explicit” is referred to the under-developed explicit memory, i.e., the memory that emerges in a more mature form around 8-10 months of age (e.g., Nelson, 1995; Nelson & Webb, 2003). This early form of memory is thought to mediate newborns’ visual recognition, such as the novelty preference in visual paired comparison tasks, by means of an accurate representation of some stimulus’s aspects (e.g., Nelson, 1995; Johnson & de Haan, 2001). The critical limit of this system is due to the fact that it does not receive inputs from the higher-level cortical regions, thus being unable to relate the different representations of the memorized stimuli with each other (de Haan et al., 2001; Nelson, 1995). The ability to compare the information from one face to another probably does not develop until the time when the cortical system underlying face recognition, between 6 and 8 weeks of life, starts to inhibit the subcortical system. Thus, in the first month of life, infants can memorize the aspects of the stimulus they directly perceive, but they cannot generalize the recognition to different images, especially if they are excessively distant to each other in terms of perceptual similarities (i.e., a face with opened or closed eyes). To test this hypothesis, de Haan and collaborators (2001) familiarized 1- and 3-month-old infants to four different faces and then tested with one of these faces paired with a computer-averaged face, which was a combination of the four familiarized faces. The rationale behind this experiment was that, if infants retain in memory each face at an individual level, the averaged face should have been perceived as novel. In contrast, if infants form a prototypic representation of the four exemplars, they should have perceived the averaged face as more familiar compared to the single familiar model. Results showed that 3-month-old, but not 1-month-old, infants can form prototypic representation of faces. This result is consistent with the hypothesis that, before the development of the cortical system (between 6 and 8 weeks of life), infants encode faces at an individual level. This is likely reflected in the nature of the face representations infants build during face processing. In particular, the face representation within the first 6 weeks of life might be pictorial, rigid and image-constrained. With development, it might evolve into a more robust, flexible and image-independent face representation as a function of the experience and the cortical maturation (e.g., de Haan et al., 2001; Johnson & de Haan, 2001). Only the resilient face representation might be effective during the recognition of the same face in different presentations. On the contrary, a rigid image-constrained face representation would lead to an image-matching process, in which if the images coincide, recognition could be achieved, but if the images differ, recognition would be poorer.

It has been demonstrated that newborns are able to acquire and retain some visual information present in the environment, allowing the discrimination and recognition of objects when some visual characteristics change. For example, neonates are able to perceive an object as invariant across the retinal changes caused by modifications in slant or distance (Slater, Mattock & Brown, 1990). Newborns are also able to perceive the similarities (closed or opened forms) across different members of opened and closed geometrical stimuli (Turati, Simion & Zanon, 2003). Therefore, it is reasonable to assume that similar competences might be shown for faces, which are a more relevant class of stimuli for newborns. They, however, are also a more complex class of stimuli, compared to objects.

Several newborns' studies have tried to investigate the nature of the face representation underlying newborns' face recognition when some characteristics change (Gava et al., 2008; Pascalis et al., 1995; Turati et al., 2006, 2008). Pascalis and colleagues (1995) showed that the preference for the mother's face disappears when they wore a scarf that hinders the external face contour. The authors concluded that newborns recognize their mother's face by relying on the outer part of the face. This finding is in line with other studies showing how, in the first month of life, infants preferentially scan the external elements respect to the inner face elements (e.g., Maurer & Salapatek, 1976). A more recent study (Turati et al., 2006) offered a slightly different explanation of these results. They first demonstrated that neonates could rely on both the inner and the outer face part alone to recognize a face (see Figure 3.2).

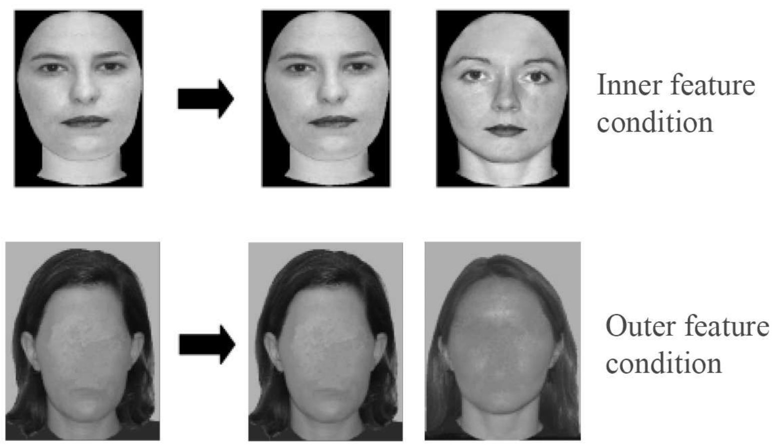


Figure 3.2. When the inner or outer face elements are presented alone, they both convey sufficient cues for recognition (Turati et al., 2006).

Second, they tested whether newborns recognize the habituated face when the inner or the outer elements are removed from the habituation to the test phase. Specifically, they habituated newborns with a full face and then tested with the same face without the inner, or the outer portion, and vice versa (see Figure 3.3). Results show that few-day-old infants showed recognition ability only in the outer facial feature condition (i.e., when the outer part is preserved and the inner part removed). On the contrary, they fail to recognize the same face when presented only with the inner part and the outer face part is removed (the inner facial feature condition). Thus, although both inner and outer elements of a face are sufficient for recognition, the latter provide more efficient cues.

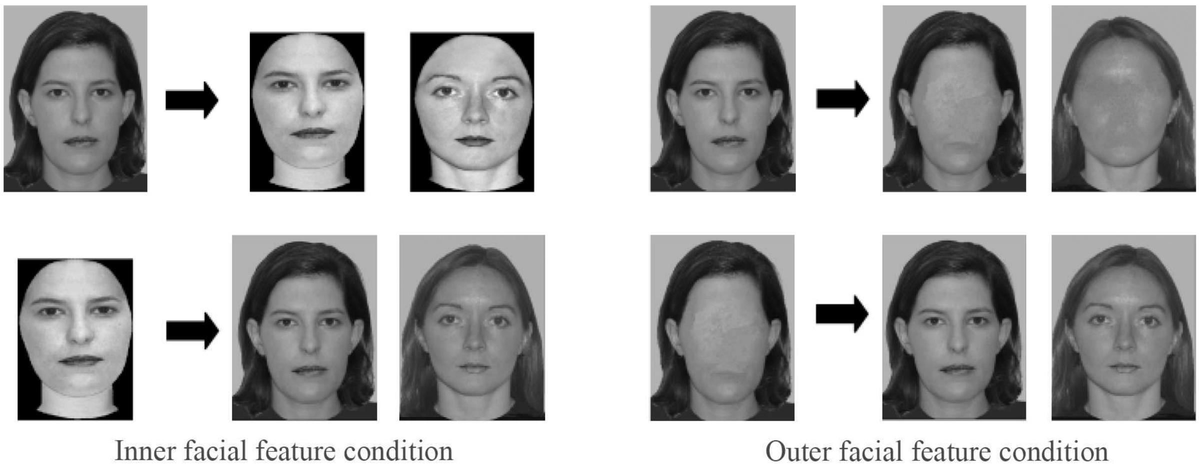


Fig 3.3. When some characteristics change from the habituation to the test phase, newborns recognize only in the outer facial feature condition (Turati et al., 2006).

The authors proposed this explanation for Pascalis et al.' s study (1995): since newborns have learned their mother's face in a full face condition in real life situations, they might have some difficulties to recognize it when the external face contour is removed. Together, these studies indicate that newborns' ability to recognize a face may be hindered if certain visual information changed from the habituation to the test phase. Moreover, they also suggest that newborns' face recognition performance may differently be affected according to the saliency of the information that is changed: if a facial aspect is particularly salient, meaning that it is particularly relevant for face recognition, the recognition becomes more difficult. Other newborns' studies support this hypothesis (Gava et al., 2008; Turati et al., 2008). For example, Gava and collaborators (2008) tested newborns' ability to recognize a face when salient facial features are occluded. In particular, given that the eyes are known to play a crucial cue in face recognition, both in adults and infants (e.g., Farroni, Massacesi, Menon & Johnson, 2007; Lewis & Edmonds, 2003), the authors wanted to investigate whether the salience, or the quantity, of the occluded face information, might determine an impact on face recognition at birth. More specifically, neonates were habituated to a full-visible face and then tested in two conditions in which both the saliency and the amount of face occlusion were manipulated: the low-salience/high amount occlusion condition, in which the eyes were still fully visible and three vertical bars hid the face; and the high-salience/low amount occlusion condition, in which the eyes were not visible, but only two bars hid the face (see Figure 3.4).

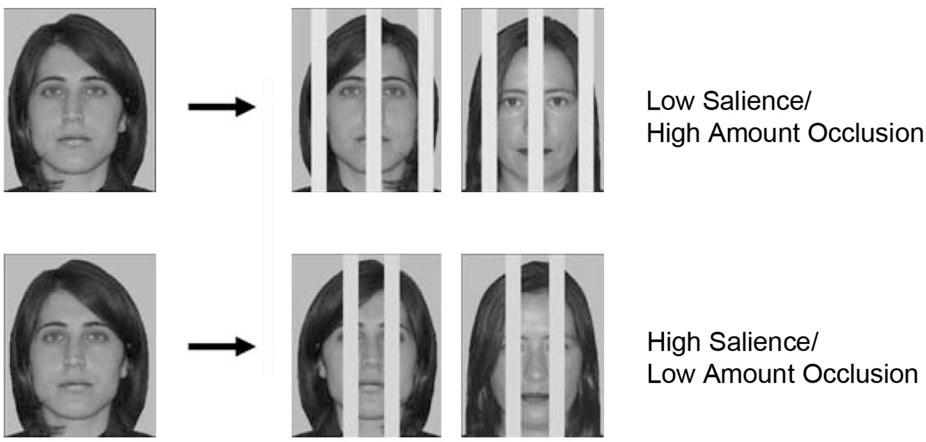


Figure 3.4. Stimuli employed in Gava et al. (2008) in the two conditions: when the eyes were visible, but the amount of the occluded information was higher (on the top) and when the eyes were hidden, but the amount of the occluded information was lower (on the bottom).

Results showed that face recognition was preserved in the low-salience/high amount occlusion condition, that is, when the eyes were not occluded: in this case, neonates were able to perceive the similarities between the habituated full-visible face and the same partially-occluded face presented in the test phase. On the contrary, eyes occlusion weakened face recognition, although more quantity of face information was available (two occluding bars instead of three). In particular, when the eyes were not visible, newborns showed a familiar preference, i.e., they directed their attention towards the habituated face. As previously mentioned, the familiarity preference is taken as an evidence of a partially formed face representation (e.g., Cohen, 2004; Sirios & Mareschal, 2002, 2004). Indeed, according to the models on infants' habituation pattern, at the initial stages of the recognition process infants direct their attention mostly towards the familiar stimulus in order to achieve a complete recognition; a shift from the familiar to the novel stimulus occurs only when the stimulus has been identified as known (showing a novelty preference; e.g., Roder, Bushnell & Sasseville, 2000; Hunter, Ames & Koopman, 1983; Rose, Gottfried, Melloy-Carminar & Bridger, 1982; Sirios & Mareschal, 2002, 2004). Thus, the absence of the eyes might inhibit the construction of a resilient face representation, essential to induce a novelty preference in a face recognition task. This finding indicates that newborns are able to recognize the identity of same face that changed in its appearance, but that this ability is strongly affected by the specific facial feature that changed across habituation and test phases: if these facial features are particularly relevant for face recognition, such as the outer face contour and the eyes, then recognition performance is inhibited (Gava et al., 2008; Turati et al., 2006).

Comparable results have been reported by Turati and colleagues (2008), who investigated newborns' ability to recognize a face over changes in viewpoint. In an orthogonal design, they habituated newborns to a frontal pose, a ¾ view (45°), or a profile pose (90°) of a face and then tested their ability to recognize the same face with a different pose (see Figure 3.5). Results showed that newborns are able to recognize the identity of the same face despite the changes in the facial poses. However, only the poses that convey enough facial information (i.e., the frontal and the ¾ views) allow newborns' face recognition over changes in viewpoint. It could be inferred therefore, that, when the profile pose was presented either in the habituation or in the test phase, newborns were not able to match the stimulus with the previously constructed mental representation, leading to an unsuccessful recognition. A possible interpretation supports the idea that the underlying face representation was image-constrained, because one can predict that, if newborns were able to extract the invariant aspects across the different facial poses, their recognition performance would have been successful. Probably, the frontal and the ¾ view provided sufficient facial information to allow an image matching process.

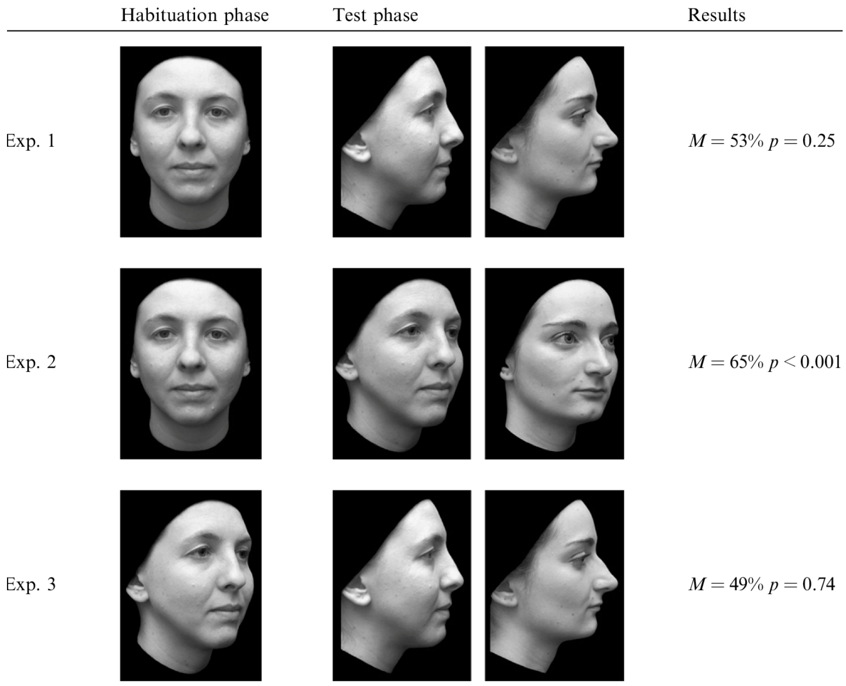


Figure 3.5. The experiments in Turati et al. (2008) testing newborns' ability to recognize faces across different profile poses. The p values on the right refer to the novelty preference score compared to the change level (50%), with a one-sample *t*-test.

Overall, these evidences suggest that, under certain visual circumstances, newborns can recognize the identity of the same face despite some visual changes. In particular, if the face that has to be memorized and the face that has to be recognized provide sufficient facial cues to allow an image matching process, then facial recognition performance takes place. In contrast, if the perceptual differences are salient, that is, particularly relevant for face recognition, then face representation results inadequate to identify the same face under different perceptual appearances (e.g., profile poses, presence of the eyes, presence of the external face contour). In this case, it has been demonstrated that facial motion may have a beneficial effect on newborns' face representation, in allowing the detection and extraction of the invariant characteristics of the same identity presented in different perceptual appearances (Bulf & Turati, 2010). In this study, newborns were able to recognize a face from its profile pose only when they have been habituated in a head-motion condition. Thus, rigid facial motion information helps to overcome the limits of the profile pose reported in Turati et al.' study (2008) and this beneficial effect is not attributable on a mere difference in the quantity of the facial pictorial information contained in the moving sequence (Exp. 2). Therefore, rigid head motion allows newborns' face recognition by enhancing the construction of a robust face representation, resilient to the perceptual distance between the different face rotations.

More recently, in our laboratory, we investigated whether the non-rigid facial motion of a face that changes facial expressions may have a beneficial effect in newborns' identity recognition (Leo, Angeli, Lunghi & Simion, in prep.). A previous study has shown that a happy face presented in motion condition facilitates identity recognition in 3- to 4-month-old infants, when compared both with a static condition, and with a multiple-static condition (that is, the same pictures shown statically; Otsuka et al., 2009). In Leo et al.'s study, newborns were habituated in a between-subject design to a moving, or a static face, posing either a happy, or a fearful expression. In the moving condition, three frames of an increasingly intense expression (levels 1, 2 and 3 of the expression) were presented in a loop so that to convey a dynamic facial expression. In the static condition, one single frame (that is, level three of intensity) was presented. Then, the same face and a new face, both with a neutral expression, were presented side by side (see Figure 3.6). To recognize the familiar face, newborns had to extract the perceptual invariances across the three dynamic frames presented in the habituation. A simply image-matching process would not be sufficient to achieve a successful recognition performance. Results have demonstrated that newborns showed a different recognition performance according to the static or dynamic condition: when they were habituated to the moving face, they manifested a preference for the stimulus with a new identity, so that demonstrating their capacity to recognize the familiar face. In contrast, when they were habituated to the static face, newborns showed a familiarity preference.

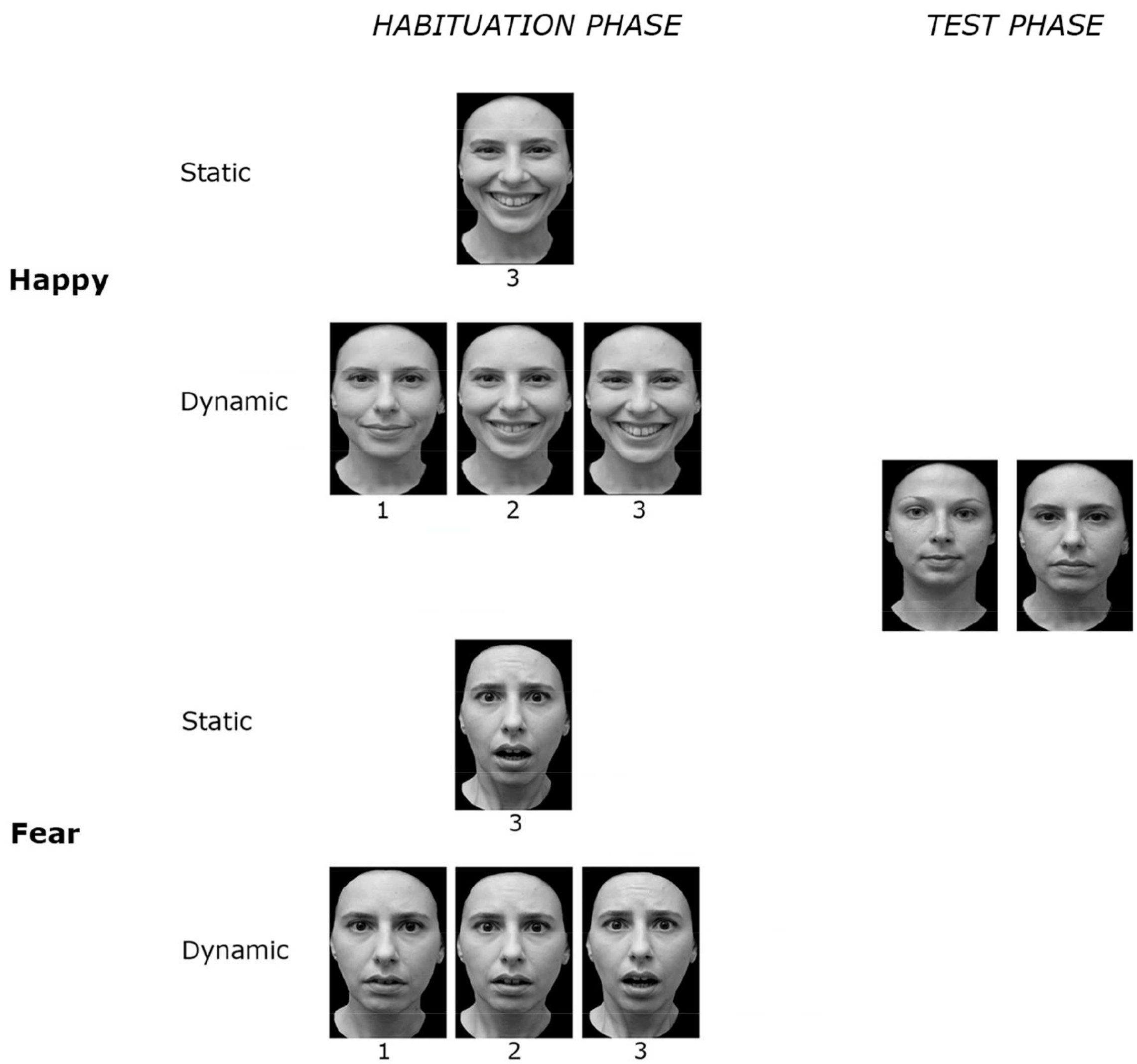


Figure 3.6. Stimuli employed in Leo et al. (in prep.). In a within subject design, newborns were habituated to happy or a fearful expression, posed in a moving or static condition. The number 1, 2 and 3 refer to the three intensities of the facial expression.

Thus, similarly to the beneficial effect played by the rigid head motion, it seems that the non-rigid motion of facial expressions leads to better recognition performance compared to a static picture, likely because it helps few-day-old babies to extract the perceptual invariances between a face depicting a facial expression and the same face with a neutral expression. In addition, the negative (i.e., fear), or positive (i.e., happy) valence of the facial expression does not seem to play any role in newborns' performances, contrary to the results obtained with both 3-month-old infants and adults (e.g., Brenna et al., 2013; Lander & Metcalfe, 2007).

However, alternative explanations might put forward the results found by Leo and collaborators. For example, one possible confound that could lead to different performances in the static and dynamic presentations is that, in the dynamic presentation, one of the frame (that is, the first frame) is perceptively similar to the neutral expression presented in the test phase (see Figure 3.6). Thus, newborns might just have used the pictorial representation of this frame to recognize the identity of the neutral face presented in the test phase. Another potential possibility is that motion may have enhanced face recognition thanks to the major quantity of static pictures contained in the moving sequences, as opposed to the single static picture of the static condition. Therefore, the difference in the available pictorial information, and not the motion information, may have lead to a better recognition performance.

The current study is aimed to disentangle these questions. Four experiments have been carried out, where the perceptual difference between the habituated face and the face presented in the test phase, as well as the quantity of the pictorial facial information were manipulated across the presence or the absence of facial motion. The general aim was to investigate the role of non-rigid motion in newborns' face recognition and, in particular, if facial motion could promote the construction of a face representation resilient to facial changes. In these experiments, only the happy facial expression, and not the fearful expression, was employed in the habituation phase, given that in the previous experiment no difference in newborns' performance according to the facial expression have been found.

In the first two experiments, the perceptual difference between the faces presented in the habituation and the test phase, along with the presence and absence of facial motion, were manipulated. The aim of these manipulations was to investigate: 1) if facial motion allows newborns to extract the invariant facial aspects, so that rendering possible the recognition of the same face despite a high perceptual difference (i.e., after being habituated to a happy moving face, newborns were presented with the same face posing a fearful expression, instead of the neutral expression); and 2) if newborns are able to identify a face as familiar when the perceptual difference is minimal, in a static condition (i.e. after being habituated with the first static frame of the happy face, newborns were presented with the same face with a neutral expression). The rationale behind this procedure is that, if facial motion enhances the construction of a flexible and robust face representation, newborns should be able to perform successful recognition despite the high perceptual differences. In contrast, if face recognition is based on a mere image-matching processing, then newborns should be able to recognize a face that slightly changed, even if they are habituated to a static picture.

The static and dynamic conditions in Leo and collaborators (in prep.) also differ for the quantity of the pictorial information: indeed, in the dynamic condition, three static frames have been presented, whereas in the static condition only a single frame was presented. Thus, the advantage produced by facial motion might be due to the additional quantity of pictorial facial information provided by the presentation of multiple views of the face, and not to motion cues per se. Experiments 3 and 4 were aimed at disentangling this question, by orthogonally manipulating the quantity of pictorial information and the presence of motion cues. In Experiment 3, one single frame (in particular, level 3) was presented in a moving condition, by means of a stroboscopic motion in which the eyes, the nose and the mouth moved horizontally from one side of the head to the other and vice versa. In Experiment 4, three frames (level 1, 2 and 3) were presented in a multi-static condition, in which each frame was shown individually and statically. The logic of this design is to investigate whether non-rigid motion per se affects newborns' face recognition, or whether the newborns' recognition advantage is simply due to the different amount of static pictorial information presented in the two different conditions.

The hypothesis predicts that, if motion per se affects face representation, so that to produce the beneficial effect already described, newborns should be able to recognize the identity of the same face presented in the habituation and the test phase also in the stroboscopic motion condition, despite the fact that a single frame is presented. On the contrary, if the quantity of facial information alone produces the beneficial effect, newborns should be able to success recognition in the multi-static condition, given that three frames are presented.

3.3 Experiment 1

The aim of the first experiment was to test the role of facial motion in newborns' identity recognition when the visual differences between the learned and the tested face are high. Newborns were habituated to a moving face composed by three frames presented in loop of an increasingly happy face. In the test phase, the habituated face and a new face were presented side by side, both posing a fearful expression (see Figure 3.7). If motion enhances the extraction of the invariant perceptual aspects of the face, a successful recognition should be performed.

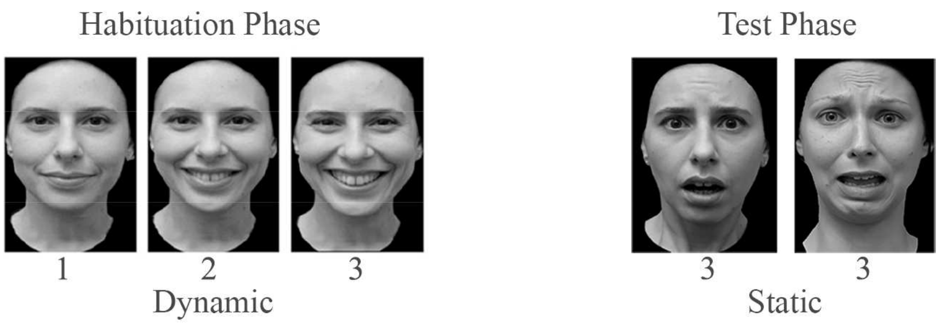


Figure 3.7. Stimuli employed in the first experiment. In the habituation phase the presentation is dynamic. Numbers refer to the intensity of the facial expressions.

3.3.1 Method

Participants

The final sample comprised a total of 14 healthy, full-term newborns (male = 10), aged 44 hours (*SD* = 29 hours). Seven additional newborns were tested, but were excluded from the final sample because of fussiness, or numbness (n = 1), side bias (more than 80% of time spent looking at one direction, n = 4), and technical problems (n = 2). They all were recruited in the maternity ward of the Pediatric Clinic of the University of Padova. All of them met the screening criteria of normal delivery, a birth weight between 2795 and 4050 g, and an Apgar score between 9 and 10 at 5 minutes. Newborns were tested only if in an alert state and after their parents gave their informed consent.

Stimuli

Stimuli were black and white pictures of two Caucasian women's faces (aged around 30 years). Models were photographed under the same lighting conditions and in a frontal pose while depicting different expressions: fear and happy. They were asked not to wear glasses or jewelry and other minor distinctive details (e.g., blemishes or pimples) were digitally removed using the software Adobe Photoshop. The hair outline of each face was removed so that recognition had to rely exclusively on the inner part of the face. Once presented on the monitor, face images measured 35° in height, and 24°-26° in width.

Apparatus

The newborns were tested in a dimly lit and quiet room. They sat on a student's lap, at a distance of about 30 cm from a screen where the stimuli were displayed. Plain white curtains were drawn on both sides of the infant to prevent interference from irrelevant distractors. Newborn's eyes were aligned with an attention getter (AG; i.e., a central red flickering disc), used to attract the newborns' gaze at the start of both the habituation and test phases. The attention getter subtended about 2° of a visual angle and, when turned on, blinked at a rate of 300 ms on and 300 ms off.

Procedure

Newborns were tested with an infant-control habituation procedure (e.g., Slater et al., 1985). Each newborn needed to complete the habituation phase and the test phase, which comprised two test trials, in which the left-right position of the two stimuli was reversed. As soon as the infant was apparently at ease and his/her gaze was properly aligned with the central attention getter, the habituation phase begun by pressing a key on a keyboard. This automatically turned off the AG and activated the habituation phase. Each habituation trial started with the presentation of a face video projected bilaterally, on each side (i.e., left and right) of the screen. The face video was composed by a set of three frames, each presented for 500 ms in loop, depicting the same identity with a happy facial expression gradually increasing its intensity. An experimenter, naïve to the stimuli presented, recorded the duration of each fixation on the stimulus by pressing a push button that was connected to the computer. Because during the habituation phase the same stimulus was presented on the left and on the right, the amount of looking was recorded irrespective of the side. A look-away criterion of 2 s was used to determine the end of each trial. In order to be sure that this criterion was strictly respected, the software was planned so that it automatically compacted two consecutive fixations that were not separated by a time interval of at least 2 s. The stimuli remained on the screen until the habituation criterion was reached. The infant was judged to have been habituated when, from the fourth fixation on, the sum of any three consecutive fixations was 50% or less than the total of the longest three (Slater et al., 1985). Only when the habituation criterion was reached, the stimuli were automatically turned off and the central AG was turned on and the test phase began. In the test phase, newborns were tested in two test trials. In each trial, two static images were presented on each side of the screen: the habituated face and a new face, both with a fearful facial expression. The both left and right position of the stimuli was reversed from the first to the second trial in order to control a possible side bias. The habituation stimulus within each pair of faces was counterbalanced between subjects, and its initial left-right position was counterbalanced across subjects. The attention getter was showed between the first and the second trial. In the test phase, the experimenter recorded the duration of newborn's fixations on each stimulus by pressing two different push buttons depending on whether the infant looked at the right or the left position. Each trial ended when a total of 20 s of looking to the novel and familiar stimuli had been accumulated and only if the participant had looked at each of the face for at least 1 second. All testing sessions were video-recorded. A second experimenter, unaware of the stimuli presented, subsequently codified videotapes of eye-movements. The mean estimate of reliability between experimenters (on-line and off-line coding), calculated on the 30% of the test trials, was .94 (Pearson Correlation), so the recording procedure has to be considered reliable.

3.3.2 Results and Discussion

To verify if the newborns' looking behavior was affected by the identity of the face stimuli, or the left-right position of the face in the test phase, preliminary ANOVA on the total fixation time (TTF) toward the stimuli, with the factors Stimulus Identity (model A, model B) and Position (left, right) were carried out. No main effects or interactions were significant (all *p*s > .050). Thus, we collapsed data over these variables for subsequent statistical analyses.

All newborns reached the habituation criterion. The average total fixation time and the number of trials needed to reach the habituation criterion were 39800 ms (*SD* = 15769 ms), and 10 (*SD* = 2.8), respectively.

In order to test whether newborns discriminated the familiar and the new face, we used paired sample *t*-tests to compare the total fixation time and number of orientations toward the new and the familiar stimuli. Newborns tended to look more to the familiar stimulus (*M* = 25168 ms, *SD* = 11261 ms) compared to the new stimulus (*M* = 18001 ms, *SD* = 11891 ms), but the difference was not statistically significant, $t(13) = -1.22$, p = .244, *ns* (see Figure 3.8). Also the number of orientations to the new face ($M = 5.9$, $SD = 4.1$) was not significantly different from the orientations to the familiar face ($M = 7.4$, $SD = 3.0$), $t(13) = -1.99$, p = .340, *ns*. Thus, when habituated to a happy moving face and then tested with the same face posing a fearful expression, newborns do not recognize the same face to which they have been habituated. To further confirm that newborns did not show significant differences in attention between the new and the familiar stimuli, we computed novelty preference scores. Each newborn's looking time at the new face during the two test trials was divided by the total looking time at both test stimuli over the two trials and was then subsequently converted into a percentage score (i.e. novelty percentage). As such, a novelty preference score above chance level (50%) indicates that newborns looked longer at the new face.

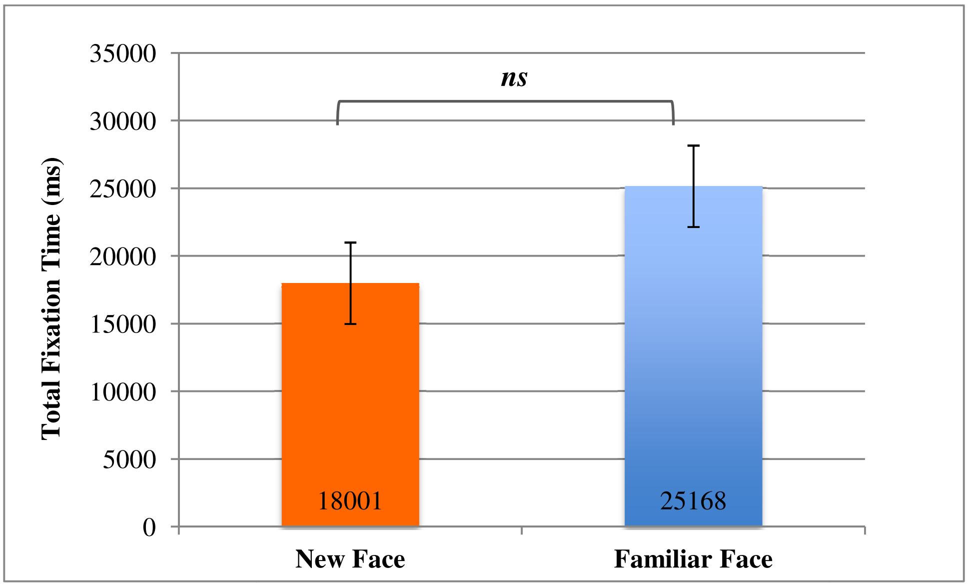


Figure 3.8. The total fixation times toward the new and familiar face in the test phase in Experiment 1. The bars represent the standard errors.

The novelty preference score towards the new face ($M = 41\%$, $SD = 25\%$) did not differ from the chance level, as indicated by an one sample *t*-test, $t(13) = -1.37$, p = .193, *ns*.

These results indicate that, when the perceptual discrepancy between the faces presented in the habituation and test phase is particularly evident, newborns' face recognition is impaired, even under motion condition. When considered together with Leo et al. (in prep.) results, the overall data suggest that motion information might enhance face recognition (that leaded to the novelty preference), compared to a static presentation (that leaded to the familiarity preference), but this ability is subordinate to the degree of the perceptual discrepancy between the different versions of the face. Specifically, as shown in the current experiment, when the different presentations of the same face are too distant to each other in terms of visual similarity, then facial motion loses its beneficial effect. This might suggest that facial motion might have only a limited impact on the construction of the underlying face representation, as it seems not resilient to important facial changes. If so, a minor perceptual difference between face presentations might allow face recognition, even in static condition. This possibility was tested in the Experiment 2.

3.4 Experiment 2

In the previous Experiment, the perceptual difference was increased and the facial movement was present. In Experiment 2, these two factors were manipulated in a reverse way: the perceptual difference was diminished and the facial movement removed. Specifically, newborns' ability to identify a face as familiar when it slightly changes from the habituation to the test phase was tested in a static condition. Neonates were habituated to the first static frame of the three frames composing the happy facial stimulus shown in Leo and colleagues' study (in prep.). Then, the same identity and a new identity, both with a neutral expression, were presented in the test phase (see Figure 3.9). If face recognition is based on an image-matching processing, then newborns should be able to recognize the same face that slightly changed in test phase, even if they are habituated to a static picture.

Figure 3.9. Stimuli employed in the second experiment. In the habituation phase, the presentation is static. Numbers refer to the intensity of the facial expression.

3.4.1 Method

Participants

The final sample comprised a total of 12 healthy, full-term newborns (male = 6), aged 49 hours (*SD* = 39 hours). Four additional newborns were tested, but were excluded from the final sample because of fussiness or numbness (*n* = 3), and side bias (more than 80% of time spent looking at one direction, *n* = 1). They all were recruited in the maternity ward of the Pediatric Clinic of the University of Padova. All of them met the screening criteria of normal delivery, a birth weight between 2905 and 4010 g, and an Apgar score of 10 at 5 minutes.

Stimuli

Stimuli were the same faces used in Experiment 1, posing a happy and a neutral expression.

Apparatus

The apparatus was identical to that used in Experiment 1.

Procedure

The procedure was identical to that used in Experiment 1, with the only difference that, during the habituation phase, the face image projected bilaterally was a single static picture depicting the intensity 1 of a happy expression. In the test phase, the same face and e new face were presented side by side, both posing a neutral expression. The mean estimate of reliability between the online and offline coding of the two experimenters, calculated on the 30% of the test trials, was .93 (Pearson Correlation).

3.4.2 Results and Discussion

To verify if the identity of the face stimuli, or the left-right position of the face in the test phase, could have affected newborns' looking behavior, we conducted the same preliminary ANOVA on the total fixation time (TTF) toward the stimuli, with the factors Stimulus Identity (model A, model B) and Position (left, right). No main effects or interactions were significant (all ps > .050). Thus, we collapsed data over these variables for subsequent statistical analyses.

All newborns reached the habituation criterion. The average total fixation time and the number of trials needed to reach the habituation criterion were 38498 ms (*SD* = 19148 ms), and 8 (*SD* = 2.4), respectively.

Paired sample *t*-tests were used to test whether newborns showed significant different looking times and number of orientations towards the familiar and the new face. As shown in Figure 3.10, newborns looked significantly longer to the new face (*M* = 28123 ms, *SD* = 10049 ms) compared to the familiar face (*M* = 15940 ms, *SD* = 6676 ms), $t(11) = 2.64$, p = .023, Cohen d = .76. Also the number of orientations to the new face (*M* = 7.7, *SD* = 2.7) was significantly higher than the orientations to the familiar face (*M* = 5.3, *SD* = 2.5), $t(11)$ = 2,48, p = .030, Cohen d = .72. These results indicate that newborns are able to recognize the habituated face as familiar, directing their attention significantly more to the new facial stimulus. To further confirm that newborns significantly looked longer toward the new face, we computed novelty preference scores. The novelty preference score towards the new face (M = 63%, SD = 17%) significantly differed from the chance level (50%), as indicated by an one sample t-test, $t(11) = 2.65$, p = .022.

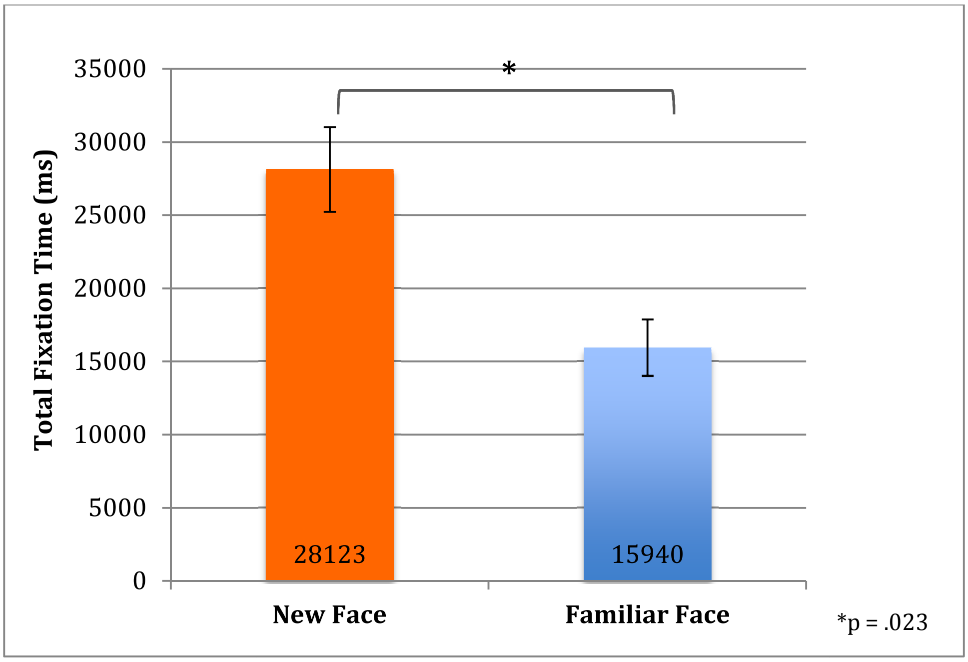


Figure 3.10. The total fixation times toward the new and familiar face in the test phase in Experiment 2. The bars represent the standard errors.

The present data indicate that, when the variation in the face configurations is subtle, thus a close similarity is present between the habituated and the test faces, newborns are able to recognize the identity of the face that changed in facial expression in a static presentation condition. The interpretation of this result is that the close resemblance between the habituated face and the test face, due to the small difference in the level of intensity of the expressed emotion, leads to a novelty preference, which is typically considered the marker of a successful recognition. In contrast, when the third level of facial expression's intensity is presented, a familiarity preference takes place (Leo et al., in prep.), which is usually taken as an evidence for a partially formed face representation. Thus, these two results together suggest that, when newborns are not provided with any motion cues, then recognition seems to rely on the newborns' ability to simply match two similar images, by means an image-based face representation: the more the two images differ (such as the level 3 of an expression's intensity presented in the habituation phase and the neutral face presented in the test phase), the more recognition becomes difficult. On the contrary, the more the two images look alike (such as the level 1 of on expression's intensity and the neutral face), the more recognition is facilitated.

Overall, the results seem to suggest a relative role of the non-rigid facial motion in face recognition at birth: when the face presented in the habituation highly differs in terms of visual similarity from the face presented in the test phase, then facial motion loses its beneficial effect. In contrast, when the face's changes are subtler, then a static presentation provides sufficient cues to allow newborns' identity recognition.

The effect of facial motion on the recognition of identity in newborns was further investigated in the next two experiments, where the role of the quantity of pictorial information was tested along with the presence and absence of motion cues.

3.5 Experiment 3

The aim of Experiment 3 was to analyze newborns' ability to recognize a face that changed facial expression in a stroboscopic motion condition. To test the role of the quantity of pictorial information, and the role of the motion cues per se on newborns' identity recognition, I decided to present one single frame (in particular, level 3) in a moving condition. Given that, in real life situations, all facial motions affect the quantity of pictorial information embedded in a face, I selected a biologically impossible facial motion. In particular, the apparent stroboscopic motion was selected because this particular motion makes the internal facial features moving without adding new static pictorial information. In particular, newborns were habituated to a single frame of the third level of intensity of a happy face, whose eyes, nose and mouth shifted on its horizontal axis at a rate of 500 ms. Then, the same identity and a new identity were presented bilaterally, both with a neutral expression (see Figure 3.11). If the motion cues, and not the amount of pictorial cues, enhance face recognition, newborns should perform a successful recognition performance. On the contrary, if the quantity of pictorial information plays a major determining role, then newborns should perform a worse recognition.

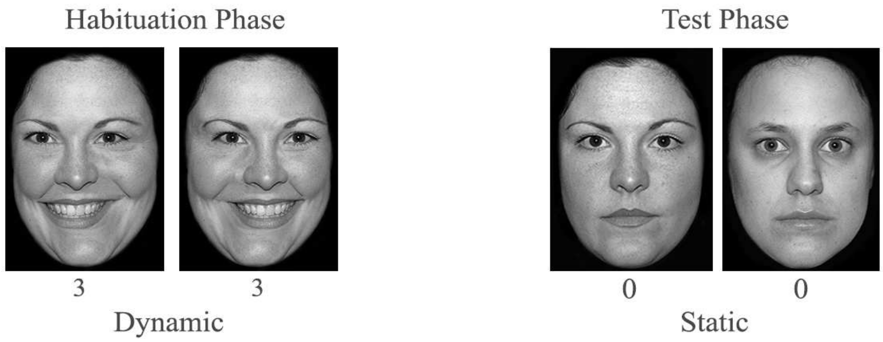


Figure 3.11. Stimuli employed in Experiment 3. In the habituation phase, the face was presented in a stroboscopic motion. Numbers refer to the intensity of the facial expression.

3.5.1 Method

Participants

The final sample comprised a total of 14 healthy, full-term newborns (male = 10), aged 48 hours (*SD* = 32 hours). Eight additional newborns were tested, but were excluded from the final sample because of fussiness or numbness (*n* = 4), side bias (more than 80% of time spent looking at one direction, *n* = 3), and experimental errors (*n* = 1). They all were recruited in the maternity ward of the Pediatric Clinic of the University of Padova. All of them met the screening criteria of normal delivery, a birth weight between 2535 and 3910 g, and an Apgar score between 9 and 10 at 5 minutes.

Stimuli

Stimuli were faces from the NimStim dataset (Tottenham et al., 2009). The stimuli' measures were identical of those in the previous experiments.

Apparatus

The apparatus was identical to that used in Experiment 1 and 2.

Procedure

The procedure was identical to that used in the previous experiments, with the only difference that, during the habituation phase, the face video projected bilaterally was a single picture whose eyes, nose and mouth shifted horizontally from a side to the other every 500 ms. The face depicted the intensity 3 of a happy expression, as in the static condition of Leo and others' study. In the test phase, the same face and e new face were presented side by side, both posing a neutral expression. The mean estimate of reliability between the online and offline coding of the two experimenters, calculated on the 30% of the test trials, was .91 (Pearson Correlation).

3.5.2 Results and Discussion

We conducted preliminary ANOVA with the factors Stimulus Identity (model A, model B) and Position (left, right), to verify if the identity of the face stimuli, or the left-right position of the face in the test phase, might have affected newborns' looking behavior on the total fixation time (TTF) toward the stimuli. No main effects or interactions were significant (all *p*s > .050). Thus, we collapsed data over these variables for subsequent statistical analyses.

All newborns reached the habituation criterion. The average total fixation time and the number of trials needed to reach the habituation criterion were 49306 ms (*SD* = 23440 ms), and 11 (*SD* = 3), respectively.

To test whether newborns showed significant different looking times and number of orientations between the familiar and the new face, paired sample *t*-tests were used. As shown in Figure 3.12, newborns did not show any significant preference for any particular face. The difference between the total fixation time to the new face (*M* = 20369 ms, *SD* = 8706 ms) and the familiar face (*M* = 21017 ms, *SD* = 7034), was not significant, $t(13) = -.162$, p = .874, *ns*.

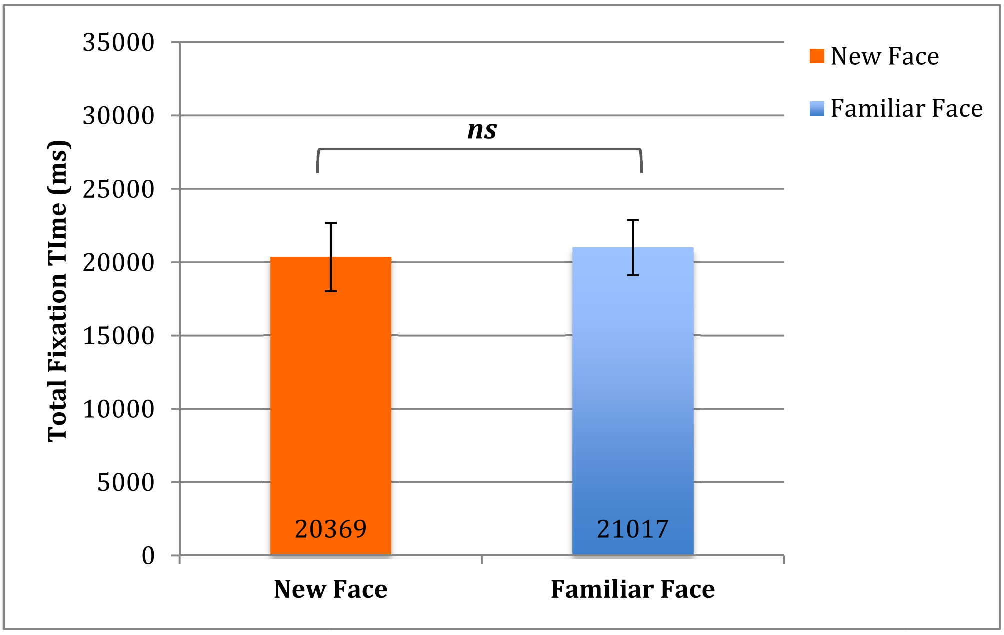


Figure 3.12. The total fixation times toward the new and familiar face in the test phase in Experiment 3. The bars represent the standard errors.

Neither the number of orientations was significantly different between the new face (*M* = 7.9, *SD* = 2.4) and the familiar face (*M* = 8.3, *SD* = 3.3), $t(13) = -.434$, p = .671, *ns*. These results reveal that, under stroboscopic motion condition, newborns are not able to recognize the face to which they have been habituated. To further confirm that newborns did not showed any significant preference for any visual stimulus, we computed novelty preference scores. The novelty preference score towards the new face (*M* = 49%, *SD* = 17%) did not significantly differed from the chance level (50%), as indicated by an one sample *t*-test, $t(13) = -.315$, p = .757, *ns*.

The results of Experiment 3 showed that, when facial motion cues were shown in a stroboscopic condition, facial motion prevented newborns' face recognition. Our aim was to investigate whether the facial motion information, or the quantity of facial pictorial information, might enhance face recognition at birth. The obtained results do not allow us to make clear conclusions regarding this question. The null preference suggests that neither the motion, nor the pictorial information, or their combination allowed newborns' face recognition. It is worth to note that, despite the fact that the happy face in this experiment and the happy face in Leo et al. (in prep.) were paired for level of intensity (i.e., 3), the stroboscopic motion leaded to a null preference, whereas the static condition in the other experiment leaded to a familiarity preference. Thus, the pictorial information being equal, the stroboscopic condition brought to worse recognition performances compared to the static condition, given that the familiarity preference demonstrates an immature, yet present, recognition. This finding was quite unexpected: the stroboscopic motion seems especially suitable for newborn babies, because it requires less smooth saccades to track the moving stimulus. For example, it has been demonstrated that stroboscopic motion, and not other kinds of motion, allows the perception of occluded objects in few-day-old infants (Valenza et al., 2006; Valenza & Bulf, 2007). However, when faces are involved, the stroboscopic motion is no longer effective in enhancing newborns' visual perception. This result seems in line with other infants' studies showing an early sensitivity to the naturalness of the motion patterns of faces (Bulf & Turati, 2010; Ichikawa et al., 2011; Xiao et al., 2014). Thus, it is possible that newborns' face recognition was inhibited because stroboscopic motion is biologically impossible to be displayed on a human face. Future studies should be carried out to examine this possibility.

3.6 Experiment 4

The aim of the current experiment was to verify whether the pictorial information of three frames presented statically might lead to an advantage on newborns' face recognition. Newborns were familiarized to the same three frames and for the same amount of time of the Leo and collaborators' dynamic condition. To pair newborns' fixation time during the learning phase, a familiarization procedure was used. In the test phase, the same identity and a new identity were presented, both posing a neutral expression. If the amount of pictorial information explains the beneficial effect, the presentation of multiple static views of the face should provide the same successful recognition.

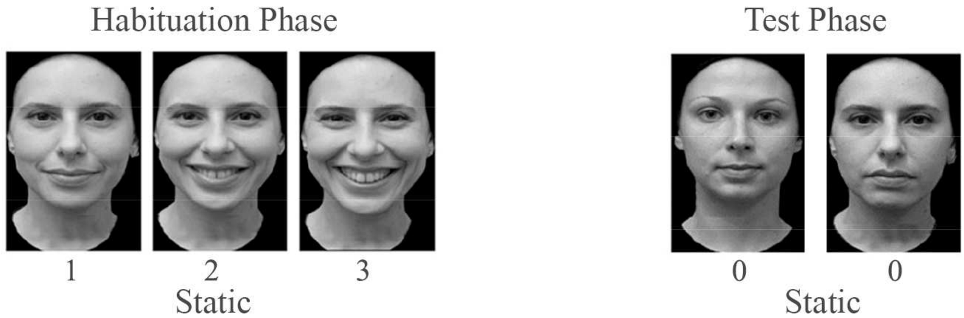


Figure 3.13. Stimuli employed in Experiment 4. In the habituation phase the presentation is static and newborns had to accumulate a fix amount of fixation time on each single frame. Numbers refer to the intensity of the facial expression.

3.6.1 Method

Participants

The final sample comprised a total of 14 healthy, full-term newborns (male = 9), aged 51 hours (*SD* = 28 hours). Five additional newborns were tested, but were excluded from the final sample because of fussiness or numbness (*n* = 1), and side bias (more than 80% of time spent looking at one direction, *n* = 4). They all were recruited in the maternity ward of the Pediatric Clinic of the University of Padova. All of them met the screening criteria of normal delivery, a birth weight between 2235 and 4150 g, and an Apgar score between 9 and 10 at 5 minutes.

Stimuli

Facial stimuli in the habituation phase were identical to those employed in Experiment 1, and facial stimuli in the test phase were identical to those employed in Experiment 2.

Apparatus

The apparatus was identical to that used in the previous experiments.

Procedure

Newborns were familiarized to three static images, each presented bilaterally. In the test phase, the same face and a new face posing a neutral expression were presented. The procedure was identical to that used in the previous experiments, with the only difference that a familiarization procedure was employed, so that the total fixation time could be paired with that employed in the dynamic happy condition of Leo et al.'s study (in prep.): the mean looking time obtained during the habituation phase was 59870 ms (*SD* = 40860 ms). In order to approximate the amount of time newborns spent on each frame, this value was divided by the number of frames. Thus, in the current experiment, each image was presented until the newborn have accumulated 19957 ms. These parameters were controlled by a familiarization program built on E-Prime 2.0, which controlled the presentation of the stimuli by means of the experimenter's on-line recordings. The mean estimate of reliability between the online and offline coding of the two experimenters, calculated on the 30% of the test trials, was .97 (Pearson Correlation).

3.6.2 Results and Discussion

In order to test whether the identity of the face stimuli, or the left-right position of the face in the test phase, might have affected newborns' looking behavior on the total fixation time (TTF), we conducted preliminary ANOVA with the factors Stimulus Identity (model A, model B) and Position (left, right). No significant main effects or interactions were found (all *ps* > .050). Thus, we collapsed data over these variables for subsequent statistical analyses.

All newborns reached the familiarization criterion, that is, an amount of 20 s ca. in each frame. The average total fixation time needed to reach the familiarization criterion was 177375 ms (*SD* = 49079 ms).

To test whether newborns showed significant different looking times and number of orientations between the familiar and the new face, paired sample *t*-tests were used. As shown in Figure 3.14, newborns did not show any significant differences the total fixation time to the new face (*M* = 22664 ms, *SD* = 7647 ms) and the familiar face (*M* = 22953 ms, *SD* = 7583), was not significant, *t*(13) = -.076, p = .941, *ns*.

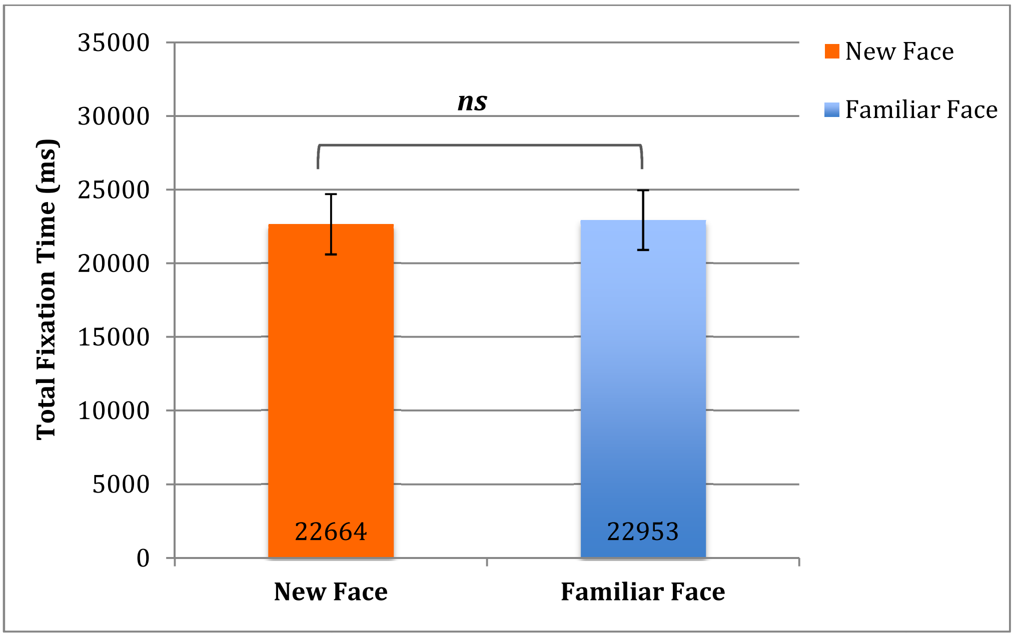


Figure 3.14. The total fixation times toward the new and familiar face in the test phase in Experiment 4. The bars represent the standard errors.

The difference between the number of orientations towards the new face (*M* = 6.5, *SD* = 3.1) and the familiar face (*M* = 8.1, *SD* = 2.7), was not statistically significant $t(13) = -1.20$, $p = .251$, *ns*. These results indicate that when provided with the static frames in static condition, newborns are not able to recognize the face to which they have been habituated. To further confirm that newborns did not showed any significant preference for any visual stimulus, we computed novelty preference scores. The novelty preference score towards the new face (*M* = 50%, *SD* = 17%) did not significantly differed from the chance level (50%), as indicated by an one sample *t*-test, $t(13) = -.079$, $p = .938$, *ns*.

In the multi-static condition, newborns did not recognize a face when it changed facial expression from the habituation to the test phase. When confronted with the dynamic condition of Leo and colleagues' study, in which the same pictorial static information was provided, this result indicates that motion cues play a critical role in enhancing face recognition at birth. Interestingly, the multi-static presentation also leaded to worse recognition performances compared to both the Experiment 2, in which newborns were habituated to a static picture of the first intensity level, and the static condition in Leo et al. (in prep.), in which newborns were habituated to a static picture of the third intensity level. One possible explanation of this unexpected result might rely in the experimental procedure. In particular, in the previous experiments newborns were free to explore the stimulus how much they wanted because they were tested in a habituation procedure. In Experiment 4, instead, a fixed amount of time was imposed for each frame, that is, 20 seconds. Therefore, the time newborns could explore each of the three face images in the multi-static condition was the half of the fixation time in the other static conditions (i.e., in Experiment 2 = 40 s ca., and in Leo et al. = 43 s ca.). This might have led to the poorer recognition performance in the multi-static condition, compared to the other two static conditions.

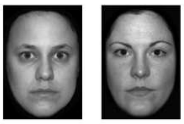
3.7 General Discussion

The general purpose of the present series of experiments was to investigate whether non-rigid facial motion might provide a beneficial effect on face recognition at birth. More specifically, we analyzed newborns' ability to recognize a face that changed facial expression from the habituation to the test phase, by manipulating 1) the presence/absence of motion, 2) the perceptual differences between images and 3) the amount of pictorial information presented in the learning phase (see Table 3.1).

In Experiment 1, we habituated newborns to a happy moving face and then the same face was presented posing a fearful expression. The aim was in to investigate whether facial motion information allows face recognition despite the high perceptual discrepancy between the face images. Results showed that newborns' face recognition was impaired, suggesting that facial motion does not support newborns' recognition performances when the face images are too contrasting in terms of visual similarities. When confronted with the moving condition of Leo et al. (in prep.), it suggests that the underlying face representation might be resilient only to certain limited degrees of perceptual variances, thus in part contradicting the representation enhancement hypothesis, according to which motion cues enhances face recognition by means of an more flexible and less image-dependent face representation.

In Experiment 2, we habituated neonates to one static first frame of the moving sequence and, in particular, the level 1 of intensity of the happy expression was selected, in order to minimize the perceptual differences between the face in the habituation phase and the face in the test phase, where the same identity was presented with a neutral expression. We wanted to investigate whether newborns could recognize a face that slightly changed its expression, under static presentation. Results indicated a successful recognition performance, supporting the idea that, when the visual differences are subtle, a static presentation provides sufficient cues to allow face recognition at birth.

Table 3.1 Summary of the whole set of experiments investigating the role of non-rigid facial motion in newborns' face recognition

	HABITUATION	TEST	CONDITIONS	RESULTS
Exp. Leo **STATIC**			**Motion** absent **Perceptual Difference** medium **Pictorial Information** single	Familiarity Preference
Exp. Leo **DYNAMIC**			**Motion** present **Perceptual Difference** medium **Pictorial Information** multiple	Novelty Preference
Exp. 1 **DYNAMIC**			**Motion** present **Perceptual Difference** high **Pictorial Information** multiple	No Preference
Exp. 2 **STATIC**			**Motion** absent **Perceptual Difference** low **Pictorial Information** single	Novelty Preference
Exp. 3 **DYNAMIC** STROBOSCOPIC			**Motion** present **Perceptual Difference** low **Pictorial Information** single	No Preference
Exp. 4 **STATIC**			**Motion** absent **Perceptual Difference** medium **Pictorial Information** multiple	No Prefernce

It is worth to confront these results with those obtained in the static condition in Leo et al. (in prep.). In particular, when the absence of motion is equated, the first level of the expression's intensity employed in the current experiment allowed a novelty preference, whereas the third level leaded to a familiarity preference, which is taken as an index of a poorer recognition (e.g., Cohen, 2004). Since the third level of intensity is perceptually more distant from the neutral face than the first level, one may claim that, when no motion cues are available, newborns rely on an image-matching process for recognition. In fact, a major perceptual distance between face images leads to a poorer recognition, compared to a minor perceptual distance. Therefore, when newborns are not provided with motion cues, the underlying face representation might be more pictorial and image-based.

The third Experiment was aimed to analyze newborns' ability to recognize a face presented with a stroboscopic motion (a face whose internal elements shifted horizontally) when re-presented in a neutral pose. The rationale behind this procedure was to test whether motion cues per se, and not the amount of static frames shown in the habituation phase, might explain the beneficial effect on face recognition. Results have shown that the stroboscopic motion prevented face recognition. The null preference showed in the test phase suggests that newborns' did not rely nor on the motion information, or on the pictorial information to encode the face during the habituation phase. As said, a possible interpretation of the disadvantage effect of the stroboscopic motion might be due to the fact that this motion is biologically impossible to be displayed on a human face. Previous studies have shown a precocious sensitivity to some characteristics of the natural motion patterns of faces (Bulf & Turati, 2010; Ichikawa et al., 2011; Xiao et al., 2014); for example, newborns' face recognition is affected by the sequence order in which the head rigid motion occurs: a random ordered sequence leads to a worse performance compared to the correct ordered sequence (Bulf & Turati, 2010). Therefore, the biological impossibility of the stroboscopic facial motion patterns might have led to an unsuccessful recognition in newborns. Moreover, the results' obtained in the stroboscopic motion also does not support the heightened featural hypothesis, according to which the non-rigid face movements might enhance face recognition because of a shift in the attentional focus from the outer contour toward the inner portion of the face (Roark et al., 2003). The results of stroboscopic condition demonstrated that simply relocating the newborns' attention to the inner face elements does not necessary support the encoding of the facial structure, because the characteristics of facial motion itself (such as a biologically possible or impossible motion) might also hinder this process.

In Experiment 4, we familiarized newborns to three frames of a happy expression, each shown statically and then tested with the same face with a neutral expression. The aim was to investigate if the quantity of facial pictorial information might explain the beneficial effect on face recognition. Results reported that newborns were not able to perform a successful recognition, thereby demonstrating that the mere amount of static images alone does not provide the recognition advantage found when the same three images were presented in motion. Given that the multi-static condition and the motion condition in Leo et al.' study are identical in terms of both the quantity of pictures and the perceptual distance, these two data together strongly support the role of motion cues in enhancing face recognition at birth. Quite unexpectedly, the current multi-static condition leaded to a worse performance than both the static condition of Experiment 2, and the static condition of the previously discussed research study (Leo et al., in prep.). This might be due to the fact that, in the multi-static procedure each image was presented only for 20 s, whereas in the other two static conditions the face image was presented for more and less twice the amount. Such limited total fixation time might have not been sufficient to support the encoding of each face image. Intriguingly, this result also hints the possibility that each single static frame is retained in memory as an independent information. This interpretation derives from the fact that infants had to accumulate only 20 seconds of exploration for each frame, but, at the same time, since the frames were three, the total amount of time for all images was still identical to that employed in the dynamic condition in Leo et al.'s study, where a successful recognition was performed. Thus, if newborns were able to create a face representation on the basis of the combination of the three images, they would have been able to perform a successful recognition, because the face representation would have been more resilient to different presentations of the same face. Instead, newborns seem to have stored in memory each face image at an individual level, without relating the three versions of the same face to each other, so the face representation they constructed was still linked to the three single images. Consequently, because of the fact that 20 seconds might have been insufficient to form an accurate face representation, newborns were not able to perform recognition despite being familiarized to three images.

In sum, the current set of experiments show several major findings. First, a non-rigid facial motion, in particular the movements of emotional expressions, plays a role in newborns' face recognition. When presented with three face images, newborns show recognition performance only when the images are presented in motion, and not if presented in a static condition. Thus, when the quality and quantity of pictorial information are exactly equated across conditions, facial motion cues have a beneficial effect, allowing face recognition despite the change in facial expression. This result supports the representation enhancement hypothesis, given that motion information provides an enhancement of the construction of a more resilient underlying face representation. By contrast, when the faces are presented statically, each face is retained in memory separately from the other and the resulting face representation is more image-related and inefficient to allow face recognition when the face changed.

Another important result of the current set of experiments shows that the role of facial motion is nevertheless subordinated to the visual difference between the different facial presentations. In other words, when the learned face and the face that has to be recognized are too distant in terms of the perceptual similarity, such as a happy face and a fearful face, then motion cues lose their beneficial effect on face recognition. This result is in line with previous newborns' studies showing that, the more salient is a facial characteristic that changed from the habituation to the test phase, the more hindered is face recognition (Gava et al., 2008; Turati et al., 2006). It seems legitimate to infer that the perceptual discrepancy between the memorized face and the face that has to be recognized plays a fundamental role in allowing or inhibiting face recognition in newborns: with a high visual difference (such as, a happy face and a fearful face), motion cues do not seem to play any role in supporting newborns' face encoding. By contrast, if the difference remains under certain degrees, then motion cues seem to play a central role, as showed by the comparison between the multi-static condition and the dynamic condition in Leo et al. (in prep.).

A third major finding is that not all typology of non-rigid motions have the same beneficial effect. On the contrary, some of them might even inhibit face recognition in newborn babies. In particular, a biologically impossible motion, such as the stroboscopic motion, leads to worse performance compared to the biologically possible motion, such as the happy facial movement. This result is in line with other infants' studies showing an early sensitivity for the naturalness of the facial dynamicity (Bulf & Turati, 2010; Ichikawa et al., 2011; Xiao et al., 2014) and, more generally, it supports the existence of an innate sensitivity to the kinetic cues characteristic of the biological motion of living beings (e.g., Bardi, Regolin & Simion, 2011; Simion, Regolin & Bulf, 2008). It is possible that another kind of non-rigid facial motion, such as talking, might have the same beneficial effect as long as it is biologically possible. Future studies should be conducted in order to verify this idea.

Overall, when the three experimental static conditions (i.e., Leo et al., Experiment 2 and Experiment 4, see Table 3.1) are considered together, one may conclude that, the more evident is the difference in facial pictorial information, the more newborns' performance is penalized. A possible interpretation of the present data is that, under static presentation, the underlying face representation is pictorial in nature, because it is strictly related to the image from which it derives. This consideration stems from three results: 1) when in the habituation phase the frame depicted the first level of intensity of the happy expression and in the test phase the same face was presented in a neutral expression, newborns performed a novelty preference, that is, a full recognition; 2) when in the habituation phase the frame depicted the third level of intensity and in the test phase was presented the neutral expression (in other words, when the perceptual difference between the faces increased), newborns performed a familiarity preference, that is, they discriminated the two stimuli but, at the same time, they discovered the dissimilarities between the habituated stimulus and the new aspect of the same stimulus in the test phase. Thus, newborns needed to encode the new aspects of the habituated stimulus re-exploring the familiar face; 3) when the three levels of intensity were shown in the habituation phase and the task required infants to accumulate 20 seconds of fixation time for each frame, and in the test phase the same identity with a neutral expression was presented, newborns performed an unsuccessful recognition. The interpretation might be that, in this condition, newborns were not able to construct a face representation combining all the three different images and retaining in memory each face as independent. Thus, when motion cues are not present, newborns seem to rely more on an image-matching process for recognition, in which the more distant are the images, the more difficult is the recognition. This finding is in line with the previous reported model of the development of memory (Johnson & de Haan, 2001; Nelson, 1995), according to which, in the first weeks of life, infants are not able to relate the information stored in memory to each other and encode faces at an individual level.

When the three dynamic conditions (i.e., Leo et al., Experiment 1 and Experiment 3, see Table 3.1) are considered together, instead, it could be concluded that, under dynamic conditions, newborns seem to construct a more resilient and not image-constrained face representation. In fact, when the same amount and the same quality of pictorial information is provided, motion cues allow face recognition, demonstrating that newborns were able to combine the information acquired from the three images, in order to create a face representation that allows face recognition when some facial characteristics changed. Notwithstanding, the beneficial effect of non-rigid facial motion seems limited to certain degrees of facial changes, meaning that, when the habituated face and the test face possess high perceptual differences (such as two different facial expressions), newborns are not able to recognize the familiar face in the test phase. Thus, perceptual discrepancy between face presentations seems to play a primary role in driving newborns' face recognition. In addition, non-rigid motion cues could also have a hindering role on newborns' face encoding: in particular, if an impossible facial motion is provided, newborns are not even able anymore to rely on the pictorial facial information to achieve recognition. Thus, one can hypothesize that, at birth, infants already might show a special sensitivity to the biologically possible facial motions. This hypothesis is supported by previous findings that demonstrate that infants are responsive to the naturalness of the facial motion patterns (Bulf & Turati, 2010; Ichikawa et al., 2011; Xiao et al., 2014) and needs to be further explored.

Chapter 4

Study 2: The categorization of dynamic facial expressions in 3-month-old infants

Humans are very proficient in extracting socially relevant information from faces, emotional expressions among them. Reading promptly and efficaciously conspecifics' emotional states is essential for social interactions and represents a fundamental adaptive advantage to survive (e.g., Darwin, 1872). The capacity to recognize others' emotional states is fundamental especially for young infants, since it provides a prerequisite to various social skills in the first year of life, such as interpersonal communication in absence of linguistic competences (e.g., Preston & de Waal, 2002), social learning, i.e., deriving information about the environment observing others' emotional reactions (e.g., Bandura & McClelland, 1977), and social referencing, i.e., using others' facial expressions in behavioral regulation (e.g., Feinman & Lewis, 1983). Accordingly, the study of facial expressions recognition has always received a lot of attention in infants. However, almost the total of the existing infant studies have employed static snapshots of facial expressions, typically at their peak point. If one considers that a facial expression is intrinsically dynamic, it becomes fundamental to investigate how infants process dynamic facial expressions.

In the present study, the role of motion cues in infants' processing of facial expressions will be examined. Although there are no explicit theories regarding the role of motion on the processing of facial expressions, it is reasonable to predict that dynamic cues might affect infants' processing of emotional expressions in similar ways as it affects the processing of facial identity. Thus, here I investigated whether facial motion cues might enhance the categorization of facial expressions in young infants, consistently with the representation enhancement hypothesis.

4.1 Recognition of facial expressions in infancy

One of the fundamental question concerns the origin of recognition of facial expressions. Evidence coming from infants supports the idea that recognition of emotion from facial expressions undergoes a protracted time course, extending even until adolescence to include adult-like interpretations (e.g. Gao & Maurer, 2010). This long developmental process has an experience-dependent nature (e.g., Leppänen & Nelson, 2009) and involves several gradual steps that start in early infancy with the detection of the perceptual information (i.e., how the expression visually appears) and proceed to the more mature knowledge about the concept of the conveyed emotion. Thanks to the gradual experience with the contingencies between a particular facial expression and meaningful events, infants gradually learn to link the perceptual appearance of the expression to the concept components of the emotion (e.g., Quinn et al., 2011).

The development of recognition of facial expressions in infancy has been studied both employing unimodal and multimodal cues, specifically from auditory or visual stimuli only, or from vocal and facial stimuli presented simultaneously. As for the latter series of studies, it seems that, when emotions are expressed both from facial and vocal channels, discrimination of emotional expressions emerges earlier compared to discrimination of emotional expressions conveyed only by unimodal (auditory and visual) stimuli (e.g., Floom & Bahrick, 2007). This is not surprising, given that for young infants, dynamic, naturalistic and multimodal displays are the optimal stimuli to process (e.g., Walker-Andrews, 1997). Multimodal events are associated with greater attentional salience and more efficient stimulus processing, as compared with the same events with no intersensory redundancy (Reynolds, Bahrick, Lickliter & Guy, 2014). Indeed, through the detection of intermodal invariants, infants discover the meaning of emotional expressions. According to Walker-Andrews (1997), perceptual development is characterized by an increasing differentiation of the information: "*infants may first recognize the affective expressions of others as part of a unified multimodal event that has an unique communicative affordance*" (Walker-Andrews, 1997, p.

449) and only later infant recognize the same information in vocal expression and facial expression alone. The present study will focus on the development of the recognition of facial expressions relying only on visual cues, in so doing, faces will be presented without any other auditory cues.

The present work is not devoted to study the development of the ability to understand the meaning of facial expressions, which is a different and fundamental aspect of recognizing expressions. Some studies suggest that this ability starts to appear around 12 months of age, when infants show the ability to use others' facial expressions to guide their behaviors: for example, with the visual cliff paradigm, Sorce and colleagues (1985) demonstrated that one-year-old infants crossed the cliff (a transparent surface over an apparent drop) only when their mothers, standing on the opposite side of the cliff, displayed positive expressions, like happiness and interest, whereas they did not feel confident to cross the surface when their mothers manifested a fear and anger face (Sorce, Emde, Campos & Klinnert, 1985). These findings suggest that infants correctly interpreted the meaning of their mothers' facial expressions to regulate accordingly their behavior in an ambiguous situation.

Perception of a facial expression as a "sign of emotion" implies responding to another's internal state, and indicates that the infant has inferred information about the underlying emotion. Before this, other fundamental and preparatory abilities have to develop: detection, discrimination and categorization. In general, detection indicates that an observer is sensitive and responsive to some information (Sekuler & Blake, 1994); discrimination refers to the ability to tell the difference between two or more objects or events (Sekuler & Blake, 1994); finally, categorization is the ability to group different objects into the same class on the basis on one, or more common properties (Bornstein, 1984).

4.1.1 Detection of facial expressions in infancy

Newborns are well prepared to rapidly develop competencies related to the perception of emotions, as they can detect affect-relevant information from faces. The particularly salient facial features, such as opened mouth and eyes, which may or may not be related to an emotion, automatically trigger some early active subcortical structures (e.g., Johnson, 2005). It has been suggested that the subcortical brain systems (including the amygdala) are functional at birth and play a role in orienting newborns attention towards faces. With experience, this mechanism gradually enhances the activation of certain cortical areas, such as the occipital regions (V1, V2), important for visual information in general, and the occipito-temporal areas (STS, fusiform gyrus) that respond selectively to faces (Adolphs, 2002; Leppänen & Nelson, 2009). This mechanism assures a relevant experience with faces from the very beginning on. Although the key components of the emotion-processing networks and their interconnectivity seem to be established soon after birth, the wiring pattern becomes more refined over the course of postnatal development. This suggests that emotion-related brain structures might be functional at the time when infants start to exhibit behavioral discrimination of facial expressions.

4.1.2 Discrimination of facial expressions in infancy

In order to recognize a facial expression infants have first to correctly *discriminate* among different facial configurations belonging to different emotional expressions, i.e., perceive the dissimilarity between two (or more) emotional stimuli. It is assumed that the capability to discriminate different facial expressions is the foundation on which the ability to detect the invariant attributes across the member of the same category develops; in other words, it is the foundation of the ability of categorization (Bornstein & Arterberry, 2003).

According to the extant available literature on infants' ability to recognize emotional expressions from static face pictures (for reviews, see de Haan & Nelson, 1998; Grossman, 2010), it seems that even newborns manifest rough capacities to discriminate among some facial expressions (e.g., Farroni, Menon, Rigato & Johnson, 2007; Field, Woodson, Greenberg & Cohen, 1982; Field, Cohen, Garcia & Collins, 1983). Field and collaborators (1982, 1983) presented newborns with live female models posing happy, sad and surprised expressions, and demonstrated that newborns' looking times increased when the expressions changed. More recently, Farroni and colleagues (2007), employing static pictures of happy, fear and neutral expressions, did not find discrimination capabilities between fear and neutral faces, but they found a preference for happy when paired with the fearful expression (see figure 4.1).

Figure 4.1. Stimuli used in Farroni and collaborators study (2007).

The authors explained such results as due to the early active subcortical route, which might be activated in the same way from neutral and fearful faces. Differently, happiness would be preferred thanks to a precocious perceptual learning mechanism, which acquires this facial expression from the very beginning, given that happiness is likely the most frequent expressions humans experience in their first days of life.

Starting from 3 months of life, the discrimination ability becomes more stable, although the results are sometimes not unanimous. At this age, infants can discriminate between happy and surprise and happy and anger, but they do not discriminate happy from sad, nor sad from surprise faces (Barrera & Maurer, 1981; Young-Browne, Rosenfeld & Horowitz, 1977). Infants can also discriminate among smiling faces that vary in their intensity (Kuchuck, Vibbert & Bornstein, 1986). At 4 months of age infants are able to discriminate among different examples of faces that vary in the fear intensity (Nelson & Ludemann, 1986). In addition, at the same age, infants manifest a preference for happy expression compared to angry and neutral faces, but they do not manifest any preference between an angry and a neutral face (LaBarbera, Izard, Vietze & Parisi, 1976). Schwartz and colleagues (Schwartz, Izard & Ansul, 1985) reported some different findings at 5 months of age: when tested with a familiarization procedure, infants can discriminate between sad and fear, but they do not discriminate between happiness and anger, nor happiness and interest. Interestingly, a characteristic pattern of responses were found: infants show discrimination ability between angry and sad, angry and fear, and angry and interest only when first familiarized to angry, but not when first familiarized to the other expressions. A similar pattern of responses has been found also at 7 months of age: infants can discriminate between happy and fear only when they are first habituated to happy and not when the expressions are presented in the reverse order (Nelson, Morse & Leavitt, 1979). This asymmetrical pattern of responses will be discussed in more details throughout the chapter.

Overall, the results of these studies suggest that, within the first half-year of life, infants are able to discriminate among several facial expressions. However, with the exception of happy emotion that seems to be steadily discriminated earlier compared to other facial expressions, developmental studies are sometimes not unanimous regarding which and when emotional expressions are discriminated. The most corroborate explanation relies upon the idea that the precocious discrimination capabilities are likely due to the detection of the difference between the salient facial features (such as the degree of the mouth and eyes opening), that could or could not be related to a particular facial expression. Indeed, the visual system in the first months of life is still under development (e.g., Banks & Salapatek, 1983) and this evidence renders unlikely that young infants discriminate facial expressions on anything other than salient facial features (e.g., Grossmann, 2010). This implies that young infants' discrimination performances may be driven by the saliency of the facial features, rather than facial expression per se, rendering the discrimination performance quite instable and dependent on the experimental conditions. The visual system undergoes relevant development only in the following months (e.g., Gwiazda, Bauer, & Held, 1989; Hainline, Riddell, Grose-Fifer & Abramov, 1992). Consequently, the issue of whether infants truly discriminate facial expressions cannot be unambiguously disentangled, since it is not clear what specific facial information infants are processing from the experimental stimuli.

Similarly, the ability to discriminate between facial expressions does not specify whether infants' responses would generalize beyond the model tested. Typically, discrimination ability is tested by presenting infants the same identity posing different facial expressions. However, when only a single model is used to depict one expression, it is difficult to know whether infants are discriminating on the basis of featural changes (i.e., any potentially salient facial characteristic, even not relevant to the expression), rather than changes in expression per se. If infants are presented with different exemplars of the same expression, the featural characteristics will change across models, reducing the likelihood that infants would attend to isolated features (deHaan & Nelson, 1998).

4.2 Categorization

There are several definitions of categorization, but, in general, it refers to the ability to group multiple objects, events, or properties of a common class into the same cluster or category (Arterberry & Bornstein, 2002; Quinn, 2002). Categorization is the foundation of cognition (e.g., Bornstein, 1984). First, it structures perception, giving order and organization to the variety of stimuli present in the sensory world. Faces are just one of the abundant examples of how the environment provides a flux of stimulation that needs to be reduced and organized in order to have sense. Categorization allows the recognition of the familiar information, promoting the storage and the retrieval of the information, given that, when a stimulus is categorized, a large amount of relevant information related to that category is made available. In this sense, infants do not need to memorize each of the mother's smiles to recognize her happy facial expression. Finally, categorization facilitates the acquisition of new knowledge, affording meaning to new stimulation: for example, possessing the category of happy facial expression facilitates the discrimination of other emotional categories, such as fear (Bornstein & Arterberry, 2003). In sum, how we perceive the surrounding environment is profoundly shaped by categorization, which guides the organization of the complexity of the stimuli information (Brosh, Pourtois & Sander, 2010). Given its central role in cognition in general, the development of the categorization ability is likely to start very early in life. Despite the growing number of studies on early categorization abilities, the underlying mechanisms and the nature of the categorization process are still debated.

Among different theories, one issue that is commonly accepted is that categorization may occur at different levels depending on the type of information infants use to group together different objects (Bornstein, 1984; Mandler, 2000; Quinn & Eimas, 1986). It has been proposed that analyzing the information that infants, and later the toddlers, use to develop their knowledge could be the optimal way to understand the development of categorization (e.g., Madole & Oakes, 1999). Indeed, with development, there are fundamental changes in the type of the object's characteristics that infants pay attention to (e.g., Gibson, 1966). Moreover, infants learn that some attributes are related with each other and, later, that the attributes can have different functions in different contexts. Consistently, several hypothesis have been made regarding the number and the typology of levels on which categorization can occur. Bornstein (1984) proposed four different categorization levels with different ages of emergence. More specifically, infants younger than 6 months of age may carry out the simplest forms of categorization based on the recognition of the same object across multiple presentations that can vary in the appearance (such as the same stimulus changing in orientation, or sensory modality), whereas only at the end of the first year of life, they learn to carry out more advanced forms, in which the equivalences are more qualitative and functional. Quinn and Eimas (1986) made a distinction between categories based on the sensory experience and those that are less dependent on perceptual data. These two types of categories are distinguished on the basis of the abstractness of the attributes that define them: the attributes that define sensory–perceptual categories seem to have their basis in the concrete, sensory-level experience, whereas the other categories are defined by semantic information or the theory-based experience. Similarly, Mandler

(2000) proposed that infants could categorize at a perceptual level, matching stimuli based on the physical appearance (i.e., how they look on the surface); otherwise, they can categorize on a conceptual level, depending on the knowledge of what the objects are, their function, their role, or other conceptual properties that cannot be inferred from the external appearance of the stimulus (Mandler, 2000). The difference between these two kinds of processes can be summarized as that between knowing how something looks like and knowing what something is.

Young infants' categories are likely based on the so-called perceptual features, because of two reasons: 1) their perceptual, motor and linguistic skills allow the access only to this kind of information (e.g., Madole & Oakes, 1999); 2) the development of the second typology of categorization requires experience. Indeed, conceptual categorization requires additional knowledge regarding, for instance, the contingencies between the object and other directly or indirectly associated events and it necessarily develops as a function of experience in the everyday life. Mandler (1992) proposed that, whereas conceptual categorization cannot be directly inferred from the sensory information, the process of perceptual analysis might be innate and the basis on which a translation process leads to the conceptual format. Therefore, conceptual and perceptual categories can coexist from infancy, even though sensory-perceptual information is insufficient most of the time to form the building blocks for conceptual representations.

Other theorists have argued against such "perceptual-conceptual" differentiation (e.g., Hayne, 1996). This debate is still under discussion and trying to answer is not the purpose of the current work. What is relevant, are the implications that such conceptualizations have on the nature of the infant's representation of a particular object. If the infant categorizes on a more conceptual basis, it can be inferred that the underlying mental representation is independent of specific attributes with which the stimulus is depicted. For example, some studies reported that infants as young as three months of age are able to categorize pictures of dogs as different from cats, and horses from zebras (Eimas & Quinn, 1994; Quinn, Eimas & Rosenkrants, 1993). However, it has been demonstrated that such early categorizations abilities are based on the capacity to detect the differences between the facial features of the animals, rather than the more global concept of the animal categories (e.g., Quinn & Eimas, 1996). These studies indicate that 3-month-olds are already able to form perceptual categories. A more advanced categorization ability was demonstrated only at the end of the first year of life: after being habituated to static displays of cars, or dogs, 9-month-old infants demonstrated the ability to recognize as familiar the instance of the same category even if depicted by point-light displays stimuli, in which only the dynamic information is available (Arterberry & Bornstein, 2002). These results suggest that their representations of cars and dogs might be more conceptual than perceptual already at nine months of age.

Moreover, the different levels at which infants may categorize different stimuli can also shed light on the mechanisms that enable the infants' categorical and perceptual-based representations to develop into the more sophisticated concepts typical of adults (e.g., Quinn et al., 2002). It has been argued that the perceptual categories, based on the concrete, perceptive information of the objects, might be the foundation on which concepts are successively formed (e.g., Madole & Oakes, 1999; Mandler, 2000; Quinn & Eimas, 1996). In this sense, the perceptual-based representations of young infants might be the bootstrapping points for the acquisition of the more abstract information related to the more advanced concept: infants first have to learn what a category looks like and then to associate these perceptual categories with other properties by means of an enrichment of the relative representations (e.g., Quinn et al., 2011).

4.2.1 Categorization of facial expressions in infancy

Facial expressions can be thought as categories marked by a bundles of correlated and different attributes that can be categorized at different levels according to the experience infants gathered with a particular class of expression (Quinn et al., 2011). In order to be useful in communication, infants need to understand that the expression conveys the same meaning across individuals. In addition, infants need to recognize that an emotional expression remains the same despite changes in its intensity (Bornstein & Arterberry, 2003). To do so, infants have to extract the relevant and invariant characteristics of the facial expression, ignoring the irrelevant and varying attributes. The categorization ability in infants has been typically studied using variants of the visual familiarization and habituation procedure: during the first experimental phase, infants are presented with more exemplars of the same emotion category, differing in the identities and/or intensities by which the expression is depicted. Afterwards, infants are presented with a novel exemplar of the familiarized category and a novel exemplar of a novel category. Successful categorization requires that infants recognize the similarity of the expressions presented in the habituation phase and the one presented in the test phase, discriminating it from the novel category's exemplar and directing their attention towards the novel one. Therefore, facial expressions can be categorized only on the basis of the facial features and their spatial relations, even without possessing any knowledge about emotions (e.g., Adolphs, 2002; Calder, Lawrence & Young, 2001). For example, one can detect the similarities between different facial configurations pictured by raised lip corners and crinkly eyes, without knowing that what is represented is a smile. On the other hand, on a more advanced level, emotional expressions can be categorized on the basis of the affective meaning conveyed by the facial expressions. In this perspective, one can suppose that infants may show the ability to categorize facial expressions much earlier as compared to the development of the understanding of the conveyed emotion. These early representations of facial expressions, even if based only on surface cues, might constitute the placeholders for the development of the more abstract category representations that gradually become associated with other sensory cues (such as the vocal intonation patterns) and, more generally, with life experiences including referencing situations (such as a fearful face when there is a threat in the environment). With development, therefore, the representations become richer, carrying also the social value.

4.2.2 State of art

Studies on infant's categorization provide information that cannot be inferred from discrimination studies. As already stated, discrimination tasks do not solve the question of whether infants discriminate expressions based on featural information, that may or may not be relevant for a particular facial expression, or based on a more configural processing of the facial features making up an emotional expression. For example, if recognition of a particular emotional expression takes place independently from the identity or the intensity with which the expression is posed, then it is possible to infer that infants' responses are not based only on featural differences in the visual information (deHaan & Nelson, 1998). To determine whether infants discriminate different emotions on an affect-relevant basis, or on the basis of isolated features unrelated to emotion, in an intriguing study, Caron and colleagues (Caron, Caron & Myers, 1985) habituated different aged-group infants (from 4 to 7 months of age) to different models posing a "toothy-angry", "non-toothy angry", or "non-toothy smiling" expression (see Fig 4.2). After habituation, infants saw two new models posing the familiarized expression and a novel expression, i.e., a "toothy-smiling". The rationale behind this is that, if infants categorize on the basis of the affective tone, they would show a novelty response when habituated to the angry expression, toothy or non-toothy. Conversely, if infants' looking behavior is mostly affected by the salient characteristics, they would show a novelty preference for the toothy smiling, only after being habituated to the non-toothy expressions, regardless of whether it depicted anger or happiness. Results showed that, until 7 months of age, infants are responsive to non-specific features (when they are available), rather than to the affective meaning. These findings suggest that particularly salient facial features (that are even more evident in static representations of facial expressions), may guide infants' behavior, detracting attention from the facial features really relevant to the expression.

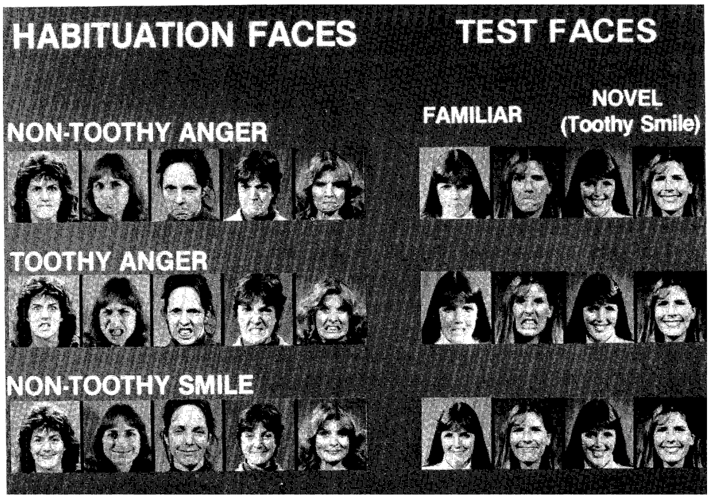


Figure 4.2. Stimuli utilized in Caron and collaborators' study (1985).

Therefore, infants might be driven by saliency of facial features, even if they could be capable of perceiving something more than just perceptual information. Consequently, the question of whether infants truly perceive emotion from facial expressions cannot be unambiguously disentangled, since it is not clear what kind of information infants are extracting from the experimental stimuli. For instance, when 7-month-old infants are grouping together different instances of the same expression on the perceptual basis of *toothiness*, it is not possible to know if they are nonetheless inferring the emotional expression from facial configuration.

However, it is worth to note that, in this study, the tooth-visibility was made particularly evident: indeed, the facial stimuli mostly differed for this feature. Maybe it is not so surprising that this facial feature drove infants' attention in this particular case (Leppänen & Nelson, 2006). With regard to this, other studies have tried to minimize the possibility that infants may rely on individual peculiar feature, by varying the salient information across the models during familiarization. For example, by showing the same facial expression depicted with different degrees of *toothiness*. In one of such investigations, 5-month-old infants were presented with the happy expression posed by several models and with differences among the exemplars in the toothy and non-toothy mouths (Bornstein & Arterberry, 2003). Results indicate that infants are able to generalize the happy emotion across variations in both individuals and intensities of smiling, responding to a fearful expression as belonging to a different emotion category.

Another interesting study investigated if infants categorize emotional expressions on the basis of the relevance of a particularly salient facial characteristic. Results showed that 7-month-old infants are able to discriminate happy from angry and fearful emotional expressions when faces are presented both in an upright and inverted orientation. Conversely, they can categorize only when stimuli are presented upright and not inverted (Kestenbaum & Nelson, 1990). These results suggest that, whereas discrimination may be based on single facial features (equally perceivable in the two orientations), categorization is based on the configural processing of the emotion-relevant information, which is orientation-specific. Interestingly, in the same study, the authors also found that, when presented with a happy expression where *toothiness* was particularly evident, and then tested with the same expression and the angry one, both with no visible teeth, infants were able to categorize happy even in the inverted orientation. These data indicate that, when a facial characteristic is explicitly notable, infants categorize facial stimuli on this basis, rather than on the emotion-relevant information.

Serrano and collaborators (Serrano, Iglesias & Leoches, 1995) reported the ability to categorize happy, angry and neutral expressions in 4- to 6- and 8- to 9-month-old infants, even though, in another study, it has been reported a failure in categorization for the same expressions in 7-month-old infants (Phillips et al., 1990). It is possible that this discrepancy might due to Serrano's study lack of investigation of the ability to discriminate within the same category: in order to conclude that infants actually respond to the emotion category, it is necessary to demonstrate that they are able to discriminate within the same category. Indeed, if infants are not able to differentiate between the exemplars of a category, a new exemplar of the familiarized category would be not observed because they would not detect the difference from the seen previously exemplars (de Hann & Nelson, 1998).

When confronted with happy and fear pair of expressions, seven-month-old infants show categorization of happy emotion posed by different models (Nelson et al., 1979; Nelson & Dolgin, 1985), and with different intensities (Kotsoni, de Haan & Johnson, 2001; Ludemann & Nelson, 1988). However, the results are asymmetrical because, when infants are familiarized with fearful faces and subsequently tested with a new identity posing fear and a new identity posing happiness, infants do not show evidence of categorization. Similar outcomes have been found also with other expressions and at different ages. For example, 24-week-old and 7-month-old infants show the ability to categorize happy expression in a happy-surprise pair, but they do not exhibit categorization ability when first familiarized to the surprised emotion (Caron, Caron & Myers, 1982; Ludemann & Nelson, 1988). Four- to 6-month-old infants are able to categorize fear and anger, but they show evidence of categorizing surprise only if they are first tested with anger and not when first tested with fear (Serrano, Iglesias & Leoches, 1992). Similarly, 7-month-olds generalize surprised expression and discriminated it from fear only when surprise is presented first (Ludemann & Nelson, 1988).

As for the happy-fear pair of expressions, some authors have argued that the asymmetry in performances may reflect a pre-existing preference for the fearful expression (e.g., Kotsoni et al., 2001; Nelson & Dolgin, 1985; Nelson et al., 1979), which seems to emerge around 7 months of age and has been demonstrated in various studies with different tasks (for a discussion, see Peltola et al., 2013). This attentional bias towards fear can cause an asymmetrical response because, after being habituated to a fearful face, in the subsequent test phase happy is the novel stimulus, but the fearful face is the preferred one, thereby creating a sort of conflict between the pre-existing preference and the novelty preference. Conversely, when happy is presented during habituation, the fearful expression is both the novel and the preferred stimulus and no conflict is generated.

Finally, Ludemann (1991) investigated 7- and 10-month-old infants' ability to group facial expressions into broader categories of positive (happiness and surprise) and negative expressions (anger and fear). Infants were habituated to different faces depicting prototypical positive expressions (i.e., happiness and surprise). Ten-month-old, but not 7-month-old infants, recognize the familiar expression when habituated to the prototypical positive expressions, generalizing discrimination of the positive affect. These results indicate that, by 10 months of age, infants begin to categorize expressions as positive or negative, recognizing the affective similarity of the familiar positive facial expressions. Importantly, this study suggests that, by the end of the first year, infants can categorize expressions based on their underlying meaning rather than perceptual similarity.

To sum up, the reported evidences on the ability to categorize facial expressions in infancy seem quite fragile, high sensitive to experimental conditions and sometimes not unanimous. In general, it seems that infants begin to develop the ability to categorize facial expressions only at 7 months of age, with the exception of happiness, which has been demonstrated to be categorized at 5 months of age (Bornstein & Arterberry, 2003). There might be several explanations for this difference, but the main view posits that happy faces are the most encountered in a normal developmental environment (e.g., Malatesta & Haviland, 1982; Nelson, 1987), whereas other negative expressions start to be displayed on caregivers' faces only at the end of the first year of life, when infants actively and independently explore the environment, putting themselves in potentially dangerous situations (e.g., Campos et al., 1990). Given that infants need frequent expositions to the variable versions of the same facial expression in order to form a mental representation, it is likely that they form an earlier representation of the happy expression (Leppänen & Nelson, 2006).

Nonetheless, 4-month-old infants failed to categorize happiness when it is confronted with surprise and anger (e.g., Caron et al., 1982, 1985), therefore the ability to categorize happy facial emotion is thought to develop only at 5 months of age.

4.3 Other studies

Some evidences coming from naturalistic observations of real face-to-face interactions with their own mothers, suggest that infants' ability to process facial expressions might have been underestimated. For example, at 2 months of age babies are already receptive to the subjective states of their mothers, detecting violation of social rules (such as timing) and expecting caregivers to produce contingent responses during both positive and negative face-to-face interactions (e.g., Nadel, Carchon, Kervella, Marcelli & Réserbat□Plantey, 1999; Nadel, Soussignan, Canet, Libert & Gérardin, 2005). A highly sensitivity to social contingencies is also demonstrated with the Still Face paradigm at a similar age (e.g., Toda & Fogel, 1993). Between 2 and 6 months of life the way infants approach to the caregiver becomes increasingly organized within the mother-infant exchanges of communications, showing a more awareness of the mothers' emotionally behavior (e.g., Kahana-Kalman & Walker-Andrews, 2001; Kaye & Fogel, 1980; Messinger, Fogel & Dickson, 1999; Trevarthen, 1993). In particular, it has been shown that the mother's positive facial expressions, among other channels (such as vocal tone and touch), play a fundamental role in the development of more structured and efficient mother-infant interactions (e.g., Lavelli & Fogel, 2005; Messinger & Fogel 2007).

All these data suggest that infants show sensitivity to emotional expressions at earlier stages and with more stability compared to what is reported by the experimental studies (5 months for happy expression and 7 months for negative expressions). Certainly, real-life situations, where stimulation is multimodal and contingent, facilitate the processing of the stimuli. It should also be noticed that the precociousness of the sensitivity to emotional information reported in these studies might rely, at least to some extent, on the vast experience infants accumulate with their mothers' face, highlighting the experience-dependent nature of the development of facial expressions' recognition. Nonetheless, these evidences demonstrate that very young infants, when provided with significant and frequent exposure to certain facial expressions, are responsive to the emotional information embedded in facial configurations. Another relevant aspect to stress is that, in the real face-to-face interactions, faces are not only multimodal, but also dynamic.

After all these considerations, the purpose of the present study is to test whether the categorization of happy facial expression is present at an earlier stage of development compared to that described in the infants' literature. Despite some evidence reports that 4-month-old infants are not able to categorize happy expression (Caron et al., 1982, 1985), here we ask the question of whether infants as young as 3 months of age will be able to categorize a very experienced and significant stimulus, such as the happy expression, when more ecological stimuli, that is expressions presented dynamically, are provided. To this end, we tested 3-month-old infants in a categorization task in which they were familiarized to different identities showing different intensities of a familiar emotion category (i.e., happiness) and a less familiar emotion category (i.e., fear). Afterwards, infants were tested with a new exemplar of the familiarized category and another exemplar of the novel category. Stimuli were presented in loop in order to give the impression of a dynamic face changing its identity and expression's intensity.

In addition to behavioral performance, we recorded infants' eye movements with an Eye Tracker. Although there are several studies investigating Caucasian infants' eye movement patterns when processing static versions of faces (e.g., Haith et al., 1977; Gaither, Pauker & Johnson 2012; Maurer & Salapatek, 1976), few studies employed dynamic facial stimuli in analyzing eye movement patterns (e.g., Hunnius & Geuze, 2004; Lewkowicz & Hansen-Tift, 2012; Wheeler et al., 2011) and even less studies investigated looking behavior with the Eye Tracker when infants are presented with facial expressions stimuli (Hunnius, de Wit, Vrins & von Hofsten, 2011; Peltola, Leppänen, Vogel-Farley, Hietanen & Nelson, 2009).

According to these studies, at two months, infants tend to scan the eye region of static faces (Maurer & Salapatek, 1976). Similar pattern was found when dynamic face stimuli were employed: when presented with a video of a woman with a neutral expression and counting, or talking, infants between 3 and 5 weeks of life tend to scan the edges of the face and start to pay attention to the eyes around 9 and 11 weeks, whereas mouth is looked quite seldom (Hait et al., 1977). Such tendency seems to increase with age: starting from 3 months onwards, infants show increasingly more fixations towards the eyes (Hunnius & Geuze, 2004; Wheeler et al., 2011). However, the looking distribution between face regions highly depends on the stimulus format. For example, if the face is speaking and the audio is made available, with increasing age infants tend to focus more on the mouth region (e.g., Lewkowicz & Hansen-Tift, 2012). It seems that infants start to adjust their way of scanning to the characteristics of the different stimuli from the age of 14 weeks on (Hunnius & Geuze, 2004). As for infants' looking pattern towards emotional face stimuli, Hunnius and collaborators (2011) investigated 4- and 7-month-old infants' and adults' looking distribution between the eyes, nose and mouth regions in threat-related expressions (i.e., anger and fear) and non-threat-related expressions (i.e., neutral, happiness and sadness). Results indicated that only adults showed distinct viewing strategies for threat-related and non-threat-related emotions, in which a more "gaze aversion strategy" was present for fearful and angry faces. In contrast, infants looked at the eyes of fearful and angry faces as much as they looked at the eyes of faces with neutral, happy, and sad expression. Similarly, Peltola and colleagues (2009) reported no differences in scanning patterns by happy, neutral or fearful faces in 7-month-old infants. Again, the eye region was shown to be the most observed area compared to the other face areas. In both these studies, however, emotional stimuli were presented statically. To our knowledge, no one has analyzed yet infants' eye movements during the presentation of dynamic expressive facial stimuli.

4.4 Experiment

The aim of the experiment was to test the ability of 3-month-old infants to categorize happy and fear facial expressions presented dynamically. In a within-subject design, each infant was familiarized to both happy and fear expressions. A familiarization procedure was employed, in which infants have to accumulate a fixed amount of time on the stimulus before the test phase. Previous studies employing dynamic facial stimuli with the same-aged infants utilized 20 and 40 seconds as shorter and longer familiarization periods, respectively (Brenna et al., 2013; Turati et al., 2011). Because of the stimuli complexity, in which infants have to process different facial expressions' intensity and different facial identities, we choose two familiarization periods too, 20 and 40 seconds as shorter and longer durations, respectively, in a between-subject design.

Several possible outcomes are possible: first, infants might show categorization ability only when familiarized to the more familiar emotion category, and not to the less familiar one. Second, the dynamic information provided in the familiarization phase (i.e., faces presented in motion) might allow infants to categorize both facial expressions. Finally, infants might not be able to categorize any facial expression, despite the dynamic presentation.

4.4.1 Method

Participants

The final sample comprised a total of twenty-four healthy Caucasian 3- to 4-month-old infants (11 males, M = 104 days, SD = 9.7). All babies met the screening criteria of normal delivery and birth weight. Infants were tested only if awake and in an alert state, after their parents gave their informed consent. Twenty-three further infants were excluded from the final analyses because of failure to complete the second familiarization session ($n = 11$), fussiness or falling asleep ($n = 5$), side bias (> 90% of time spent looking at one direction; $n = 4$), failure to reach the familiarization criterion ($n = 2$) and experimental error ($n = 1$).

Stimuli

Stimuli were chromatic photographs of twelve Caucasian women's face (aged 20-30). Each face was photographed in a frontal pose, under the same lighting conditions. Women were asked not to wear glasses or jewelry. Actresses were instructed to produce the facial expressions of fear and happiness. They were provided with sample images from the NimStim dataset of Facial Expressions (Tottenham et al., 2009) and asked to imitate them as naturally as possible, thinking to personal experiences and/or visualizing a particular event that could elicit the target emotion.

Several trials were made before the women reported to be ready. With Adobe Photoshop, all images were successively equated for luminance and contrast and the minor distinctive details were removed. The faces were inserted in an oval black shape of 19 x 12,5 cm (18° x 12° ca.) to cover the outer face contour so that infants could focus exclusively on the inner part of the face. In the test phase, the distance between the stimuli was 9,5 cm (9° ca.)

During familiarization, stimuli were dynamic video-clips composed by five 500-ms frames, in which four women, each one with a different identity, posed four different degrees of intensity of the same expression of happiness (in the happy session), and fear (in the fear session). Specifically, the four intensity grades that have been presented during familiarization phase were grade 1, 2, 4 and 5. During each single familiarization, on repeated trials the four frames were displayed in loop in order of intensity, to give the impression of a moving and increasing happy and fear expression, despite the fact that each frame showed a different face. In the loop, the frames were overlapped so that the position of the eyes and the mouth was approximately the same and the dynamic was more fluent. The fifth frame was a black frame inserted between grade 5 and grade 1, to render clear the beginning of each single loop of the facial expression. The duration of a single expression loop was 2000ms. During the test phase, two static pictures of two different identities were presented side by side: one woman posed a not-before-seen midpoint (grade 3) of the familiarized expression and the other woman posed the novel expression paired for the degree of facial expression's intensity (see Figure 4.3). Four different series were created: two for the familiarization to the happy expression (Happy A and Happy B) and two series for the familiarization to the fear expression (Fear A and Fear B). Different identities across happy and fear sessions were used, so that each session showed twelve different identities (six each: four in the familiarization and two in the test phase), with the constraint that different persons modeled each degree of the expressions.

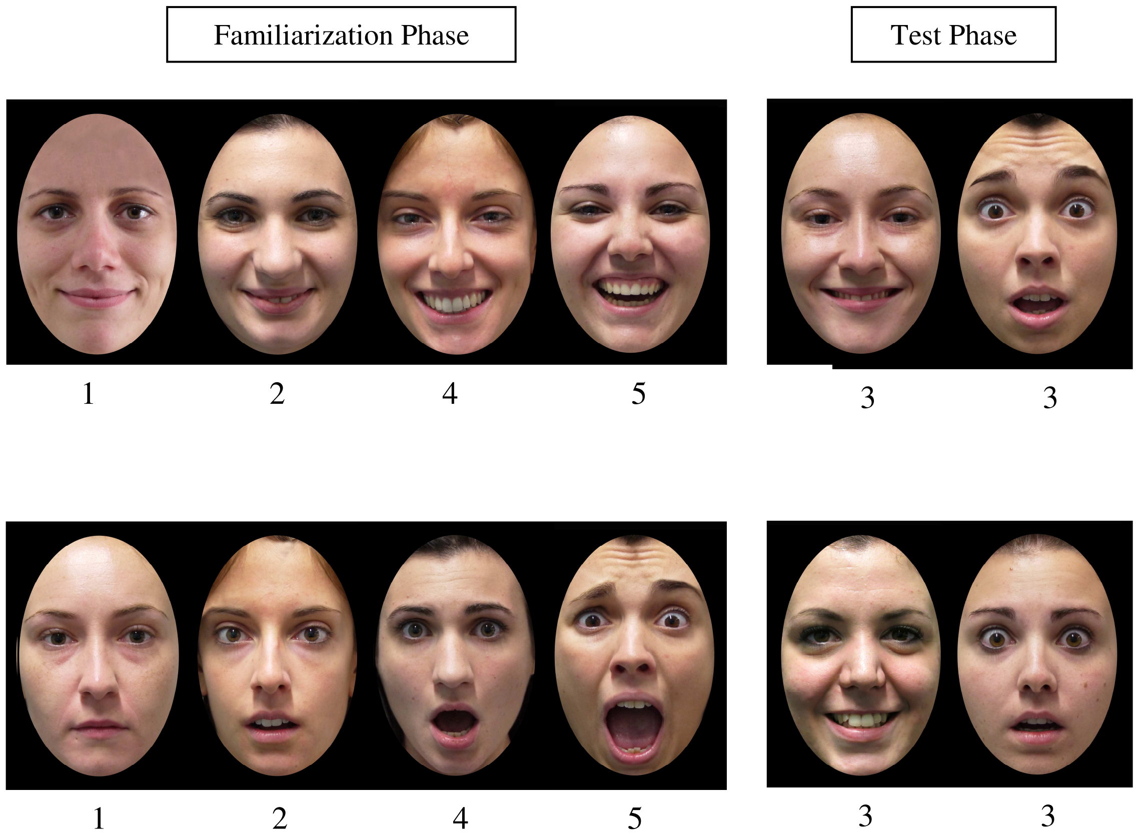


Figure 4.3. Two of the four series of stimuli employed both in Familiarization Phase and Test Phase. On the top the happy expression, on the bottom the fear expression. Numbers refer to the intensity level.

The infants underwent two consecutive familiarizations (Happy A and Fear A or Happy B and Fear B) without any identity's repetition. With a rate from 1 to 5, twelve adults judged the intensity of the happy and fearful expressions of the 24 pictures employed in the four series (12 identities x 2 expressions), confirming the order of the intensities in all series.

Apparatus and Procedure

Infants were tested in a dark and quiet infant lab at the Department of Developmental and Social Psychology of the University of Padova. They were seated in an infants' car seat 60 cm away from the screen on which the stimuli were displayed. The parents were instructed to remain as quite as possible during the experimental sessions. Stimuli presentation and data collection were performed using E-Prime 2.0. An Applied Science Laboratories (ASL) Eye Tracker with a 50 Hz sample rate was used to record infants' eye movements. The screen was 19-inch monitor with resolution of 1024 X 768 pixels. All stimuli were presented on a black background.

An experimenter-controlled familiarization procedure was used. Half infants were randomly assigned to the short (20sec) familiarization, the other half to the long (40sec) familiarization. In a within-subject design, each infant underwent to two consecutive familiarizations, one for each facial expression. As a brief break between the two familiarization sessions, 2 min of a cartoon-theme was shown on the screen. Within each session, the order of presentation (happy first or fear first) was counterbalanced across infants.

The happy familiarization was preceded by a calibration phase and was followed by the test phase, composed by two presentations. During the calibration, a noisy cartoon character was presented at three different locations across the screen (the top left-corner, the center and the bottom right-corner). Calibration accuracy was checked and, if necessary, it was repeated until successful. After the calibration procedure, a colored, dynamic and noisy attention getter (AG) was projected in the center of the screen. As soon as infants had accumulated 500ms of fixation time, the AG turned off and the familiarization phase began. Infants were presented with a video in the center of the screen of a happy facial expression performed by four different identities with four different intensities (i.e., 1, 2, 4 and 5). The infant began to accumulate looking time when he/she looked at the stimulus for enough time so that to be considered a fixation, defined as a period of at least 100 ms during which the fixation point did not change by more than 1° of visual degree. The familiarization phase ended when the familiarization criterion was reached, i.e., 20sec of total fixation time in the short familiarization condition and 40sec in the long familiarization condition. Only when this criterion was reached, the stimulus was automatically turned off and the AG was turned on. After 500ms of fixation time, the AG turned off and the test phase began. The same AG was used also between the two test presentations. In the test phase, two new identities were presented side-by-side, one posing the familiar facial expression (happy) and the other posing the new facial expression (fear), both facial expressions with a new degree of intensity (i.e., 3). In the test phase, a total of 10 s of looking time have to be accumulated, with the only constrain that at least 1 s has to be dedicated to both stimuli. Because of that, the 10 s of total looking time could exceed if the infant was still looking at the same stimulus when the amount of 10 s was already reached. In this case, the trial continued until the last fixation was spontaneously terminated. In the second test-presentation, the left-right stimulus position of the stimuli was reversed. In addition, the position of the stimuli in the first presentation was counterbalanced across infants.

The fearful familiarization was the same as the happy one, except that the video in the familiarization phase conveyed a fearful emotion.

4.4.2 Results

Familiarization Phase

Table 1 shows the average looking time that infants took to reach the familiarization criterions (i.e., 20 and 40). An Index of interest was calculated dividing the criterion (20 or 40) by the time infants needed to reach it and subsequently converted into a percentage score. This Index of interest indicated the proportion of time toward the stimulus on the total time used to reach the criterion. To know whether familiarization's data were affected by the familiarized emotion, or the familiarization periods, one repeated analyses of variance (ANOVA) was carried out on the Index, with Familiarized Emotion (happy and fear) as within-subject factor and Familiarization Period (20 and 40) as between subject factor. Results revealed a significant two way interaction $F(1,22) = 6.2$, $p = .02$, $\eta^2_p = .24$, which indicated that, when familiarized to the fear expression, infants are faster to reach the criterion compared to when they were familiarized to the happy expression, but only if the criterion to reach was 20 seconds (M = 60%; SD = 22% in the fear condition and M = 73%; SD = 24% in the happy condition).

Table 4.1. *Mean total looking time (in seconds) to reach the familiarization criterions. Standard deviations in the brackets.*

Criterion	Happy	Fear
20	37.46 (13.05)	32.88 (19.64)
40	66.25 (17.27)	72.65 (24.98)

In contrast, when the familiarization time to reach the criterion was 40 seconds, no difference in the index were found (M = 64%; SD = 16% in the fear condition and M = 61%; SD = 20% in the happy condition). A possible interpretation of this result is that infants were immediately attracted by the fear stimulus, but then this interest waned with time. This result is in line with some adult studies reporting how fearful faces are rapidly detected (e.g., Lundqvist & Ohman, 2005; Williams & Mattingley, 2006), but are subsequently no longer looked at (Becker & Detweiler-Bedell, 2009).

Test Phase

To test whether infants were able to recognize the new instance of the familiar emotion category from the novel instance of the novel emotion category in the test phase, a novelty preference score was computed. Each infant's looking time at the novel stimulus during the two test presentations was divided by the total looking time to both test stimuli over the two presentations and subsequently converted into a percentage score (novelty percentage, NP). Hence, a novelty preference score above chance level (50%) indicates that infants looked longer at the novel stimulus than the familiarized one, and vice versa for a novelty preference score lower than 50%. The percentage of novelty preference, but not the raw looking time toward the stimuli was chosen as a dependent variable because infants had to accumulate the same amount of time (10 s) for each test phases, therefore the total looking time for each infant was approximately the same.

To verify if the series of stimuli, or the order of happy and fear conditions interfere with the results, preliminary ANOVAs on NP scores toward the stimuli were carried out, with the factors Stimulus Series (Happy A and Fear A; Happy B and Fear B), or Condition Order (happy first and fear first). No significant main effects or interactions were found (all *p*s > .05). Therefore, we collapsed data over these variables for subsequent statistical analyses.

To determine whether infants' looking preferences were influenced by the familiarized emotion and the familiarization periods, a mixed ANOVA on novelty percentages with Familiarized Emotion (happy and fear) as within-subject factor and Familiarized Period (20 and 40) as between-subject factor was carried out.

The analysis revealed a significant main effect of Familiarized Emotion, $F(1,22) = 10.96$, $p = .003$, $\eta^2_p = .33$, which indicated that, when familiarized to the happy emotion category, infants significantly looked longer to the novel exemplar of the novel category (NP = 56.3%, *SD* = 11.5%, t[23] = 2.68, p = .013), whereas when familiarized to the fear emotion category, infants did not manifest any significant novelty preference (NP = 43.5%, *SD* = 16.7%, t[23] = -1.9, p = .069, *ns*.). Thus, it seems that 3-month-old infants categorize only when habituated to happy and not to the fear emotion category, even though they show a tendency to direct their attention towards the new exemplar of the familiar category when familiarized to the fear emotion. However, due to the high variability of the infants' NPs, the result is not statistically significant. No other significant effect or interaction was found.

Eye movement patterns

To examine how infants process dynamic facial expression, we investigated infants' eye movement patterns both in the Familiarization and Test phase. We first determine three areas of interest (AOIs; see Figure 4.1): eyes, nose and mouth, the same as in Hunnius et al. (2011). The three rectangles were identical. Next, we calculated the proportion of looking time infants spent in each AOI, by dividing the total looking time for each AOI (eyes, nose and mouth) by the sum of the total looking time in all the three areas and then converting this value in percentage.

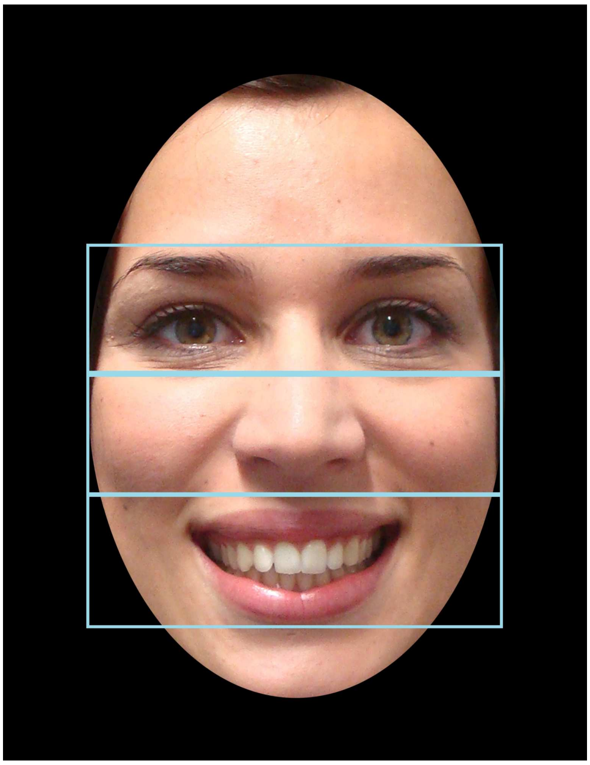


Figure 4.1. An illustration of the eyes, nose and mouth areas.

As for the Familiarization Phase, to investigate whether infants show a distinct looking distribution between happy and fear, and if such looking behavior might be influenced by the amount of familiarization time infants had to reach, a mixed ANOVA was performed on the percentage looking time (%). The Familiarized Expression (happy, fear) and the AOI (eyes, nose, mouth) were selected as within-subject factors and Familiarization Period (20, 40) as between-subject factor. The results showed a significant AOI main effect, $F(2, 44) = 14.47$, $p < .001$, $\eta^2_P = .4$ (Fig 4.2). We did, however, not find any other significant effect or interaction.

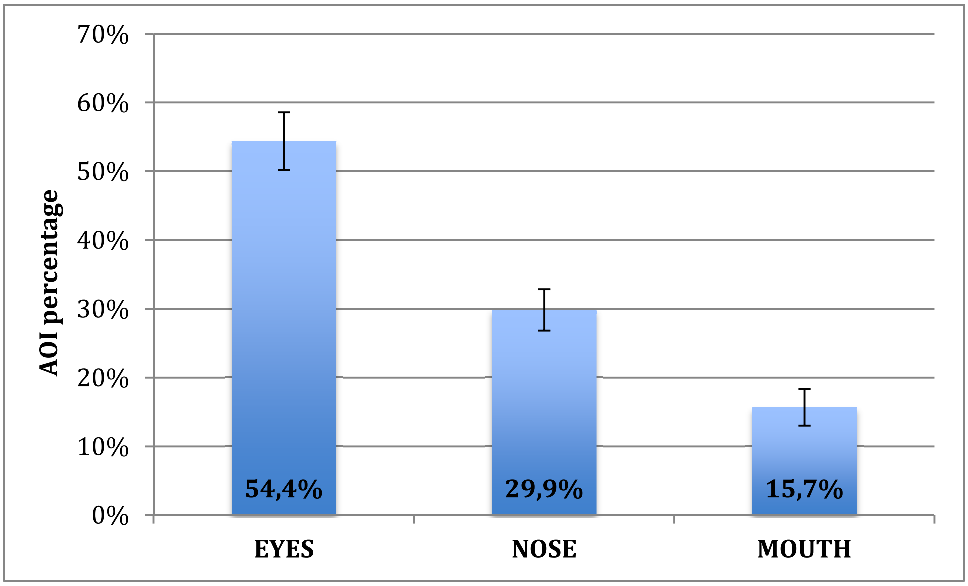


Figure 4.2. Proportion of looking time towards the three AOIs during familiarization, independently from the Familiarized Emotion and Familiarization Period.

The significant main effect suggests that infants showed different distribution in AOIs, independently from the expression they have been familiarized, or the length of the familiarization phase. In particular, infants looked at the eyes area ($M_{eyes} = 54.4\%$, $SD = 29.1\%$) significantly more than the nose ($M_{nose} = 29.9\%$, $SD = 20.8\%$; $t[47] = 3.6$, $p = .001$) and the mouth areas ($M_{mouth} = 15.7\%$, $SD = 18.4\%$, $t[47] = 6.09$, $p < .001$) and the nose area significantly more than the mouth area ($t[47] = 3.74$, $p = .001$). Moreover, both the eyes and the mouth area differed from the chance of 33%: $t(47) = 5.09$, $p > .001$, and $t(47) = -6.53$, $p > .001$, respectively. Thus, infants significantly looked towards the eyes, whereas they significantly disregarded the mouth area. By contrast, infants did not look at the nose area differently from chance level, $t(47) = -1.04$, $p = .305$, *ns*.

As for the Test Phase, in order to investigate whether infants showed different viewing strategies according to the novelty of the facial expression (familiar vs novel stimulus), or the familiarization length (20 vs. 40), we performed two separate ANOVAs on the proportional looking time (%) for each familiarization (happy and fear), with AOI (eyes, nose and mouth) and Novelty (Familiar, Novel) as within-subject factors and Familiarization Period (20, 40) as between-subject factor. Regarding the familiarization to the happy emotion, the analysis revealed a significant main effect of AOI, $F(2,44) = 19$, $p < .001$, $\eta^2_P = .46$, which indicated that infants looked longer at the eyes area ($M_{eyes} = 58.4\%$, $SD = 28\%$) compared to the nose area ($M_{nose} = 25.5\%$, $SD = 17.9\%$, $t[47] = 5.31$, $p > .001$), and to the mouth area ($M_{mouth} = 16.1\%$, $SD = 19.3\%$, $t[47] = 6.57$, $p > .001$), as well as the nose area longer than the mouth area, $t(47) = 2.66$, $p = .011$. No other significant effect or interaction was found. Such looking distribution pattern strictly resembles that one showed during the familiarization phase. This result indicates that, when familiarized to the happy expression, infants showed the same looking distribution pattern independently from the novelty of the stimulus, and the familiarization period.

Regarding the familiarization to the fearful emotion, the analysis revealed the same main effect of AOI, $F(2,44) = 5,4$, $p = .008$, $\eta^2_P = .19$, indicating that infants looked longer at the eye area ($M_{eyes} = 46.2\%$, $SD = 28.4\%$) compared to the nose area ($M_{nose} = 32.7\%$, $SD = 17.9\%$, $t[47] = 2.26$, $p = .029$) and to the mouth area ($M_{mouth} = 16.1\%$, $SD = 23.1\%$, $t[47] = 3.60$, $p = .001$), and the nose longer than the mouth area, $t(47) = 2.70$, $p = .010$, similarly as the happy familiarization. No other significant effect or interaction was found. Together, eye movement analyses revealed that infants focus their attention mainly towards the eyes, less to the nose and seldom to the mouth, regardless the facial expression they process.

4.4.3 Discussion

The current study examined 3-month-old infants' ability to categorize happy and fearful facial expressions when dynamic facial stimuli are employed. We obtained several findings. First, infants showed novelty preference (i.e., recognize the new exemplar of the familiarized category and direct their attention to the new exemplar of the new category) only in the happy condition, and not in the fear condition. Second, the eye-movements analyses revealed a) no differences in scanning behavior between happy and fear and b) that infants looked longer at the eyes region. Third, these effects were found both in 20 and 40 seconds of familiarization periods.

When familiarized to different identities posing different intensities of the happy category emotion, 3 month olds showed significant novelty preference, demonstrating the capacity to detect the similarities between the different exemplars of the happy category and the new instance of the same category, prefering to look longer at the new instance of the different fearful category. In contrast, when familiarized to the fearful category, they did not show categorization ability. This was the expected result and it is in line with the naturalistic observational studies on infants-mother interactions (e.g., Trevarthen, 1993), as well as the intermodal preference tasks (e.g., Kahana-Kalman & Walker-Andrews, 2001), showing how infants as young as 2 and 3 months of life are sensitive to positive facial expression when presented with salient, multimodal, familiar and dynamic face stimuli. Importantly, this result demonstrates an earlier categorization ability for happy expression compared to that one reported in the classical behavioral studies (e.g., Caron et al., 1982, 1985), where static version of faces have been used to test whether infants are able to categorize emotional expressions. This highlights the role of the dynamic facial information in enhancing the ability to process facial expressions in infants in a way consistent with the representation enhancement hypothesis. In particular, Caron and colleagues' studies (1982, 1985) suggest that, under static presentation, the face representation seems image-constrained because it did not allow categorization. In contrast, the successful categorization found in the current experiment indicates that, when provided with moving faces, infants are able to extract the invariant aspects between the four different models depicting different intensities of happiness, and recognize the same expression posed by a fifth model depicting a new degree of intensity. Thus, dynamic facial expression enhances the construction of a representation resilient to facial changes that allowed categorization of the happy facial expression already at 3 months of age.

Despite the facilitation effect of the dynamic presentation, 3-month-old infants did not achieve the categorization task when familiarized to the fearful category. The lack of a novelty preference for the new expression in the fear condition stresses the role of experience in the development of facial expressions' processing. In a typical growing environment, positive facial expressions are usually the most frequently experienced by infants because most frequently exhibited by the caregivers (Malatesta & Haviland, 1982). It has been suggested that the caregivers' positive expressions have the fundamental role to promote and reinforce the infant-caregivers relationships, especially in the first months of life (e.g., Lavelli & Fogel, 2005; Messinger & Fogel 2007). By contrast, negative facial expressions, such as fear, are rarely experienced before the end of the first year of life (Campos et al., 2000). Indeed, when infants start to actively explore the environment (crawling and, later, walking), they put themselves in potentially dangerous situations: since the distal distance from the caregiver increases, reading the caregiver's facial reactions become more important in order to detect the possible threats in the environment. Consequently, caregivers themselves produce more negative facial expressions, giving infants the possibility to discover the connections between particular facial configurations and significant contingent events (Campos et al., 2000). This explanation is in line with the hypothesis that the development of facial expressions' recognition might follow a trend according to the functional role that a certain expression can fulfill in a particular developmental stage (Izard, 1991). From this perspective, the recognition of the happy expression is adaptive very early in life, whereas recognizing negative facial expressions may become relevant only later. Accordingly, the available infants' literature reports that infants start to develop the ability to categorize negative facial expressions presented statically around 7 months of age (e.g., for a discussion, Peltola et al., 2013). Given the beneficial effect that dynamic facial stimuli have exerted with the happy emotion, it is possible that, employing dynamic facial stimuli, an earlier capacity to categorize fearful faces might be found, even though later than 3 months of age. Future studies should be carried out to test this idea.

Given that similar perceptual attributes might be sufficient to shape a perceptual category (where exemplars are matched on the basis of the external appearance; Mandler, 2000), a possible interpretation might be that infants were able to form categories relying upon the multiple exemplars presented during the experiment, even in absence of some prior experience with the category (e.g., de Haan & Nelson, 1998). However, this interpretation can be rejected in the light of the face that infants were not able to form a category of fearful faces based on the experience during the experiment. A factor that can hinder the formation of a category is showing few exemplars (Quinn, 1987): if infants are exposed to more instances of the same category during familiarization, this may enhance the process itself, given that more prototypes share a greater number of features with other exemplars of the same category. At the same time, more prototypes also shear the least number of features in common with the contrasting category (deHaan & Nelson, 1998). It might be that the four exemplars showed during the familiarization in the present study were not sufficient to allow 3-month-olds to form a category of the fear expression.

We also analyzed the eye movement distribution during both familiarization and test phases in the three face areas: eyes, nose and mouth. Overall, the analysis of the scanning pattern showed that infants look longer at the eyes than at the other face areas. The mouth area is the face region less observed by infants. This scanning pattern is in line with previous infants' studies employing both static and dynamic stimuli (e.g., Haith et al., 1977; Hunnius & Geuze, 2004; Hunnius et al., 2011; Wheeler et al., 2011) and highlights the important role played by the eyes when processing a face and, in particular, the emotional information conveyed by a face (e.g., Matsumoto, 1989): when adult are asked to judge facial expressions they tend to direct their first fixations toward the eye area of the face (Hall, Hutton, & Morgan, 2010). The crucial role of the eyes when processing faces and facial expressions is reported also in several newborns' studies (e.g., Batki, Baron-Cohen, Wheelwright, Connellan & Ahluwalia, 2000; Farroni, Csibra, Simion & Johnson, 2002; Rigato, Menon, Johnson & Farroni, 2011; Rigato, Menon, Johnson, Faraguna & Farroni, 2011). The early tendency to fixate the eye region might stem from the characteristics of the early infant-caregivers interactions: such interactions are indeed characterized by attracting attention to the eyes region and eye contact, making exaggerated facial movements and signals of pleasure (e.g., Papoušek & Papoušek, 1989). As for the mouth area, it has been shown that infants start to look at it when they begin to learn the language, around the end of the first year of life (e.g., Lewcowikz & Hansen-Tift, 2012). Again, such developmental pattern in infants looking behavior seems to follow a functional trend, in which certain face areas are more or less observed according to the functional role they could fulfill in a particular developmental stage.

Interestingly, such scanning distribution pattern (eyes > nose > mouth) does not differ between happy and fear expressions. This is in line with other studies showing that, differently from adults, infants younger than 7 months of age do not show specific viewing strategies during visual exploration of different emotional expressions (Hunnius et al., 2011; Peltola et al., 2009), not even when presented with dynamic faces. This finding indicates that the successful categorization of the happy emotion is not due to a difference in the way infants scan the happy and fearful stimuli. Overall, the current eye movement analyses, together with previous infants' studies, suggest that, in the first half year of life, the processing of facial expressions (presented statically or dynamically) may be more perceptual than conceptual in nature, as stated by Bornstein (1984).

Finally, the current study also showed how different familiarization lengths (20 or 40 sec) do not have a role in influencing infants' categorization performance. This means that an accumulation of 20 seconds is a sufficient amount of time to process the happy emotion category when conveyed by four different identities and with four different intensities. This result is in line with previous studies employing dynamic facial stimuli with 3-month-old infants (e.g., Turati et al., 2011). As for fear emotion category, not even 40 seconds are sufficient to allow infants to form a category of fear expression. The only effect of the lengths of familiarization was shown in the familiarization phase: infants were faster to reach the criterion of 20 seconds of looking time when familiarized to the fearful emotion category compared to when they were familiarized to the happy emotion category. Such difference was not evident when the criterion to reach was 40 seconds. These data might be explained by the fact that a fearful face is a salient stimulus, automatically detected thanks to its characteristics that trigger some subcortical response, both in adults and infants (Lundqvist & Ohman, 2005; Williams & Mattingley, 2006; see Johnson, 2005 and Leppänen & Nelson, 2012 for discussions). However, this fast and automatic detection is subsequently replaced by a more voluntary response, in which fearful configurations are no longer looked at (Becker & Detweiler-Bedell, 2009). Thus, fearful face seems to be an attractive stimulus that might trigger attention and activate attention-getting mechanisms. However, the attention-holding mechanisms do not maintain the focus of attention for a sustained period on such stimuli (e.g., Cohen, 1973). It has been proposed that such mechanism might be due to an evolutionary ancient mechanism that forces an alerting response to dangers in the environment (e.g., Nelson, 1987).

To conclude, the present study supports the role of facial motion in infants' processing of facial expressions in a way consistent with the representation enhancement hypothesis: when presented with dynamic expressive faces, 3-month-old infants are able to extract the invariant aspects across the different presentations of the same happy expression.

Chapter 5

The discrimination of facial expressions from face movement in infants: A study with point-light display.

Currently, the available literature on infants' recognition of facial expressions has focused almost exclusively on the ability to process static expressive information by using static images (e.g., de Haan & Nelson, 1998). Given the role played by facial motion in infants' face identity recognition, here I have proposed the hypothesis that similar benefits may also be extended to infants' processing of facial expressions. In the previous chapter, we tested the possibility that facial motion may support the processing of facial expressions in a manner consistent with the representation enhancement hypothesis. Specifically, 3-month-old infants' ability to categorize facial expressions has been tested under moving condition. Results showed that dynamic facial expressions lead to an earlier capability to categorize the happy expression, compared to that reported when static picture of facial expressions are employed (e.g., Bornstein & Arterberry, 2003). Thus, motion information may enhance the processing of facial expressions in early infancy, as they do in adult population (Krumhumber et al., 2013). This result is in line with the representation enhancement hypothesis, as it indicates that facial motion cues may enhance the construction of a face representation resilient to the different versions of the same facial expression.

The second hypothesis regarding a possible role of facial motion on infants' processing of facial expressions is the supplemental information hypothesis. As explained in the Introduction, one way to test this hypothesis is to verify the ability to infer socially relevant information, such as identity, from facial motion alone (e.g., Hill & Johnston, 2001). It has been demonstrated that 4- to 8-month-old infants are able to discriminate individuals from facial movement patterns alone (Spencer et al., 2006). The aim of the current study is to explore infants' ability to process facial expressions from facial motion alone. Specifically, we wanted to investigate infants' ability to discriminate facial expressions by relying exclusively on dynamic facial information, when other static pictorial cues (e.g., shapes, colors, and texture) are absent.

5.1 The processing of motion information alone: the point-light display stimuli

To date, very few infant studies have employed moving facial expressions as experimental stimuli. Since they all were reported in the Introduction, I just recall them briefly. Existing studies showed that infants as young as 3 months of age can discriminate expressions in audio-visual condition (e.g., Kahana-Kalman & Walker-Andrews, 2001). Brenna and colleagues (2013) found that 3-month-olds could discriminate the identity of two neutral faces, only when they were habituated with a happy, but not with negative, dynamic facial expression of the same face. Furthermore, presenting facial expression in apparent motion led 6- to 7-month-olds to discriminate subtle happy expression (Ichikawa et al., 2014). In sum, these studies demonstrated that infants are sensitive to the dynamic component of facial expressions. However, considering the fact that the dynamic expressive stimuli used in these studies also included static pictorial expressive information, these findings were insufficient to conclude that infants are able to use the dynamic information alone to process facial expressions.

The best way to isolate the motion information is the employment of point-light displays (Johansson, 1973), stimuli in which moving figures (a face, a body) are pictured by some markers located in critical points of the surface. In video clips, the only visible elements are the illuminated moving points of the figure, so as to separate the dynamic information from other cues revealed by the pictorial representation of the stimulus, such as forms, colors, texture and others. Indeed, static versions of point-light bodies and faces typically provide little information (e.g., Berry, 1990, 1991; Pavlova & Sokolov, 2003), but, when presented in motion, meaningless arrays of dots can convey a variety of important information (e.g., Troje, 2008). PLDs have been substantially utilized for the study of the perception of biological motion, the motion of living beings (Johnson, 2006; Troje, 2013). Employing PLD stimuli, many studies have now demonstrated the extraordinary capability of adults to infer a variety of socially relevant information on the basis of bodily kinetic cues alone. Naïve observers immediately and effortlessly perceive a person walking, running, jumping, kicking, dancing or whatever activity the person is engaged in (e.g., Dittrich, 1993; Norman, Payton, Long & Hawkes, 2004). Observers are also able to encode information like the identity of familiar individuals (Cutting & Kozlowski, 1977), even from a single arm movement (Hill & Pollick, 2000). Also personality inclinations (such as vulnerability), personality traits (such as shyness, trustworthiness, warmth, etc.), age and gender can be inferred from moving walker PLDs (e.g., Gunns, Johnston & Hudson, 2002; Heberlein, Adolphs, Tranel & Damasio, 2004; Kozlowski & Cutting, 1977; Montepare & Zebrowitz-McArthur, 1988). Adults are capable of identifying the gender even when performers are attempting to deceive, acting like a member of the opposite sex (Runeson & Frykholm, 1983). A salient characteristic conveyed by bodily movements is the emotional state. Different PLDs' studies have indeed demonstrated that the human perceptual system is endowed with a high sensitivity to motion information incorporated into emotional expression movements. For example, observers can accurately perceive distinct emotions portrayed in the movements of a point-light dancer (e.g., Dittrich, Troscianko, Lea, & Morgan, 1996), as well as in PLD bodies performing various types of movements (e.g., Atkinson, Dittrich, Gemmell & Young, 2004; Atkinson et al., 2012; Heberlein et al., 2004). Recognition success is enhanced when pairs of PLD actors are engaged in interpersonal communication (Clarke, Bradshaw, Field, Hampson & Rose, 2005) and it differs for individual emotions (e.g., Chouchourelou Matsuka, Harber & Shiffrar, 2006). People can identify a range of internal states even from point-light displays of human arms performing drinking and knocking movements (e.g., Pollick, Paterson, Bruderlin & Sanford, 2001).

Less is known about the social knowledge revealed by facial movement. By means of PLD stimuli, researchers have demonstrated perceivers' capability to detect age-related person qualities from facial motion patterns, such as physical and social power (Berry, 1990). Adults are also able to discriminate gender from moving faces involved in reciting the alphabet and telling jokes, and 5-year-old children achieve the same task when are shown with interacting PL faces (Berry, 1991; Hill, Jinno & Johnston, 2003). Identity information available from facial PLDs seems less easy to perceive: albeit Bruce and Valentine (Bruce & Valentine, 1988) found that subjects could recognize familiar faces, accuracy levels were poor. In addition, Humphreys and collaborators (Humphreys, Donnelly & Riddoch, 1993) report the clinical case of a prosopagnosic patient poor in judging expressions and gender from static pictures, which performs at normal levels on these judgments when presented with facial motion without other pictorial cues. Faces are also effective channels to communicate emotions when only motion cues are available. Bassili (Bassili, 1978) first employed PLD methodology to study the perception of facial expressions from motion information alone. In this study, 100 white patches were attached on actors' faces, which were filmed while expressing emotions. These films were then reproduced so that only the white patches were visible. Bassili demonstrated that adults are able to discriminate the six basic emotional expressions from these displays, showing for the first time that individuals' emotional states can be inferred from facial motion patterns without any other structural cues available. In a successive study (Bassili, 1979), the author also demonstrated that upper and lower facial areas' movements are differently important for the perception of distinct facial expressions (i.e., lower region is critical for happiness and disgust, whereas upper face is more relevant for anger and fear). More recently, with more advanced techniques to create PL facial stimuli, Bassili's results have been confirmed and deepened: observers are able to identify emotional states from facial PLDs (Atkinson et al., 2012) and this process is influenced by manipulation of temporal and, especially, spatial properties of facial kinematics (Pollick et al., 2003). Doi and collaborators (Doi et al., 2008) extended these findings to 4- to 6-year-old children, who demonstrated to be able to match happy and surprise expressions portrayed in point-light displays to the corresponding schematic images. All these evidences indicate that humans possess the ability to derive emotional meanings from conspecifics' movements. Such capability could stem from the precocious sensitivity to kinetic salient cues present in the visual world and related to human beings (see Simion et al., 2013 for a discussion).

5.2 Infants' processing of motion information

The ability to perceive PL depictions of human motion arises early, as evidenced by different studies. For example, starting from 3 months of life, babies show visual preferences for an upright walker PLD compared to the same stimulus in a random, or in an inverted version (e.g., Bertenthal, Proffitt & Cutting, 1984; Fox & McDaniel, 1982). At 6 months, infants distinguish directionality of a point-light walker (Kuhlmeier, Troje & Lee, 2010) and perceive it as a solid form (Moore et al., 2007). Sensitivity to body motion is also evidenced by differences in amplitude of event-related potentials (ERPs) to upright versus scrambled, inverted and impossible bodily PL animations, in 8-month-old infants (Hirai & Hiraki 2005; Reid, Hoehl & Striano, 2006; Reid, Hoehl, Landt & Striano, 2008). However, while several studies have investigated infants' general motion perception (i.e., perceive human body structures and kinematics from PLDs), only one very recent study assessed the capability to retrieve social information from PLDs. Missana and collaborators (Missana et al., 2015) examined 4- and 8-month-old babies' ERPs in response to point-light displays of happy and fearful body expressions, both in upright and upside-down orientations. The results revealed that 8-month-old infants' brain responses differ between happy and fearful body expressions; moreover, such differences are evident only when the stimuli are shown in the upright orientation and not in the inverted one. None of these effects were found in younger babies' ERPs. These data demonstrate that orientation- and emotion-sensitive brain processes emerge between 4 and 8 months of age, indicating an important developmental evolution during this time window in neural processing underpinning emotion detection and discrimination from body movements. This study not only indicates an early sensitivity for emotions portrayed by body motion patterns, but it also proves that infants as young as 8 months of age are able to discriminate happy and fearful bodily expressions from motion information alone.

Although no study has directly examined whether infants can process facial expression from PLDs, two evidences suggest that infants can process facial information from facial motion at a very early stage of life. I just recall them briefly, since they have been already reported in the Introduction. First, Stucki and collaborators (Stucki et al., 1987) presented 3-month-old infants with a PLD either of a face pretending to interact with a baby, or of a rubber mask animated by a hand. Results showed that infants can distinguish facial motion from inanimate motion on the basis of kinetic information alone. Second, using near-infrared spectroscopy (NIRS) with 7- to 8-month-old-infants, Ichikawa and colleagues (2010) demonstrated that facial movement conveyed by a surprised facial expression induces different brain responses in the right temporal brain area for upright, but not inverted PLD. This is the first study demonstrating that infants' brain activity is sensitive to a facial expression motion pattern conveyed by a PLD stimulus, as well as to its orientation. Thus, infants as young as 3 months of age seem to be sensitive to the facial motion cues conveyed by facial PLDs and, starting from 7 months of life, they show a sensitivity to the emotional expressions conveyed by facial PLDs. Together with Missana and collaborators' finding (2015), these data suggest that infants as young as 3 months of age can discriminate lower-level facial motion attributes, such as raising eyebrows and opening mouth, and older infants appear to process higher-level facial motion attributes from facial motion signals, such as facial expression.

According to the current theories on the early perception development (Lewkowicz & Ghazanfar, 2009; Maurer & Werker, 2014), we hypothesized an "attunement" developmental scenario in infants' ability to process facial expressive PLDs in the first year of life. In particular, young infants are able to process facial PLDs based on lower-level facial motion attributes, but they cannot process higher-level facial motion attributes. With increased age, the ability to process lower-level facial motion attributes will be replaced by an ability to process higher-level facial motion attributes (e.g., expression and identity). Thereby, older infants would be sensitive to the facial expression differences inherent in PLDs, but they would ignore the lower-level facial motion attributes difference. To examine this developmental scenario, we focused on infants at 3, 6, and 9 months of age.

The current study used a habituation and visual paired comparison (VPC) task to probe infants' ability to process facial expressions from happy and fear face PLDs with a within-subject design. In the happy condition, infants were habituated with a happy PLD. Their expression discrimination performance was then tested by a paired display of happy and fear PLDs. An increased looking to the novel fear PLD (i.e., novelty preference) indicates a successful discrimination. In the fear condition, everything is the same except that infants were habituated with fear PLD.

Prior studies have shown that infants are to be able to process happy, but not negative facial expressions from facial motion signals (e.g., Ichikawa & Yamaguchi, 2014; Kahana-Kalman & Walker-Andrews, 2001; Montague & Walker-Andrews, 2002). For example, infants' face discrimination can only benefit by happy, but not fear or angry dynamic facial expressions (Brenna et al., 2013; Otsuka et al., 2009). Moreover, infants only discriminated subtle happy, but not subtle angry facial expression from motion (Ichikawa & Yamaguchi, 2014; Ichikawa et al., 2014). It is because, in typical environments, infants are more likely to be exposed to happy than any negative dynamic facial expression (e.g., Campos, et al., 2000; Malatesta & Havildand, 1982). As a consequence, infants may only be able to process happy, but not fear expression from facial motion signals in the first year of life.

We used this happy expression specificity to probe whether infants can process higher-level facial expressive information form PLDs. If infants are able to process expressive information from PLDs, they should show a reliable novelty preference only in the happy PLD condition. It is because infants can use expression inherent in happy PLD to discriminate happy versus fear PLDs. However, they should not be able to discriminate the happy versus fear PLDs in the fear PLD condition. It is because of two reasons: 1) they cannot process fear expression from PLDs because of the lack of experience with dynamic fear expression; and 2) they would ignore the difference in lower-level facial motion attributes between happy and fear PLDs. This is because according to the "attunement" development theory (Lewkowicz & Ghazanfar, 2009), when infants are able to process higher-level attributes (e.g., facial expression), they would ignore lower-level attributes (e.g., raising eyebrows and opening mouth). Alternatively, if infants are unable to process higher-level facial expression from motion signals, they would use lower-level facial motion attributes to discriminate happy and fear PLDs. Thereby, we should observe novelty preferences in both the happy and fear conditions. In terms of the developmental change, young infants should show equal successful discrimination in the happy and fear conditions. Older infants would show novelty preference only for the happy, but not for the fear condition.

Apart from lower- and higher-level facial motion attributes, PLDs also contain basic kinetic information, such as the velocity, acceleration, and moving direction of each "point". Infants might also use only the kinetic characteristics to discriminate the happy and fear PLDs. To investigate this possibility, we also examined infants' discrimination of inverted PLDs. In these inverted PLD conditions, everything is identical to the upright conditions, except for the fact that the PLDs were presented upside-down. Inverted PLD contains identical kinetic information to upright ones, but inversion prevents integration of the illuminated points of PLD into a coherent dynamic configuration (e.g., Pavlova, 2012). If infants' PLD discrimination is based on a configural face-related processing of the motion patterns, any observed results should be specific to upright PLDs. Alternatively, if the discrimination is based only on PLD kinetic information, infants should be able to discriminate both the upright and inverted PLDs in a similar way.

In addition to behavioral discrimination performance, we recorded infants' eye movements with an eye tracker. Prior studies have shown specific eye movement patterns in processing facial expressions by showing an increased looking time to the upper face half (Jack, Blais, Scheepers, Schyns, & Caldara, 2009; Jack, Caldara, & Schyns, 2012). We expect to observe a similar eye movement pattern specific to happy expressive PLDs, which could serve as supplemental evidence for facial expression processing in infants. As for fear and inverted PLD, infants should not show this expression processing related eye movement pattern.

5.3 Experiment 1

5.3.1 Method

Participants

The final sample comprised a total of 79 Asian healthy infants: 27 3- to 4-month-old infants (15 females, *M* = 110 days, *Range*: 92-140 days), 26 6-month-old infants (17 females, *M* = 190 days, *Range*: 165-209 days) and 26 9-month-old infants (11 females, *M* = 277 days, *Range*: 243-305 days). All participants were recruited through community message board. Additional 55 infants participated in the current study, but were excluded from the final analyses because of failure to complete two test sessions (*n* = 25), fussiness or falling asleep (*n* = 10), experimental errors (*n* = 4), strong side bias (more than 95% of time spent looking at one direction, *n* = 2), failure to reach the habituation criterion (*n* = 2), and extreme long looking time (i.e., beyond 2 SD to the mean of total looking time to both stimuli in the test phase; *n* = 12).

Stimuli

PLD stimulus creation

We filmed expressive PLDs from five adult actors (3 women and 2 men, aged 26-31 years). Each actor was asked to imitate typical fear and happy facial expressions from the NimStim dataset of Facial Expressions (Tottenham et al., 2009). To record their facial expressive movements, we placed 41 reflective passive markers (diameter: 0.6 cm) to each actor's face. These markers were symmetrically arranged in the following face areas: one on the top of the forehead, four on the middle of the forehead (with the two lateral points placed slightly higher than the central ones), 8 surrounding each eye, four on each cheek, one on the nose, two below the nose, 6 surrounding the mouth, and three on the chin. During actors performing facial expressions, the 3-dimentional (3D) positions of each marker were recorded at 140 Hz by a SMART-D motion analysis system (Bioengineering Technology and Systems).

We performed several pre-processing procedures on the raw 3D locations data to generate 2D frontal view PLDs. First, we used a smooth algorithm to remove jitters in marker locations to ensure each marker moves smoothly. Second, we removed rigid head movement to ensure the PLDs only reflect muscle and bone movements without changing in viewpoints. Third, we converted 3D PLDs to 2D PLDs by projecting 3D locations to a 2D plane, which depicts frontal viewpoint. Finally, we added 8 additional dots with linear interpolation approach to make the PLDs resemble face configurations. These pre-processing generated 2D smooth facial expressive PLDs with 49 dots.

We then performed temporal adjustment to ensure that each PLD moves in similar pace. To do so, we first added 250 ms static clips at the beginning, which depicted the first frame of motion onset of each PLD. Then, to equate all the PLDs' durations, we chose to adjust the duration of period when PLDs reached peak expression. Because the PLDs remain static during their peak periods, adjusting this peak duration would not affect the naturalness of the dynamic facial expression information in PLDs. Finally, we added a static presentation of the last frame of facial expression offsets, which were the last frame when movement terminates. The resultant PLDs have the same duration of 2 seconds, which start to move at 250 ms.

PLD Stimuli selection

We recruited 15 novice adults (10 females, aged 19-55 years) to rate the happy and fear PLDs from the 5 actors. In each rating trial, a PLD presented in the center of a computer screen, and participants were required to choose one out of 4 expression labels to indicate which facial expression the PLD showed. The four candidate expression labels were: happy, fear, angry, and sad. Based on the rating accuracy, we chose two actors' PLDs as experimental materials, which showing the most representative facial expressions. One of them is a male actor, and the other is a female actress. The mean percentage of participants who chose the correct happy and fearful emotion label under the upright condition was 70% actor and 63% respectively. This range of percentage values is in line with previous studies in which the ratings of facial expressions conveyed by PLDs show high scores' variability across subjects and lowest accuracy for fear expression (e.g., Bassili et al., 1978, 1979; Pollick et al., 2003). When the videos were shown upside-down, proportions dropped to 20% and 40% for the happy and fear, respectively. When the PLDs were presented upright, percentage values were above the chance level of 25% for happy ($t[29] = 5.29$, $p < .001$) and for fear actors ($t[29] = 4.28$, $p < .001$). Instead, they did not differ from chance level when stimuli were presented inverted (all ps > .05).

The four final stimuli consisted in the happy and fear facial expressions modeled by the selected male and female actors. Dots (subtending approximately 0.47° each) were black embedded in a white frame measured about 11° × 14.5° of visual angle. The screen were the frames were projected was black. In the experimental test phase the distance between the two PLD's frames was 5.13 cm (about 5°). Within one frame, the distance between the dots of the happy stimuli ranged from 8.9 × 11.5 cm (about 8.5 ×11°) at the neutral state, to 8.9 × 12 cm (about 8.5 ×11.5°) at the peak point. As for fear stimuli, it ranged from 8.8 × 11.2 cm (about 8.5 ×11°) at the neutral state, to 8.7 × 12.9 cm (about 8.5 ×12.5°) at the peak point.

Apparatus and procedure

Infants were tested in a dimly lit and quiet room. They were seated on their parents' lap approximately 60 cm away from a 17-inch eye tracker screen, on which the stimuli were displayed. To reduce the possible interference from the parents, they were required to wear an eye-mask and remain as quiet as possible during the experimental sessions.

Each session started with an infant friendly calibration phase. Infants have to successfully fixated at a cartoon figure showing at the four corners and the center of the screen to start the test. This calibration phase ensures infants' eye movements can be recorded accurately and precisely. A habituation program built on E-Prime 2.0 controls PLD stimuli presentation in response to infants' looking behavior, which is recorded by an eye tracker (Tobii 1750, 50 Hz, 17-inch monitor).

Each infant needed to finish two experimental conditions: the happy and fear conditions. Each condition includes an infant-control habituation phase (Slater et al., 1985) and two gaze-contingent visual paired comparison (Gaze-contingent VPC) trials with a reversed left-right position of the two stimuli. In the happy condition, participants were first habituated with a happy PLD. Each habituation trial started with an animation video in the center of screen to attract infants' attention. Whenever infants looked at this animation for more than 1 second, the animation was replaced with a happy PLD video. The happy PLD video played until infants looked away from it for more than 1 second (Arterberry & Bornstein, 2001; Stucki et al., 1987), or infants looked at it for 20 seconds in total. The habituation phase terminated when infants reached the habituation criterion, which the average looking time of any of three consecutive trials was 50% or less than the longest average looking time of three consecutive trials. The habituation phase also terminated when infants looked at 20 habituation trials, but not reached the habituation criterion. This situation was regarded as “failed to habituated” and the data would be excluded from data analysis.

Two test trials followed the habituation phase. In each test trial, the habituated happy PLD video and a novel fear PLD video were presented on each side of screen. Because infant’s attention is very sensitive to motion signals, the simultaneous presentation of two PLD moving videos might affect infants’ looking behaviors. For example, when an infant is looking at the novel PLD, the motion of the habituated PLD may trigger infant’s attention from the currently fixated PLD. To solve this issue, we specifically designed a gaze-contingent VPC display. The major difference of this gaze-contingent VPC display from traditional VPC display is that PLD stimuli move only if participants look at them. When an infant is looking at the novel PLD, the novel PLD video is on and will play, but the habituated PLD remains or becomes static, and vice versa. Moreover, when infants did not look at neither of the two PLDs (e.g., at the beginning of each test phase), both PLD videos start to play concurrently so as to attract infants’ attention to the stimuli. Each PLD test trial ends when the total looking time to the habituated and novel PLD reaches 10 seconds, only if participants have looked at each of the PLDs for at least 1 second (e.g., Looking $\text{Time}_{\text{novel}}$ = 6.70 s and Looking $\text{Time}_{\text{habituated}}$ = 3.30 s). This design ensures that participants look at each of the PLD stimuli. The order of the two PLD test trials was randomized across experimental sessions among participants. The identity of the actor was the same for both the habituation and test phase.

The procedure of the fear condition was identical to the happy condition except for the difference in facial expression PLD represented. The identity of the actors in the PLD happy condition was different from the identity of the PLD in the fear condition. The identity of the two actors in the happy and fear conditions was counterbalanced across participants. An interval of 5 minutes separated the two conditions. Infants were randomly assigned to the upright or to the inverted condition in a between subjects design. For the inverted condition, the procedure was identical as in the upright condition except for the fact that all the PLDs were presented upside-down.

5.3.2 Results and Discussion

Habituation

Table 1 shows the average looking time and the number of trials that infants needed to reach the habituation criterion. To understand if habituation's data differed as a function of stimuli orientation, facial expression and age, two repeated measure analyses of variance (ANOVAs) were carried out on total looking time and number of trials, with Emotion (happy and fear) as within-subject factor and Orientation (upright and inverted) and Age (3, 6, and 9) as between-subject factors. No significant main effects or interactions were significant (all *p*s > .05).

Table 5.1 The mean total looking time (TLT, in second) and number of trials to reach the habituation criterion. Standard errors are in the brackets.

		Happy		Fear	
		Upright	Inverted	Upright	Inverted
3 months	TLT	85.1 (14.8)	79.6 (20.6)	90 (18.6)	48.7 (7)
	Trials	8.6 (.7)	8.3 (1.2)	8.8 (1)	8.4 (1)
6 months	TLT	108.2 (23.1)	60.3 (9.6)	77.9 (11)	64.9 (11.8)
	Trials	12.3 (1.4)	8.6 (1.3)	10.9 (1.1)	9.2 (1.2)
9 months	TLT	69.3 (10.3)	60.5 (13.3)	60.1 (13.3)	77.8 (25.5)
	Trials	9.4 (.9)	8.9 (.9)	8.2 (1.2)	9.2 (1.3)

PLD Discrimination

To test whether infants were able to discriminate the habituated PLD from the novel one in the test phase, we computed novelty preference scores. Each infant's looking time at the novel PLD during the two test trials was divided by the total looking time to both test stimuli over the two presentations and subsequently converted into a percentage score (novelty percentage, NP). Hence, a novelty preference score above chance level (50%) indicates that infants looked longer at the novel PLD. The percentage novelty preference score but not the raw looking time toward the stimuli was chosen as dependent variable because infants had to accumulate the same amount of time (10 s) for each test trial, therefore the total looking time for each infant was approximately the same.

To verify if the gender of the actor of the PLD stimuli, or the order of happy and fear conditions interferes with the results, preliminary ANOVAs on NP scores toward the stimuli were carried out, with the factors Stimulus Gender (male and female), or Condition Order (happy first and fear first). No significant main effects or interactions were significant (all *p*s > .050). Therefore, we collapsed data over these variables for subsequent statistical analyses. The following analysis focused on our two hypotheses: the happy expressive PLD specificity and upright PLD specificity.

Happy PLD specificity

To determine whether infants' looking preferences were influenced by the habituated emotion, PLD orientation, and age, we performed a mixed ANOVA on novelty percentages with Habituated emotion (happy and fear) as within-subject factor and Orientation (upright and inverted) and Age (3, 6, and 9) as between-subject factors.

The analysis revealed a significant interaction Emotion × Orientation, $F(1, 73) = 4.30$, $p = .042$, $\eta^2_p = .06$: in the upright condition, NP was 63% for the happy and 56% for fearful conditions, whereas in the inverted condition, NP was 55% and 56% for the happy and fear conditions. This interaction indicated that there was a difference in NPs between the happy and fear conditions only in the upright PLD condition.

More importantly, the results showed a significant Emotion × Orientation × Age interaction (F[2, 73] = 3.35, p = .040, η^2_p = .08). This 3-way interaction indicated that the development of PLD discrimination in the happy and fear conditions differed in the upright and inverted PLD orientations. Thus, we separated the data according to PLD orientation and performed two mixed ANOVAs on the novelty preference for upright and inverted PLD, with Habituated emotion (happy and fear) as within-subject factor and Age (3, 6, and 9) as between-subject factor.

With regard to upright PLDs, the happy PLDs led to a significantly larger novelty preference (M = 63%) than the fear PLDs (M = 56%, F[1, 37] = 8.19, p = .007, η^2_p = .18). Moreover, the Emotion × Age interaction reached significance, $F(2, 37) = 5.60$, p = .007, η^2_p = .23, indicating that the development of PLDs discrimination was different between the happy and fear conditions, as shown in Figure 5.1. To further explore this interaction, we performed a series of paired-sample t-tests to examine whether the novelty preference in the happy and fear conditions are significantly different. The results revealed that 3- and 6-month-olds did not show different novelty preference between the happy and fear conditions (3-month-olds: t[13] = 0.39, p = .702; 6-month-olds: t[12] = 1.28, p = .224). Nine-month-olds showed significant larger novelty preference for the happy than the fear conditions (t[12] = 2.52, p = .027). Moreover, we performed a series of one-sample t-tests against chance level (50%) to explore the novelty preference in the happy and fear conditions of each age group. With regard to the happy condition, all of the three age groups showed that infants were able to discriminate the happy and fear PLDs after being habituated with the happy PLDs (3-month-olds: t[13] = 2.28, p = .041; 6-month-olds: t[12] = 2.25, p = .044; and 9-month-olds: t[12] = 4.91, p < .001). By contrast, in the fear PLDs condition, only the 3-month-old infants showed significant discrimination (t[13] = 3.81, p = .002). Neither the 6- or 9-month-olds showed reliable discrimination (6-month-olds: t[12] = 1.92, p = .079; 9-month-olds: t[12] = -0.54, p = .601).

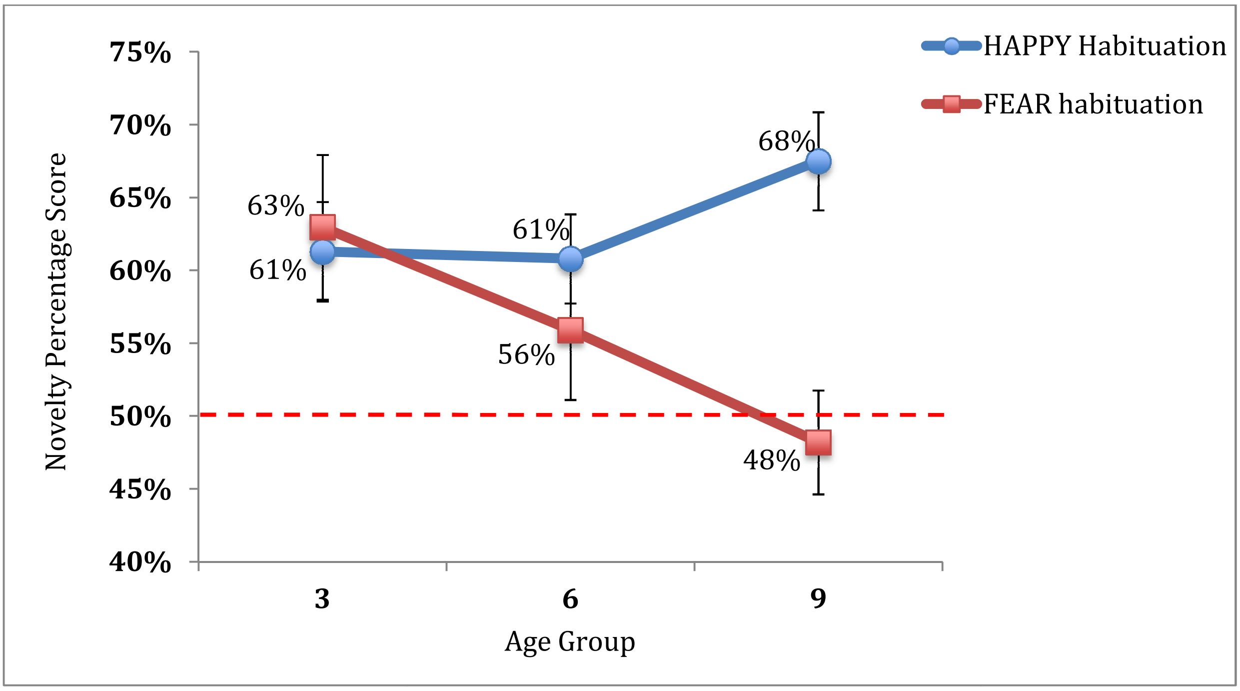


Figure 5.1. Mean novelty preference for each upright PLDs condition. Error bars represent unit standard error.

These results indicated that 3- and 6-month-old infants showed similar PLD discrimination for the two conditions, suggesting they processed the happy and fear PLDs in a similar way. By contrast, 9-month-old infants exhibited PLD discrimination specific to happy PLDs, suggesting that they processed happy and fear PLDs differently, which is consistent with our happy PLD specificity hypothesis. This developmental change further indicated that infants developed the ability to process facial expression purely from facial motion signals between 6 to 9 months of age.

To further probe the developmental changes in infants processing of happy and fear PLDs, we investigated the relation between the novelty preference scores for the happy and fear conditions. If infants processed the happy and fear PLDs in the same way, we should observe a positive correlation between the two. Alternatively, if infants processed the happy and fear PLD stimuli differently, there should be no correlation between them. In terms of the age-related change we predicted a positive correlation in young groups, but no correlation in the oldest group.

To examine these hypotheses, we first performed a multi-variant regression with the novelty preference score in the happy condition as outcome variable, and the novelty preference score in the fear condition, age in months, and their interaction as predictors. The results showed a significant effect of interaction (t = -2.54, p = .015), indicating that the relations between the novelty preference in the happy and fear conditions were significantly different in the three age groups. To explore specific relation in 3 age groups, we conducted *Pearson* correlations between the two in each age group. As shown in Figure 5.2, we found significant positive correlations in 3- (r = .52, *One-tailed* p = .027) and 6 months old infants (r = .60, *One-tailed* p = .015). However, 9-month-olds did not show significant correlation (r = -.35, *One-tailed* p = .124).

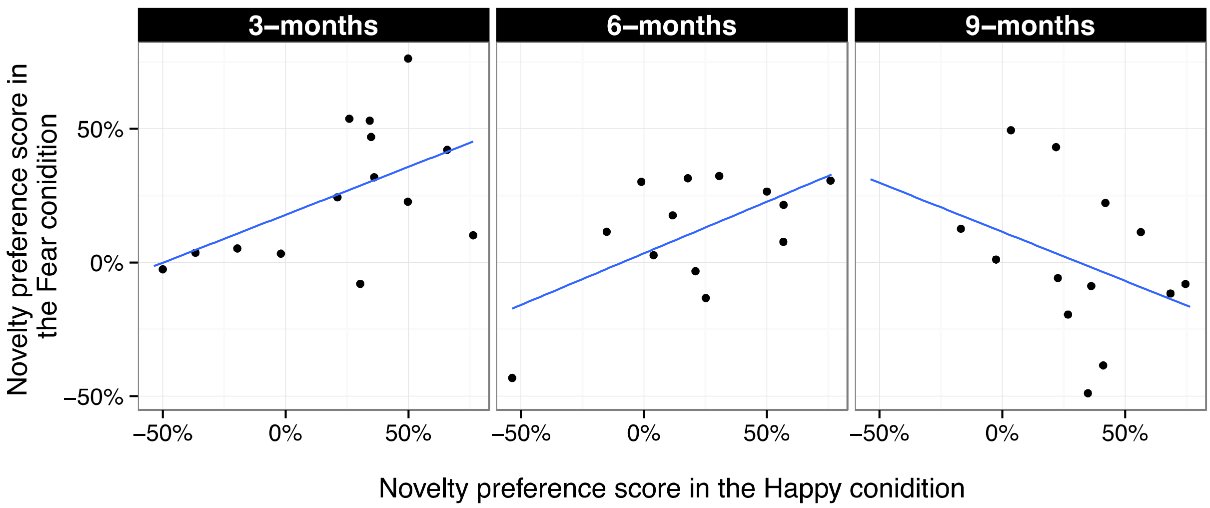


Figure 5.2. Relations between the novelty preference scores in the upright fear and happy PLDs habituation conditions. Blue lines represent linear trends between the two.

These correlational results were consistent with novelty preference results, indicating that young infants processed the happy and fear PLDs with similar processing mechanism. Nine-month-old infants developed a distinctive processing mechanism for happy PLDs from that for fear PLDs between 6 to 9 months of age. These results collectively demonstrated the emergence of the ability to process happy facial expression from its dynamic characteristics.

Upright PLD specificity

We then focused on the novelty preference in the inverted conditions to examine whether the observed happy PLD specificity is specific to the upright PLDs. The same Habituated emotion (happy and fear) and Age (3, 6, and 9) mixed ANOVA was conducted on the novelty preferences in the inverted conditions. The results showed no significant main effects or interactions, (*p*s > .05; see Figure 5.3). It indicated the developmental change in processing PLDs found in the upright conditions was specific to the upright PLDs.

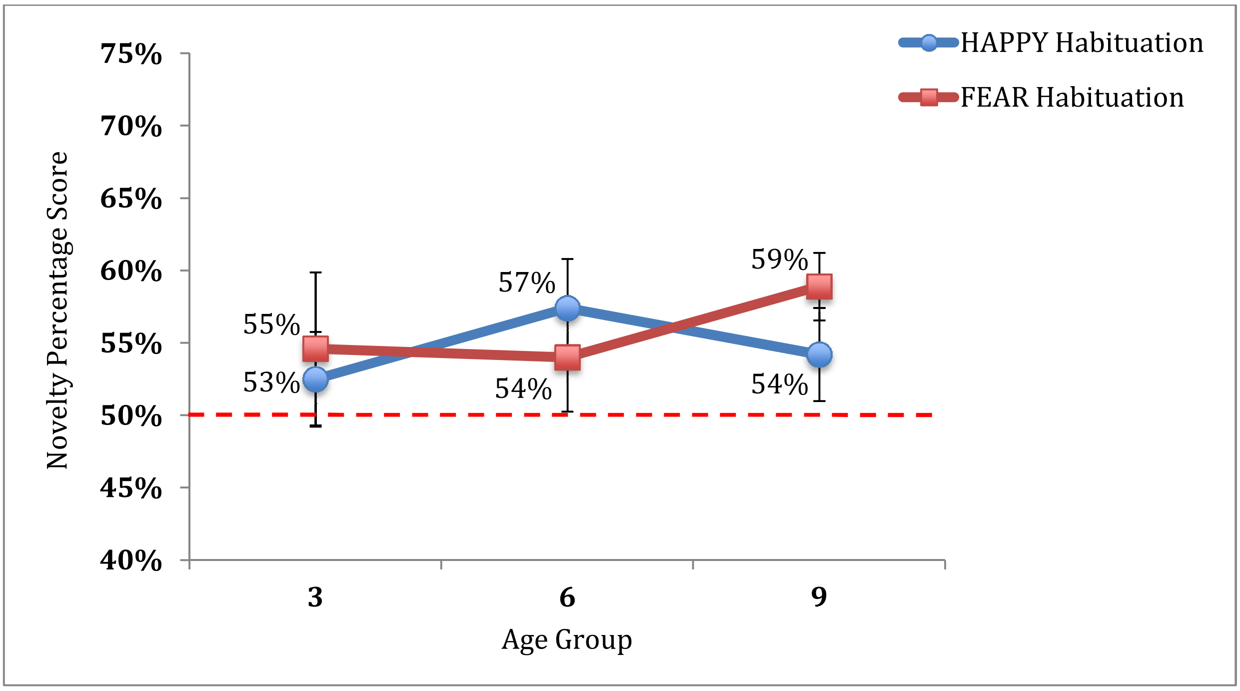


Figure 5.3. Graph shows NP scores across facial expressions and age groups in the inverted condition.

We have performed the same multi-regression to probe the relation between the inverted PLD novelty preference in the happy and fear conditions. The regression failed to show any significant results (ps > .317). It further suggests that infants' ability to process PLDs was specific to upright PLDs. In sum, the results obtained with inverted PLDs suggest that infants used lower- or higher facial motion attributes, rather than basic kinetic information to discriminate facial expressive PLDs.

Eye Movement Analysis

To examine how infants process facial expression from the PLD stimuli, we investigated infants' eye movement patterns for the PLD stimuli in the habituation phase. Prior studies showed that Asian adults tended to use information from the top half of a face to process facial expression (Jack et al., & Caldara, 2009; Jack et al., 2012). The similar eye movement pattern was also observed in Asian infants when they looked at expressive faces (Caldara et al., 2016). Thus, the top half focused looking pattern is an indicator for facial expression processing in Asian population, and we used it to examine whether infants processed expression from PLD stimuli. If, with increased age, infants gradually process facial expression from PLDs, we should observe an age related increase in looking time to the top half of PLDs.

We first generated fixation data by filtering raw eye tracking data with a dispersion based fixation definition with an area of 30 pixels dispersion for more than 100 ms. To determine the fixation locations, we defined two areas of interest (AOIs): upper and lower PLD halves, which meet at the middle point of each PLD (Figure 5.4). Next, we calculated the proportional looking time to the top half. This is achieved by dividing the total top half looking time by total looking time to the whole PLD within each PLD playbacks, then averaging the derived proportional time across PLD playbacks and habituation trials. These pre-processing steps generated the proportional looking time to the top half of PLD stimuli for each participant.

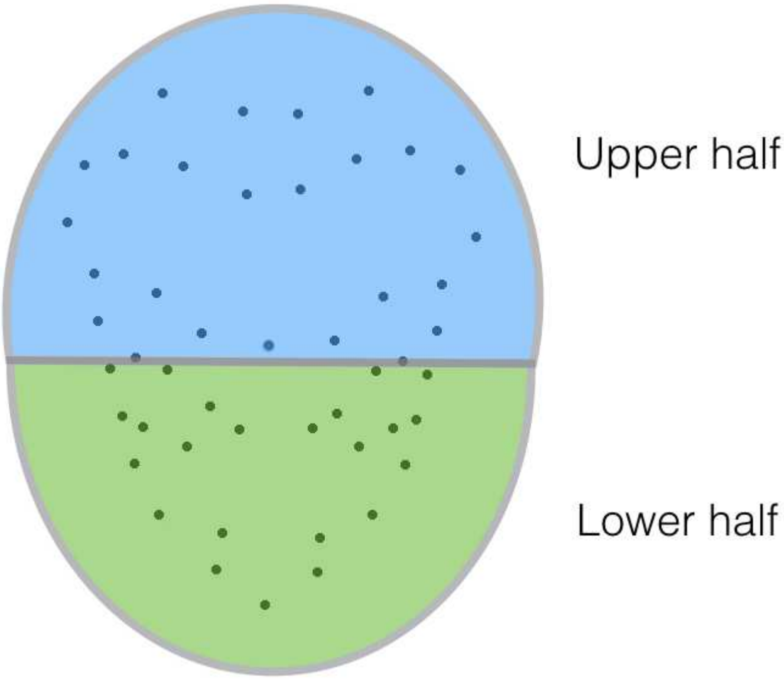


Figure 5.4. An illustration of the definition of the upper and lower half AOI for PLDs.

A mixed ANOVA was performed on the top half proportional looking time in the upright condition with Age (between-subject variable, 3, 6, & 9 months) and Emotion (within-subject variable: happy & fear). The results showed a significant interaction between Age and Emotion (F[2, 37] = 3.38, p = .045, η^2_P = .15). We, however, did not find any significant main effect of age (F[2, 37] = 1.95, p = .157, η^2_P = .10) or emotion (F[2, 37] = 3.33, p = .076, η^2_P = .08) The significant interaction suggests that infants showed different age-related looking time change between the happy and fear PLDs. Thereby, we performed two one-way ANOVAs to examine the development of top half looking time in happy and fear PLDs separately. For happy PLDs, as shown in Figure 5.5, the top half looking time increased significantly with age ($M_{3\text{-months}}$ = 32.10%, $M_{6\text{-months}}$ = 46.50%, $M_{9\text{-months}}$ = 59.53%, F[2, 37] = 3.91, p = .029, η^2_P = .17). By contrast, the looking time for the top half of fear PLDs did not change with age ($M_{3\text{-months}}$ = 45.83%, $M_{6\text{-months}}$ = 56.09%, $M_{9\text{-months}}$ = 53.51%, F[2, 37] = 0.56, p = .578, η^2_P = .03). These results demonstrated an increased looking to the top half of the happy PLDs, suggesting that infants developed the ability to process happy facial expression from its dynamic characteristics. On the contrary, infants were not able to process fear facial expression from motion cues only. In sum, these eye movement results are consistent with the behavioral findings, and collectively indicated the development of the ability to process happy facial expressions from PLDs from 3 to 9 months of age.

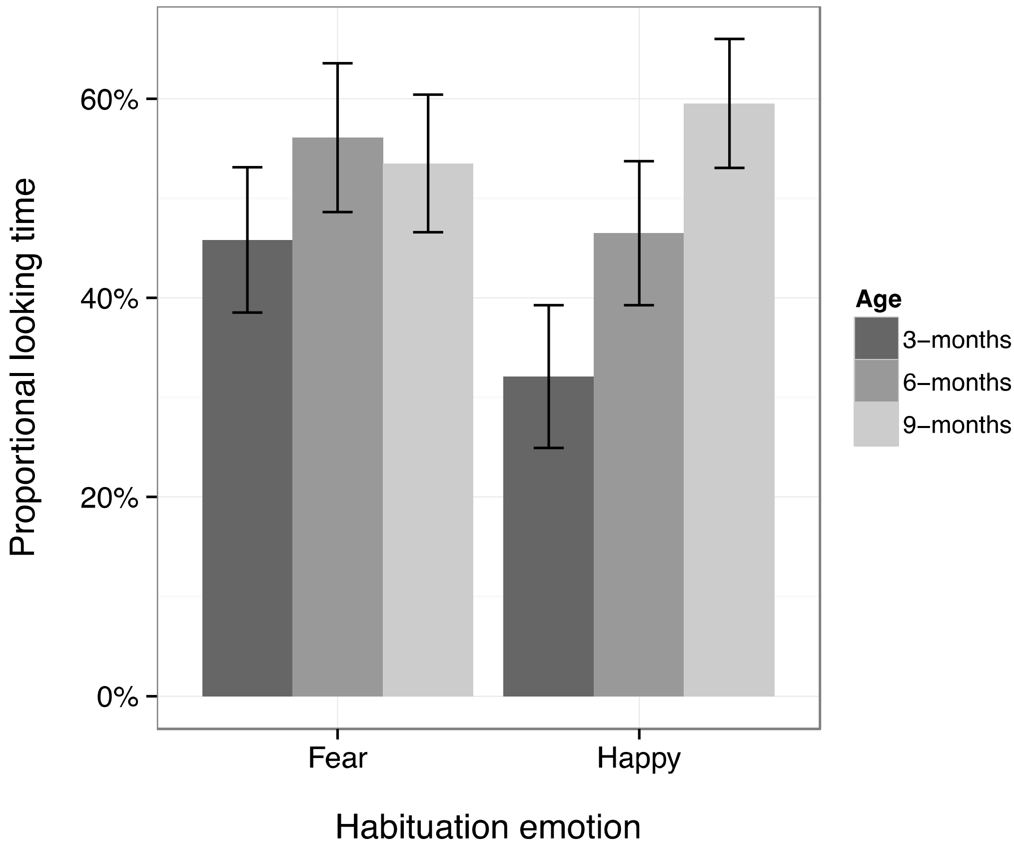


Figure 5.5. Mean proportional looking time to upper half of the upright happy and fear PLDs during habituation phase in 3, 6, and 9 month-olds. Error bars represent unit standard error.

We also examined the proportional looking time to the top half of the inverted PLD stimuli (see Figure 6.6). Because we applied identical AOIs to the inverted PLDs, the top half of the inverted PLDs was the part presented at bottom. The same two-way mixed ANOVA was performed with Age (between-subject variable, 3, 6, & 9 months) and Emotion (within-subject variable: happy & fear) as independent variables and the proportional looking time as dependent variable. The results showed a significant main effect of age (*F*[2, 36] = 6.53, *p* = .004, η^2_P = .27), demonstrating that 3-month-olds looked longer at the top half than 6- or 9-month-olds. In addition, we also found that infants looked longer at the top half of the inverted fear PLDs (*M* = 31.49%) than that of the inverted happy PLDs (*M* = 23.79%, *F*[1, 36] = 7.29, *p* = .011, η^2_P = .17). It might be due to that fear PLDs contain faster movement than happy PLDs in the top half, which attracted more attention. Moreover, the interaction between age and emotion was not significant (*F*[1, 36] = 1.92, *p* = .161, η^2_P = .10), indicating that the age-related looking time change was not different between the inverted happy and fear PLDs.

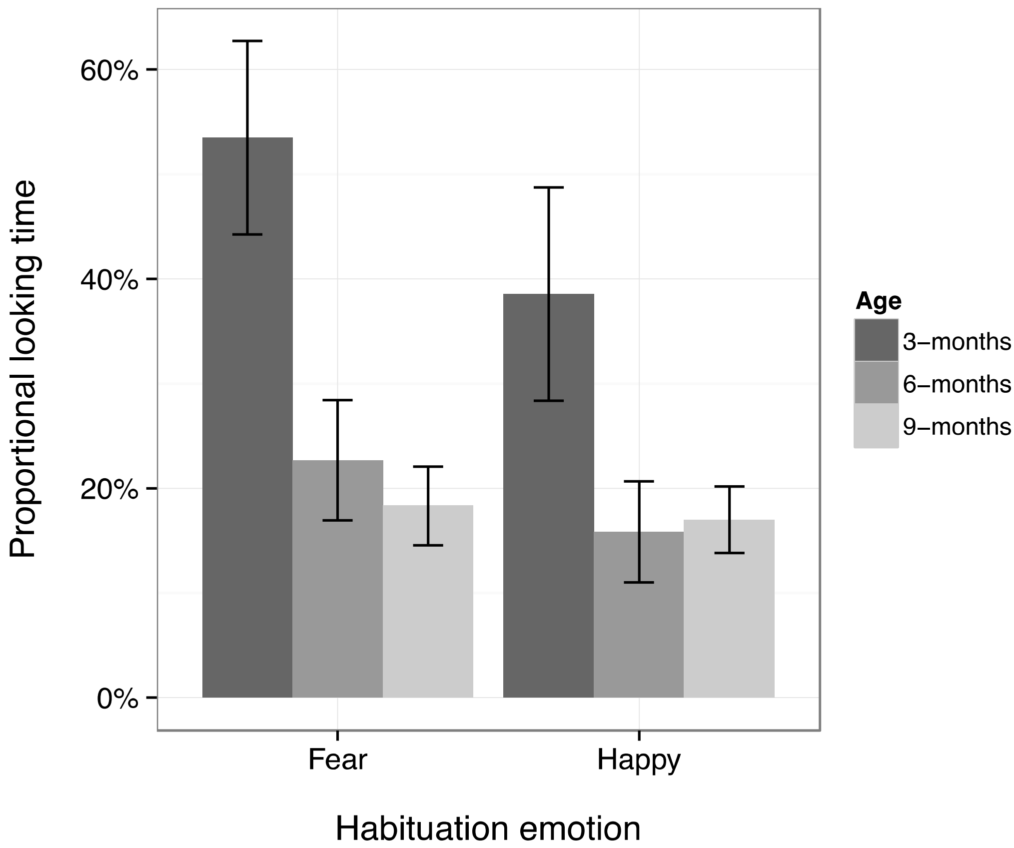


Figure 6.6. Mean proportional looking time to upper half of the inverted happy and fear PLDs during habituation phase in 3, 6, and 9 month-olds. Error bars represent unit standard error.

Thereby, we did not observe any happy PLD specific effect in infants' looking pattern for inverted PLDs. These results further support that infants developed special sensitivity to upright face PLDs to process happy expression from facial motion.

Overall, these results of discrimination performance and eye movement patterns consistently showed that infants developed the ability to process higher-level facial expression information from PLDs between 6 to 9 months of age, which is specific to happy expression. The age-related changes further indicate the role of experience of dynamic facial expressions in the development of the ability of processing expression purely from facial motion signals.

However, it should be noted that these observed PLD discrimination performance can also be explained by the development of spontaneous preference for fear facial expression. Prior studies consistently found that infants showed visual preference for static pictures of fear facial expression at around the second half of the first year of life (for a review, see Peltola et al., 2013). The fear expression spontaneous preference might be the reason why older infants only showed novelty preference in the happy, but not fear conditions. If infants were habituated with happy PLD, the novelty preference pluses fear expression preference would lead to a stronger novelty preference to the fear PLD. By contrast, when the habituation stimulus is a fear PLD, the novelty preference for happy PLD and the fear expression preference would cancel out each other, therefore leading to a non-preference. In other words, this hypothesis argues that infants could process both happy and fear facial expressions from PLDs, indicating the ability to process expression is independent of experience. This account is in conflict with the hypothesis that a ability is largely driven by the asymmetric experience with happy facial expressions, which leads infants to develop the ability to process happy, but not fear expression from motion signals. To resolve these two theoretical arguments, we conducted Experiment 2 to directly examine whether infants show spontaneous preference for fear PLD.

5.4 Experiment 2

Experiment 2 investigated whether 6- and 9-month-old infants showed a spontaneous preference for the fear PLDs.

5.4.1 Method

Participants

The final sample comprised a total of 35 healthy infants: 19 6-month-old infants (9 females, M = 186 days, range: 178-191 days) and 16 9-month-old infants (10 females, M = 263 days, range: 242-283 days). Eight further babies were excluded from the final analyses because of fussiness ($n = 4$), experimental error ($n = 1$) and because of being outliers (i.e., 2 SD distant from the mean of total looking time to both stimuli; $n = 3$).

Stimuli

The stimuli were the same four PLDs utilized in the previous Experiment: the happy and fear facial expressions modeled by the selected male and the female actors, presented in an upright orientation.

Apparatus and Procedure

The apparatus and procedure were the same as that used in Experiment 1, except that participants underwent only the two gaze-contingent VPC trials, without any previous habituation phase. And we only used upright PLDs in Experiment 2.

5.4.2 Results and Discussion

To test whether infants showed a spontaneous preference for the fear PLD, we computed preference scores. Each infant's looking time at the fear PLD during the two presentations was divided by the total looking time to the happy and fear PLDs over the two test displays and then converted into a fear percentage score. Thus, only scores significantly above 50% indicated a preference for the fear expression. To determine whether infants had a spontaneous preference for fear PLD, two one-sample *t*-tests were performed against the chance level (50%) for each age group respectively. The scores were 47.4% (SD = 13.71%) for 6-month-old infants and 54% (SD = 20.3%) for 9-month-old infants. Results showed that infants in both age groups do not manifest any significant preference for fear PLD (6-month-olds: $t[18] = -0.83$, $p = .418$; 9-month-olds: $t[15] = -0.81$, $p = .433$). These results indicated that infants at 6 and 9 months of age did not show spontaneous preference for fear PLDs.

5.5 General Discussion

The current study examined the development of infants' ability to process facial expression by relying on motion cues, when other static pictorial facial expressive cues are absent. We obtained several major findings: 1) infants at 9 months of age showed significantly different discrimination when habituated to a happy or fear PLD. When habituated to happy PLDs, they manifested a novelty preference that was not present when habituated to fear PLDs; 2) three-months old infants showed a novelty preference independently from the expression to which they have been habituated and 3) this developmental change in discriminating happy and fear PLDs was only present in the upright, but not in the inverted PLD conditions. These findings indicate that infants are able to process facial expression purely from motion signals in the second half of the first year of life.

Nine-month-olds were able to discriminate happy versus fear PLDs only when they were habituated with happy PLDs, but not when they were habituated with fear PLDs. This happy expression specific discrimination indicates that 9-month-olds are able to process expression from facial motion information. It is because this ability to process facial expression is believed to be driven by experience with dynamic facial expressions, which is more likely to be revealed in familiar than unfamiliar facial expressions. Indeed, with increasingly more experience with different facial expressions, the representations infants develop become more accurate according to the experience accumulated with a particular emotional expression: the more frequent and significant experience, the more detailed and elaborate is the representation (e.g., Adolphs, 2002; Machado & Bachevalier, 2003). Infants in the first year of life typically see mostly happy facial expression (e.g., Malatesta & Haviland, 1982), whereas fear expression is rare to see (e.g., Campos et al., 2000). As a consequence of this asymmetric experience with dynamic facial expressions, the ability to process expression from facial motion is expected to be specialized to happy facial expression. The representation of the happy emotion infants have developed within the first half of the first year of life might therefore benefit the encoding of the happy facial movement. In the current experiment, when infants view the happy dynamic expression, the familiar motion pattern is linked to the related stored representation, thereby facilitating the recognition of the same movement pattern to which infants have been habituated during the habituation procedure. Consistent with this rationale, the finding that 9-month-olds showed discrimination only in the happy, but not in the fear PLD habituation condition, indicated that they can process expression from PLD, which is specific to happy facial motion pattern. Otherwise, they should show discrimination in both the happy and fear conditions.

In addition to the ability to extract higher-level expression information, the current results of 9-month-olds suggest that the ability to process facial expression from motion also inhibits the processing of the lower-level facial motion attributes (e.g., raising eyebrows and opening mouth). The lack of any preference in the fear habituation condition in 9-month-olds might be explained by two reasons: 1) infants are not able to process expression from fear PLD; and 2) they inhibit the processing of the lower-level facial motion attributes. Thereby, they could discriminate neither the expression difference nor the lower-level facial motion attribute differences between the habituated and the novel PLDs in the fear condition. Furthermore, we also found 9-month-olds' discrimination in the happy condition did not correlate with that in the fear condition, suggesting that they process happy PLD differently from fear PLD. In line with these findings, prior studies with dynamic facial expressions have consistently reported a happy expression specificity in processing moving expressive faces by infants (Brenna et al., 2013; Ichikawa & Yamaguchi, 2014; Ichikawa et al., 2014; Kahana-Kalman & Walker-Andrews, 2001). In sum, the observed happy expression specificity in 9-month-olds demonstrates that infants at this age are able to process expression purely from facial motion signals.

This happy PLD specificity was not observed in 3- or 6-months old infants: they showed similar discrimination between the happy and fear habituation conditions. Moreover, their discrimination in the happy and fear PLD conditions were positively correlated. However, these findings should not be taken as an evidence that they were able to process both happy and fear facial expression. Instead, this discrimination in 3- and 6-month-olds is likely to suggest that young infants discriminate the happy versus fear PLDs based on differences in lower-level facial movement attributes, rather than that in facial expressions. This interpretation is in line with the findings that young infants are able to process lower-level facial motion attributes (Spencer et al., 2006; Stucki et al., 1987). But the ability to process higher-level facial motion attribute does not emerge until the second half of the first year of life (e.g., Ichikawa et al., 2011; Missana et al., 2015). Interestingly, one-sample *t*-tests showed that 6-month-olds exhibited successful discrimination only in the happy, but not in the fear condition, which resembles the pattern of 9-month-olds. This pattern suggests that 6-months old infants may be at a transitional stage (e.g., Hoehl & Striano, 2010), which sits between a lower-level motion attribute based processing in the 3-month-olds, and a higher-level motion attribute based processing in 9-month-olds.

The results of 3, 6, and 9 months old infants together revealed a developmental scenario in processing facial motion signals by infants. The ability to process lower-level facial movement attributes (e.g., raising eyebrows and opening mouth) seems to emerge first. With increased experience with facial movements, this ability is gradually replaced by a higher-level ability, which focuses on processing higher-level facial attributes (e.g., face identity and facial expression) from movement patterns. Specifically, young infants process facial movements based on lower-level facial movement attributes, but they were unable to process higher-level ones inherent in facial movements. Old infants are able and tend to process facial movements based on specific higher-level attributes, which depict the most frequent and significant attributes in their real-life experience (e.g., dynamic happy facial expression). It should be noted that, old infants would ignore using lower-level facial movement attributes. This explains why 9-month-olds failed to show a preference in the fear habituation condition, even though the two PLDs are clearly different in their lower-level facial movement attributes. Thus, even though the pattern of results obtained with the fearful facial expression resembles on the surface the developmental trajectory of the phenomenon of the perceptual narrowing (a discrimination ability present at earliest stages of life that disappears after few months as a function of experience), what happened in the current study is definitely not a decline of discrimination capacities, rather it is a shift in detection of different facial cues, a perception of new stimulus properties and, therefore, a qualitative improvement of the information processed in the face. The progressive shift in the reliance on different aspects of the stimulus during perception is a proof of the experience-driven, multiform and active nature of the development of visual perception and could provide an alternative theoretical framework to the classic dichotomy that describes the development of perception functions either solely in terms of perceptual improvement, or solely in terms of perceptual narrowing (e.g., Lewcovicz & Ghazanfar, 2009).

This developmental pattern in infants' processing facial movements is consistent with the attunement theory of perception development (see Maurer & Werker, 2014, for a review). This attunement view posits development as an experience-expectant process, in which experience enhances and sharpens certain perceptual sensitivities from lower to higher levels. The lack of experience would lead to a loss of the initial perceptual sensitivity. This attunement view has been supported by studies on the development of various perceptual domains, such as facial information processing strategies (Cashon & Cohen, 2004; Cohen & Cashon, 2001; Schwarzer et al., 2007), visual speech processing (Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012; Weikum, Vouloumanos, Navarra, Soto-Faraco, Sebastián-Gallés, & Werker, 2007), and audio/visual speech perception (Walker-Andrews, 1986; see Lewkowicz & Ghazanfar, 2009 for a review). Together, the current findings and those from other perception domains provide convergent evidences to highlight the significant role of experience in shaping the development of perception in the first year of life.

This development in processing dynamic facial expression signals is further supported by an eye movement analysis. We found an age-related increase in the looking time to the top half of happy PLDs. This top half looking pattern has been recognized as an indicator for facial expression processing by Eastern Asian adults and infants (Caldara et al., 2016; Jack et al., 2009, 2012). By contrast, the same infants failed to show any age-related change in their looking time to the top half of fear PLDs. This eye movement pattern suggests that the facial expression processing only reveals in happy, but not fear PLDs. This result provides a supplemental evidence supporting that the processing of facial expressive movements undergoes a broad lower-level to specific higher-level developmental scenario.

With regard to inverted PLDs, we did not find any of the effect that we found in the upright PLDs condition. Infants performed in a similar way regardless of the habituated emotion or age in the inverted condition. The discrepant results obtained in the upright versus inverted conditions suggest that infants from 3 months of age onward process upright face PLDs based not merely on kinetic characteristics (e.g., amount of motion and acceleration). Rather, they also process a coherent facial figure from the point-light moving patterns. These results further support an argument that infants from 3 months of age onwards already formed a representation for human facial movements (Stucki et al., 1987; Ichikawa et al., 2010, 2011; Xiao et al., 2014).

In addition to the major findings of facial expression processing, the current study also introduced a novel research paradigm for studying dynamic face processing. The current study creatively used a gaze contingent paradigm, which combines traditional habituation and visual paired comparison (VPC) paradigm with advancing eye tracking technology. This gaze contingent paradigm is especially important for VPC task using dynamic stimuli. Ideally, in a VPC task, the looking time to each stimulus should reflect the time in processing each stimulus. This looking time would be inaccurate when the visual processing is interrupted. Motion information is one of such interrupting factors. In a VPC display with dynamic stimuli, participants' attention would be easily influenced by the motion of the non-attended stimuli, which distracts infants' attention from the currently fixated stimulus. As a consequence, the looking time measurement may underestimate the processing time infants actually need, therefore leading to an inaccurate measurement. The current gaze contingent paradigm solves this issue by adaptively presenting dynamic stimuli according to infants' looking. If infants look at one stimulus, the attended stimulus would play. At the same time the non-attended one would stop playing or remain static. This design eliminates the motion distraction from the non-attended stimulus. Thereby, the looking time to each stimulus could better reflect infants processing time. Considering the growing body of moving face processing studies, this gaze contingent paradigm would serve as a useful tool to probe the development of face processing in our real world situations.

In conclusion, the current study demonstrated that infants develop the ability to process expressions purely from facial motion signals between 6 and 9 months of age. This finding highlights the role of facial movement information in the development of face processing in the first year of life. Importantly, this result supports a role of facial motion in infants' processing of facial expressions in a way consistent with the supplemental information hypothesis: infants as young as 3 months of age are able to process the facial motion information alone, not as a bundle of kinematic characteristics, but in a face-related manner. As a function of experience, they also learn to infer socially relevant information from facial motion cues, such as facial expressions.

Conclusions

One of the key features of facial behavior is its dynamicity. Notwithstanding, both adults' and infants' studies on face perception have focused almost exclusively on the ability to process faces by using static images. Only recently researchers have begun to consider the role of facial motion on adults' processing of facial identity and facial expressions (for reviews, see Krumhuber et al., 2013; Roark et al., 2003). Especially for infants, facial motion may constitute a particularly relevant information, given that infants' face experience mostly occurs in face-to-face interactions with caregivers that typically display exaggerated facial gestures (e.g., Stern, 1974). Moreover, reading facial behavior constitutes a way to communicate in the infant-caregivers relationships in the absence of linguistic competences (de Haan & Nelson, 1998). In addition, given the immaturity of the infants' visual system, it is likely that infants would rely even more on motion cues than adults do (Roark et al., 2003). Therefore, it becomes fundamental to understand how the dynamic information embedded in faces could affect infants' way to process faces. Despite these considerations, still an impressive low numbers of studies have examined how facial motion may impact the processing of faces in infants. The current dissertation was aimed to fill this significant gap in the literature.

Two main hypotheses have been proposed to explain how facial motion cues may affect adults' face processing (e.g., Roark et al., 2003). In particular, according to the *supplementary information hypothesis*, facial movement provides idiosyncratic facial information in addition to the invariant structure of the face. Thus, facial motion alone could convey socially relevant information. The *representation enhancement hypothesis* posits, instead, that facial motion supports the encoding of the facial structure and enhances the construction of the face representation, which, in turn, improves face recognition ability. In the current dissertation, I investigated if facial motion could impact face processing in infants in a way consistent with these two hypotheses.

Previous studies have shown that when newborns have to recognize a face that changed in some characteristics (such as from the frontal to the profile pose), recognition ability is inhibited (e.g., Turati et al., 2008), unless the same face is presented in a rigid head motion condition (Bulf & Turati, 2010). In study 1, I tested the role of non-rigid facial motion on newborns' ability to recognize a face that changed facial expression from the habituation to the test phase. Results showed that, when the same three face images are presented, newborns succeed to recognize the identity only when the images are presented in motion and not in static condition (Exp. 4). Thus, when the quantity of pictorial information is equated, facial motion allows identity recognition despite the change in facial expression. This result supports the representation enhancement hypothesis, given that the same quantity of static pictorial information does not provide the same recognition advantage found in the motion condition: motion information supports the construction of a face representation less image-constrained and more effective in recognizing a face that changed for some characteristics. However, the facial motion could have a beneficial effect only under certain degrees of perceptual differences between the habituated face and the face to recognize. In fact, when the perceptual difference between the habituated face and the test face is high (i.e., the same face posing a happy or a fearful expression), facial motion cannot support identity recognition at birth (Exp. 1). By contrast, when the perceptual difference is subtle, even a static presentation provides sufficient cues to allow face recognition (Exp.2). Thus, the perceptual difference between the habituated and the test face plays a primary role in allowing identity recognition in newborn babies, in that, when the perceptual discrepancy is particularly high, motion information could have only a subordinate effect. This result is in line with other studies showing that the saliency and the amount of the visual differences between face images drive newborns' face recognition (Gava et al., 2008; Turati et al., 2006, 2008). Finally, results also showed that the type of facial motion, that is, a possible or impossible motion, plays a fundamental role in allowing or inhibiting identity recognition at birth (Exp. 3). In particular, an impossible facial movement hinders newborns' face recognition. This result is in line with previous studies showing that infants are responsive to some characteristics of the natural facial motion (Bulf & Turati, 2010; Ichikawa et al., 2011; Xiao et al., 2014) and suggests the existence of an early sensitivity to the naturalness of facial motion patterns in newborn babies. Moreover, this specific result also supports the representation enhancement hypothesis, since the disadvantage of the biologically impossible motion might be related to the underlying face representation: when the characteristics of a particular facial motion diverge from the characteristics of the facial movements usually perceived, recognition performance is prevented (Xiao et al., 2014). If so, one may suppose that other typologies of non-rigid facial motion, such as talking, blinking, or blowing, might have a beneficial effect, as long as it is a biologically possible motion. Future studies should be conducted in order to verify this idea.

In study 2, the role of facial motion in the ability to categorize happy and fear facial expressions was tested in 3-month-old infants. In contrast to the age reported in the available infants' literature (i.e., 5 to 7 months of age; for a review, Quinn et al., 2011), in which static snapshots of emotional expressions are typically employed, results of study 2 showed that infants are able to categorize the happy dynamic expression, but not the fear dynamic expression, as early as 3 months of age. The difference between happy and fear is likely due to the different level of familiarity of these facial expressions for young infants (Malatesta & Haviland, 1982) and it highlights the role of experience in shaping infants' perceptual abilities. Importantly, this result supports the representation enhancement hypothesis: although in study 2 we did not test infants in a static condition, previous studies employing static pictures have shown that infants as young as 4 months are not able to categorize the happy expression (Caron et al., 1982, 1985). A possible explanations might rely in the fact that, under static presentation, the face representation seems more pictorial and image-constrained because it did not allow categorization. In contrast, the successful categorization found in study 2 indicates that, when provided with moving faces, infants were able to extract the invariant aspects between the four different models depicting four different intensities of happiness, and recognize the same expression posed by a fifth model depicting a new degree of intensity. Thus, the dynamic information embedded in facial expression enhances the construction of a representation resilient to facial changes, which, in turn, allowed categorization of the happy facial expression already at 3 months of age. Future studies need to be carried out with dynamic facial stimuli in order to investigate both the ability to discriminate and to categorize facial expressions in infants. The current literature is often not clear regarding the age at which certain facial expressions are discriminated and categorized (e.g., de Haan & Nelson, 1998), but several studies coming from naturalistic observations, or other experimental paradigms (e.g., intermodal preference task), suggest an early sensitivity to the emotional content of facial expressions (see Bornstein & Arterberry, 2003, for a discussion). It is possible that, the employment of more ecological stimuli, such as dynamic expressive faces, might lead to demonstrate earlier perceptual capacities than those derived from experimental studies in laboratories.

Study 1 and study 2 together suggest the idea that, when one or more static images are presented, infants might retain the visual information in memory as a separate information, without relating the stored information to each other. The consequent face representation results inefficient to allow face recognition when the face changes, because it is strictly related to the image stored in memory. Thus, under static condition, recognition might be based on a simply image-matching process, in which the more evident is the difference in facial pictorial information, the more infants' performance is penalized. By contrast, when the faces are presented dynamically, infants might construct a more resilient and not image-based face representation that allow recognition by means of the extraction of the invariant aspects across face presentations. This idea is on the basis of the representation enhancement hypothesis and highlights the role of facial motion in enhancing face processing in very young infants.

The results of study 1 and study 2 together follow the developmental pattern of the memory system proposed by some theoretical models (Johnson & de Haan, 2001; Nelson, 1995, 2011). In particular, it has been proposed that face recognition in the first weeks of life is mediated by a hippocampal-based pre-explicit memory system, which is able to form an accurate representation of the visual stimulus (Nelson, 1995, 2011). However, because of an initial disconnection of the subcortical and the higher-level cortical structures (e.g., Johnson, 2005), such system does not relate the stored visual information to each other, retaining each visual input at an individual level. This might explain the primary role of the perceptual differences between the habituated and the test faces in newborns' identity recognition in study 1, and why motion cues have only a partial role in supporting the construction of the face representation. With the development of the cortical structures and the relative connections between cortical and subcortical pathways around 6 and 8 weeks of life (e.g., de Haan & Johnson, 2001), infants become able to relate the information stored in memory to each other and, as a consequence, they can form an averaged face representation, which is not constrained by the image (de Haan et al., 2001). Consistent with this view, the results of study 2 suggest that infants did not store each face separately; otherwise they would never have succeeded in categorization task, given that infants were presented with several, different versions of the same facial expression. The fact that infants treated the new face depicting a new intensity of the familiarized happy expression as familiar, suggests that they were averaging the familiarization face together, rather than only storing individual exemplars. A mere image-matching process could never achieve a similar task. Thus, at 3 months of age, facial motion may play a major role in enhancing face processing, compared to few-day-old babies.

In sum, the first two studies indicate that, in a condition when dynamic facial information is presented, both identity and facial expression are processed differently from a condition when only static facial information is presented. These results are consistent with the representation enhancement hypothesis. First, face identity and facial expressions learned in motion are better recognized that face learned from the same pictorial information showed statically; second, there seems to be an early sensitivity to the naturalness of facial motion; finally, facial motion seems to affect the construction of the face representation, enhancing, in turn, face recognition.

Study 3 investigated whether infants could process the movements inherent in facial expressions when other pictorial cues are absent. To this aim, in Experiment 1, I tested 3-, 6- and 9-month-old infants' ability to discriminate happy and fear facial expressions conveyed by point-light displays. Stimuli were presented both upright or inverted in order to test whether infants process the motion patterns as faces. Results have shown that, when habituated to the happy expression, all the three age groups show discrimination ability; on the contrary, when habituated to the fear expressions, only the youngest infant group shows a successful discrimination. None of these effects were found in the inverted condition. Experiment 2 ruled out the possibility that a spontaneous preference for the fearful configuration might have affected infants' looking behavior. This pattern of results has been interpreted in light of the attunement theory of perception development (Maurer & Werker, 2014). In particular, the successful performance in both happy and fear conditions of 3-month-old infants might be due to an initial sensitivity to the lower-level facial attributes, that is, how the expressions simply move, without any higher-level processing of the underlying emotion. With experience, this early sensitivity is replaced by a higher-level ability, which focuses on the processing of higher-level facial attributes, that is, facial expression. Since happiness is the most experienced expression in infants growing environment, infants develop a special sensitivity for the happy dynamic pattern, leading to a successful recognition only when habituated to the happy PLD. By contrast, the relative minor experience with fearful facial motion pattern penalizes older infants' discrimination abilities. Further studies are needed to confirm this hypothesis. For example, a possible study might consider to habituate infants to facial expressions conveyed by PLDs and then present them real moving faces. If infants process the high-level facial expression, they should transfer the expression's moving patterns to the real stimulus, recognizing the same facial expression as familiar.

To summarize, the results of study 3 indicate that the ability to use motion information alone to process facial expressions emerges between 6 and 9 months of age. These results support the supplemental information hypothesis, in that not only facial motion information can be processed directly as a visual cue separated from static facial information, but also that such information by itself could convey emotion-specific information. As already said, this idea represents a fundamental difference from the classic assumption that the facial expressions are encoded only on the basis of the features that capture the facial configuration (Roark et al., 2003; Xiao et al., 2014). Overall, study 3 and prior studies on infants processing of static facial expression together support the idea that, in order to process facial expressions, infants can use both the static and dynamic facial information alone, as happens with adults (e.g., Bassili et al., 1978; Ekman et al., 1972).

This conclusion raises the question regarding the relative contributions of static and dynamic facial information in face processing by infants. Current theories suggest that when both static and dynamic information is present, people usually rely more on the static information, because it provides a more reliable marker of facial identity and facial expressions (O'Toole et al., 2002; O'Toole & Roark, 2010; Roark et al., 2003). Consistently, it has been demonstrated that the presentation of facial expressions conveyed by motion cues only (for example, PLDs) leads to significantly poorer recognition compared to when facial expressions are conveyed by moving faces and static faces (e.g., Bassili, 1978, 1979). Similar results have been reported for identity recognition (see Roark et al., 2003, for a discussion). Accordingly, in the second study of the current dissertation, infants as young as 3 months of age demonstrate the ability to categorize happy expression from moving face stimuli, whereas in the third study of the current work, the ability to use dynamic information alone to discriminate happy facial expression emerges later, between 6 and 9 months of life. Thus, when the pictorial facial information is available, facial motion information seems to be a less relevant cue for recognition. However, several studies have shown that infants may rely more on the dynamic facial information for face processing, in certain visual conditions (e.g., Bulf & Turati, 2010; Ichikawa et al., 2014; Layton & Rochat, 2007; Otsuka et al., 2009; Xiao et al., 2014). Thus, it is unclear whether infants rely more on static or dynamic facial information to process faces. The results of study 3 suggest that infants may rely more on static facial expression information, at least for facial expression processing. It is because of two reasons: first, the ability to use dynamic facial information to process expression emerges much later than the ability to use static facial information. Consistent findings have shown that few-day-old infants are already capable of discriminating among static facial expressions (e.g., Farroni et al., 2007;

Field et al., 1982). However, the current study showed that the ability to use dynamic cues to process facial expressions emerges between 6 to 9 months of age. Second, infants can process and discriminate different facial expressions from static images (e.g., Young-Browne et al., 1977; Schwartz et al., 1985; Serrano et al., 1992). By contrast, the study 3 showed that they could only process their most experienced facial expression from motion. This suggests that infants may process other facial expressions by exclusively relying on static facial information. In sum, existing studies seem to suggest that infants are capable of using dynamic facial information to process face expression, although it may serve as a secondary role to static expressive cues.

However, the statement that dynamic expressive cues play a secondary role may not apply for the real world contexts. Real-life situations, where facial expressions are subtle and swift, contrasts to those in laboratories, where facial expressions are presented statically in their "peak" moments for a certain amount of time. Under real-life circumstances, dynamic facial information may play a more important role in expression processing by infants. Studies have consistently reported that dynamic facial information facilitates subtle facial expression discrimination in infants and adults (Bould & Morris, 2008; Ambadar et al., 2005; Ichikawa et al., 2014). This suggests that facial motion may play a critical role in processing subtle facial expressions, especially when static expressive information is not obviously presented. Moreover, the relative late developed ability to process expression from facial motion signals does not necessarily suggest a secondary role in later stage of life. Some authors have argued that processing dynamic facial information simply requires more time and experience (Xiao et al., 2014).

To conclude, it seems that facial motion impact infants' face processing in ways that are similar to those reported in adults. Infants are sensitive to the facial motion component from the first days of life. Facial movements drive infants' processing strategies, supporting the processing of the facial invariant structure and, in turn, the construction of a more reliable face representation, useful for recognition. Moreover, infants are able to process the facial motion information alone, when other pictorial cues are not available. Infants are also capable to process socially relevant information from facial motion cues only, such as the facial expressions. After these considerations, one may wonder to what extent the available findings obtained with static faces are generalizable. Future studies should consider using stimuli and research paradigms that are more reflective of infants' real-life environments to better explore such processes in early development.

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