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Mother-Infant Interaction: an Exploration of Maternal Frontal Alpha Asymmetry During the Still-Face Procedure

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Abstract

Early interactions with the mother have been proven to play a crucial role for the socio-emotional and cognitive development of the infant. The EEG hyperscanning technique allows researchers to dive into the brain dynamics of the dyad. Frontal Alpha Asymmetry (FAA), an index of emotion regulation and motivational processes, is defined as the imbalance of activation between the frontal areas of the two hemispheres. In our study, we combined measures of FAA with the Still-Face Procedure (SFP) from Tronick, which allows us to observe what strategies the mother and the infant display to reconnect following a disruption of the interaction and how this process associates with FAA. We aimed to investigate maternal fluctuation in FAA values across the procedure, as well as the associations between maternal asymmetry and behaviors from the mothers and from the infants. Our results didn't find any episode effect for maternal FAA. We have also found that positive emotionality displayed by children was significantly associated with positive values in the FAA of the mother during the Play episode of the SFP. This result was further confirmed by associations we found between maternal FAA during the Still-Face episode and the self-report of their infants' emotions during the same episode.

This research experiment joins the few existing studies that merge SFP and FAA, which give contrasting results. Nonetheless, our study gives further feasibility to the employment of SFP and FAA together in order to investigate interactional dynamics in the mother-infant dyad. We were also able to employ micro-analytic coding of behaviors, which can help future research to gain deeper knowledge of the strategies deployed by the dyad in order to achieve emotional and behavioral regulation.

Chapter 1 – The mother-infant dyad

Before disclosing the different authors and pathways that brought infant research where it is now and marked the steps for future researchers, I find it appropriate to introduce the dyad as a system, within the theoretical framework that represented the starting point for all the scientists that I'm going to introduce later and their critical contributions to the field.

First of all, what do we mean when we talk about a dyad? The dyad is *"an entity consisting of two elements"* (Colman, 2015). Therefore, the dyad can be considered as a system, but this system is composed of two distinct individuals that remain separate, although working together in the dyad. Their development doesn't only depend on what happens within the dyad. According to Galton (1876), every individual is the outcome of the interaction between their genes (or nature) and the environment in which they develop (or nurture). Therefore, development might be guided by the innate codes that compose our genome, by the impact of the environment, or by their interaction (Thelen & Smith, 1998). But how do these simple early interactions become increasingly complex during development ?

The answer is that individuals don't act by themselves, isolated, especially if we think about newborns: it is impossible to depict them as self-sufficient organisms. What has been groundbreaking for this field is when researchers understood that infants don't rely on their mothers only for physiological needs, like eating. Still, their interaction is crucial also for their future cognitive and socio-emotional development.

Here comes the concept of dyad as we know it today: it is considered a dynamic system.

1.1 - The dyad as a system

According to Thelen and Smith (1998) a system is composed by different and distinct elements that work together in order to reach a common goal. A dynamic system is characterized by the fact that elements are not stable but go through changes. These changes are necessary for the system to adapt to what's happening around it. The interaction between the environment and a dynamic system is bidirectional: the environment influences the system that simultaneously shapes the environment around it. The dynamic system works according to the principle of continuity and coupling (Skoranski et al., 2019). Coupling is defined as the never-ending mutual interactions happening between the distinct elements that compose the system. Continuity means that all the processes happening in the system occur continuously over time and build upon each other.

If we need to adapt these concepts to explain how infants' development occurs, we could say that future behaviors are influenced by what happened in a specific point in time. This assumption can be extended to every level of development: these reciprocal interactions influence every context of development, from genetics to the environment. Another critical concept is that developmental processes take different amounts of time, from less than a second to many years, both across levels and individuals (Gibbs & Cameron, 2008).

1.2 - The Dynamic System Theory (DST)

Dynamic Systems Theory (DST) originated as an extension of General Systems Theory. This framework wasn't designed for psychology, but to explain the behavior of self-organizing systems in the physical sciences (Bertalanffy, 1969). Over time, DST has been applied to diverse fields such as human development (Sameroff, 1994; Thelen & Smith, 1998), to describe how relationships between people work (Gottman & Levenson, 2002; Granic & Hollenstein, 2003) and neuroscience (Zanone & Kelso, 1997). In the context of development, DST has been applied to the dyadic interaction between mother and infant: it views developing minds as complex systems that keep evolving thanks to the interaction between their different components and their interaction with the environment (M. D. Lewis et al., 1999). Development is, therefore, occurring because individuals feature the characteristics of self-organizing systems, establishing order through the automatic coordination of their parts. Self-organization, unpredictability, and non-linearity are key attributes of DST, adapted from the General-System Theory (GST). One of the key features of a dynamic system is the constant state of change of the system itself, persistently losing and regaining its balance. The development of a dynamic system also changes the environment that surrounds it. This process is described by the epigenetic landscape, conceptualized by Waddington (1957). According to his view, the environment shapes genes' expression and vice versa. This representation of the interplay between genes and environment assumes that people begin their lives in a state that is determined by their genetic heritage. Growing up, the environment interacts with the genes shaping the developmental outcomes of the individual. This interplay will guide the ball, representing the individual, through the landscape creating valleys and peaks. The valleys represent the comfort zone, the states and the behaviors that the person will display more often. The peaks represent perturbations that, if experienced consistently, will change the landscape (Saunders, 1990). At the same time, the idea is that dynamic states are always open to novel stimuli able to modify their state (Thelen & Smith, 1998). While remaining open to external stimuli, they preserve a certain degree of stability, which is maintained until critical changes happen in the system, such as particularly strong or persistent stimulations (Fogel & Thelen, 1987). The changes produced by internal or external variables will be unpredictable as their direction is determined by the interaction of all the components rather than by a single part of the system. This means that the system develops in a non-linear manner. If we want to translate this to human development, it can happen that unforeseen events can radically alter children's environment and, as a consequence, their internal system.

The core idea of Dynamic Systems Theory is that a child's behaviors are the result of a dynamic system influenced by various factors, including the impact the child has on the environment through his body and his movement, previously acquired skills and experiences, environmental opportunities, and the specific times at which some events happen (L. B. Smith & Thelen, 2003; Thelen & Smith, 1998; Thelen & Ulrich, 1991). According to this theory, there is continuity in behavioral development, as present factors shape behaviors at any given moment, and past experiences influence the developmental context in which future behaviors will take place (Babik et al., 2022). From a dynamic systems perspective, when a mother and her child are interacting face-to-face, they constitute a dynamic system whose components are, in fact, the infant and the mother (Fogel & Thelen, 1987). These two partners both take part actively in regulating their interaction, despite them having different means to do that (Beebe et al., 1992). In this context, a recurring and stable pattern of communication between the dyad can be viewed as an *attractor state*—a preferred and stable organization of behaviors within the dyad under specific conditions.

Dynamic Systems Theory suggests that differences in the balance of these states arise from self-organizing processes in the system itself. Since the elements of a dyadic interaction are constantly going through changes (Thelen & Ulrich, 1991), two types of self-organizing processes can influence how attractor states reorganize: augmenting and suppressing processes. A suppressing process is defined as the system arranging itself to maintain stability. In this case, the interactive pattern in the dyad will remain the same. An augmenting process involves the system reorganizing itself, leading to a shift away from the present state. When the augmenting process takes over, the present interactive pattern becomes less stable and it will probably shift to a new state (Hsu & Fogel, 2003). The dyad could move from one state to another flexibly and unpredictably, where flexibility stands for the amount of times the dyad shifts to another state before and after a mismatch (Hollenstein, 2007; Lunkenheimer et al., 2012)

It is necessary to stress the bidirectional direction of these influences: this whole process is possible thanks to the mother's presence which helps her infant to regulate his/her emotions. Exploring the strategies and behaviors that mothers use in this process can help us better understand which factors of the interaction and of the surrounding environment exert an impact on the infant's socio-emotional development.

To sum up, the DST posits that infants' development can only be studied in the context of the mother-infant interaction. This caused infant research to switch the focus from the baby to the dyad and its relational dynamics.

1.3 - History of infant research

Developmental research can be defined as the field that investigates the development and the changes of the individual throughout the lifespan, taking into account psychological, physical, cognitive, emotional and social factors.

The mother-infant dyad has been in the spotlight of developmental research for a very long time now. What I will try to do now, is to give a brief insight into the history of this field of research highlighting the many changes, contributions and advances that infant research underwent.

Infant research is a branch of developmental psychology that focuses on babies with an age comprised between one month and one year.

Right now, this developmental stage is among the most studied, as researchers have found extended evidence that links the very early experiences that the infant lives in this period to developmental outcomes in socio-emotional, cognitive and language development. But it hasn't always been like that. When Wilhelm Wundt founded experimental psychology, infants were not given even closely the importance we give them now. In fact, he thought that observing such immature individuals would not bring any benefit to the discipline because their behavior was too unpredictable. However, it has been argued (Rochat, 2009) that the reason for which early studies on infants didn't reach any significant result was because of the inadequacy of the methods employed in those studies. Many experimental psychology paradigms of the time were based on introspection or verbal materials, for example, all abilities that an infant can't display.

The 19th and the 20th centuries could be the ones that gave a twist to this discipline. Starting with Darwin which contributed to the shift from a perspective that focused more on phylogeny (e.g. understanding the evolution among the species or groups of organisms), to ontogeny (e.g. the development of single individuals from the earliest stages to adulthood). In the 20th century, we have the first psychologist who focused his studies and theories on infants in order to explain cognitive development also in later stages. Piaget (1952)) proposed that cognitive development occurs in stages characterized by different ways of thinking and understanding the world.

Infants nowadays are defined as complex and active agents for what concerns their socio-emotional and cognitive experiences (Trevarthen, 1974). Still, they highly depend on their caregivers. Parents are not there only to quench the physiological needs of their children, but also to provide cognitive, social and emotional scaffoldings that are fundamental for the children's development in each of these areas. That is the main reason why infant research shouldn't be run outside the parent-infant interaction context.

1.4 – From the individual to the dyad

Trevharten (1974) was among the first to propose a theory that focused on the interaction between the mother and the child. He believed the child had an innate push to communication, which can be seen from the first days of life when children can already recognize their mother's face and voice. The child engages the caregiver in communicational exchanges through smiling, vocalizations and gaze. He defined intersubjectivity as the ability of infants to adapt their behavior to their partner's *subjectivity* (e.g. their consciousness and intentionality). He posits that intersubjectivity develops in two stages: a *primary intersubjectivity* is achieved around two months and it corresponds to the infant's ability to respond to their caregivers. The next stage, *secondary intersubjectivity*, involves dyadic interaction with an object and cooperative communication. It is achieved at around 9 months of age (Trevarthen, C., & Hubley, P., 1978). The purpose of this intersubjectivity is to share the emotions with the caregiver in the context of their interaction.

Another very important concept when we talk about infants is meaning-making. Meaning-making refers to the process through which individuals interpret, understand and build expectations about themselves, their interactions and the world surrounding them. This process is not something that the infant does by itself. This is only possible in the context of the parent-infant interaction: the baby receives feedback and information from the caregiver that allows them to build expectations and meaning of the world and them as individuals. This happens because babies use the feedback they receive about their behaviors from the caregivers to learn something new about themselves (E. Tronick & Beeghly, 2011). An example of feedback coming from the caregiver is the one that regards emotions. Caregivers are prone to the mirroring of their infants' emotions. In this way, infants receive feedback that allows them to regulate their own emotions. These exchanges make it possible for infants to lay the foundations for higher-level functions such as empathy and mentalization (Rochat, 2009). The adequate development of abilities like the ones I just mentioned will be fundamental for the infant to achieve an ideal socio-emotional development and for the parent-infant interaction quality (Fonagy et al., 2007).

What these findings mean is that interaction in the dyad does not only regard the communication between the infant and the caregiver, but it teaches infants to perceive themselves in the interaction with a parent.

Talking about the interaction between the caregiver and the infant, it is impossible to not mention attachment. Attachment is defined by Bowlby (1979) as a deep emotional bond that is developed between the infant and the primary caregiver, usually the mother, during the first years of the life of the child. The attachment style that the dyad develops will be crucial for the socio-emotional development of the child and it is strongly influenced by early interactions between parents and infants. Ainsworth and colleagues (1978) found that when infants experience synchronized interactions with their mothers, they will most likely develop a secure attachment. In contrast, if the interactions are asynchronous, the infant may be more prone to insecure attachment. One thing that must be pointed out is that the quality of these interactions is not solely dependent on the caregiver's ability to connect with the infant since a significant role is also played by the infant's characteristics. Temperamental traits such as irritability, sociability, and enjoyment of close physical contact can influence the interaction between mother and child, and consequently, their attachment style (Sroufe, 1985). Notably, a study by Lewis and Feiring (1989) on separation-reunion dynamics in parent-infant dyads suggested that the infant's behavior is a better predictor of their future attachment style rather than their mother's behavior. This finding does not diminish the importance of the mother's sensitivity in fostering a healthy attachment but rather emphasizes the bidirectional nature of the influence between a caregiver and their infant. This again supports the idea that babies are not passive agents in the interaction, but these are shaped by the mutual exchanges that happen between the caregiver and the infant (Beebe et al., 1992).

1.5 - Louis Sanders

Sander is often considered as one of the pioneers of infant research. His scientific interest in caregiver-infant dyads started during the '50s, making him one of the first researchers to focus on the study of infancy (Seligman, 2019). His work foreshadows many contemporary theories and findings regarding the impact of caregiver-infant relationships on later adult development (Jaffe et al., 2001; Main, M., & Hesse, E, 1990; Seligman, 2017). Nonetheless, his results were, in part, made possible by techniques developed by other researchers, such as Daniel Stern's microanalytic approach (1971) which enabled detailed analysis of the dynamics within caregiver-infant relationships.

Sander's approach to infant research reflected Dynamic Systems Theory (DST) principles. He considered development to be a non-linear and dynamic process. He took Waddington's model (C. H. Waddington, 1957) as a reference in order to sustain the importance of early caregiver-infant interactions. The model posits that sensitivity to the early environment plays a fundamental role in developmental pathways. Sander believed that an organism cannot be observed in isolation from its environment; newborns are part of a system (Sander, 2002). Their development is shaped by the ruptures and repairs that happen in the dyadic relationship with the caregiver (Seligman, 2019).

Willing to create a comprehensive theory applicable to psychoanalytic interpretations of development, Sander tried to integrate infant research not only with DST but also with neuroscience and theoretical biology. Despite his main focus being the analysis of caregiver-infant relationships, he also tried to include other forms of relationships, from sociocultural interactions to therapist-patient dynamics, and even microscopic physical and chemical interactions (Seligman, 2019).

One of Sander's key contributions is the concept of the *recognition process*. He defined recognition as a moment of shared awareness between the caregiver and the infant. To cite him: a feeling that "*one is known by another*" (Sander, 2002). This process evolves through increasingly complex tasks aimed at building an ideal relationship (Sander, 2002) between the infant and the parent. Each successful adaptive task in this relationship sets the stage for the next, unfolding in a non-linear, dynamic manner. In the interaction's context, the negotiation between disruption and repair fosters coordination between the parent and the infant, while allowing each of them to maintain their individuality. If this negotiation is followed by a positive emotional experience, it reinforces future interactions (Sander, 2000). His biopsychosocial relational model of development is built around this concept of the recognition process. In this process, the infant both shapes and is shaped by the environment through a continuous exchange of information. The infant is viewed as an active agent, capable of self-regulation and resolving tensions with their caregiver (Seligman, 2019). Within this model, Sander outlines seven phases of adaptation between the members of the dyad, which occur during the first three years of life.

The primary objective of the infant over his first three months of life is to establish the regulation of the basic physiological rhythms. At this stage, the infant relies entirely on the interaction with the mother to regulate these functions. Between the 4th and 6th months, the infant enters the second stage. This phase is marked by spontaneous reciprocal exchanges which take part mostly through the display of smiling behaviors. Here the baby is aware of the meaning of these social cues that he can imitate (Wörmann et al., 2012). During the third phase, between the 7th and 9th months, the infant begins to engage in finalized activities designed to create mutual social exchanges with the mother and to exert some control over their environment. This is when the infant starts to develop a sense of agency, realizing they can actively influence their surroundings in terms of the physical environment and also their mother's behavior. In the fourth stage, from 10 to 13 months of age, the infant begins to express specific needs to the mother and explores more. In the time between 14 and 20 months of age, which corresponds to the fifth phase, the infant starts developing autonomy, sometimes exhibiting behaviors that can enter into conflict with the mother's expectations, leading to temporary separation. In the last two phases, which both span from 18 to 36 months, the infant begins to articulate their perceptions and intentions using language. Infants also begin to manage disruptions and repairs in the relationship with the mother. Through these stages, infants gradually gain a deeper understanding of both their internal states and those of others. This development occurs through experiencing and resolving disruptions in the dyad's relationship (Sander, 2002).

1.6 - Edward Tronick

Sander's model of caregiver-infant interactions has been influential in the work of later developmental researchers, such as Edward Tronick, who can be considered as one of the most relevant.

For Tronick, as for Sander, time and dyadic rhythms are crucial factors that exert a huge impact on the development of expectations and future behaviors (Gianino & Tronick, 1988). Infants are born with a set of emotional abilities that can activate a reaction from their caregivers. The capacity to get and maintain their partner's attention helps them fulfill several goals that range from the physical ones (closeness to the mother) to the ones that are more internally oriented (emotion regulation) (Tronick, E, 1980).

Nonetheless, the abilities that children are born with are not enough for them to take care of all their needs by themselves. The only possibility they have to upgrade their set of socio-emotional skills is through the interaction with the caregiver.

He defined these interactions as structured systems of mutually regulated behavioral units (E. Tronick et al., 1979), emphasizing that they should not be analyzed as individual behaviors but rather altogether, globally (E. Tronick et al., 1980). Tronick supported the idea that early mother-infant interactions are dynamic patterns in which both partners influence each other in a bidirectional manner, as previously suggested by other researchers (e.g., (Gottman & Ringland, 1981).

According to Tronick, these interactions take place within an "*affective communication system*" (E. Z. Tronick, 1989). Caregivers, after having interpreted their infant's emotional responses, categorize them according to three dimensions: hedonic tone (positive or negative), activation (sleep or excitement), and orientation (internal or external; (Emde, 1983). These categories represent expressive modalities through which infants convey messages about their emotional state, allowing also babies to interact with the partner.

Research has shown that mothers specifically respond to their infants' facial expressions that convey emotional responses rather than random facial movements like shudders (Malatesta & Izard, 1984). This means that, from the first weeks of life, caregivers quickly master the interpretation and understanding of their infants' emotions. However, infants also become experts in reading those emotional cues from the caregiver which serve them as crucial guides for their behavior. This experiment by Campos and colleagues (Campos et al., 1989) can serve as an example of what has just been said. These researchers demonstrated that infants whose mothers displayed positive emotions and encouraging comments were more prone to engage in crossing an obstacle than the ones whose mothers displayed negative emotions like fear or anger.

Caregivers' emotions serve infants not only for behavioral regulation, but also for their meaning-making process (E. Tronick & Beeghly, 2011). At a few months of age, infants have both *external goals* (e.g. about social interactions with other individuals) and *internal goals* (e.g., related to maintaining homeostasis) already. To achieve these goals, they continuously evaluate their behaviors and draw on past and present experiences to inform their future actions (Tronick, E, 1980). Emotions play a central role in this process of behavior evaluation: if infants manage to achieve their goals, they will be encouraged to seek more interactive experiences by the positive emotions that derive from their successful interactions. Unsuccessful interactions will instead cause negative emotions and will make the infant give up on further social engagement (E. Z. Tronick, 1989). Thus, emotions are not merely disruptive but serve as powerful motivators for the infant's behavior (Campos et al., 1989; Izard, 1978).

The achievement of their internal and external goals is not only possible through interaction with the caregiver. Infants can also rely on internal coping mechanisms, such as self-comforting and self-stimulation, which Gianino and Tronick refer to as *self-directed regulatory behaviors* (Gianino & Tronick, 1988). However, these behaviors are usually insufficient for the regulation of their emotions and physiological states (E. Z. Tronick, 1989). Caregivers play a crucial role by employing *other-directed regulatory behaviors* (Gianino & Tronick, 1988), which involve mirroring the infant's emotions and responding to them, thereby helping to transform negative emotions into positive ones. According to Gianino and Tronick (Gianino & Tronick, 1988), the interactive skills developed through the caregiver-infant relationship will eventually be internalized by the infant becoming part of their self-regulatory behaviors. The impact of these self and other-directed behaviors becomes evident when they get disrupted, for instance, by instructing a mother to be unresponsive, as in the Still-Face Procedure (SFP), which resembles the disengagement seen in some depressed mothers (Cohn & Tronick, 1983; Tronick, E, 1980).

Now, let's go into more detail about some of Tronick's key concepts.

1.6.1 - Mutual regulation model

To describe the caregiver-infant relationship, Tronick developed the Mutual Regulation Model (MRM; Gianino & Tronick, 1988). This model emphasizes that both infants and caregivers share one goal: the achievement of reciprocity (in terms of intentions and meanings) and mutual regulation. Through interactions characterized by mutual recognition of emotions and responsive communication, each component of the dyad can interpret the other's intentions and also find the space to express their own. This process leads to mutual affective regulation and can be seen as a co-creative process (Gianino & Tronick, 1988). Additionally, these early interactions enable the infant to develop *implicit relational knowledge* about them (Stern et al., 1998; E. Z. Tronick, 2002), which guides their future relational behaviors. The MRM is significant in developmental science because it challenges the traditional view of the infant as a passive recipient whose only role in the interaction is receiving external stimuli, instead portraying the infant as an active participant in the relationship.

1.6.2. - Dyadic Expansion of Consciousness Hypothesis

Years later the development of the Mutual Regulation Model, Tronick introduced the Dyadic Expansion of Consciousness Hypothesis (E. Z. Tronick et al., 1998). This theoretical framework is grounded in the Dynamic Systems Theory, which posits that biological systems are self-organizing but can also expand when influenced by external inputs. According to it, a *state of consciousness* is defined as “an individual’s continuously developing knowledge of the world and their relationship to it” (Mesman et al., 2009). Tronick posits that each individual is able to self-organize and create their own states of consciousness, which will be expanded, becoming more coherent and complex, through the interaction with another individual with the same characteristics (E. Z. Tronick & Cohn, 1989).

Tronick views the mother-infant dyad as an expanded system, possessing a more complex state of consciousness than just the sum of the individual states of the two partners. Within this model, the author wanted to emphasize the role of mutual regulation in the dyad. He argues that the infant’s affective regulation is not solely based on mirroring and imitating the mother’s emotional expressions but also on actively responding to them. For instance, an infant might act defensively in response to the mother’s anger rather than mirroring it. This reaction, in turn, influences the mother’s emotional response, highlighting a process of mutual regulation. Children can in fact detect emotions and meanings from the caregiver and they will adapt their behavior to those of the caregiver from the very first months of their life. Moreover, this might bring us to affirm that affective manifestations play a role in interactive behaviors. The child's emotional expression can be seen as a result of an evaluation of the emotional valence of the episode he is involved in (Gianino & Tronick, 1988). This is how the child expresses to the mother what kind of judgment he is giving to the interaction so that the caregiver can modify it. A sensitive partner will help the child build expectations and meanings about the interaction.

Tronick asserts that this mutual regulation is crucial for the expansion of the dyadic system (E. Z. Tronick & Cohn, 1989). Notably, the aim of this framework was not only to describe the mother-infant relationship but also to be applied to the therapist-client dyad.

1.6.3. - Match, Mismatch, Reparation

Tronick (E. Tronick et al., 1979) and Brazelton (Brazelton et al., 1974) describe the mother-infant interaction as evolving through phases of match, mismatch, and reparation (**Figure 1**). This dynamic process is characterized by a cycle where interactions shift from coordinated, synchronous states (matching) to uncoordinated, dyssynchronous ones (mismatch), and back to matching states through active repair (E. Z. Tronick, 1989). Contrary to an idealized notion of smooth and constant synchronization, interactions between mother and infant are often "messy" and marked by frequent shifts (E. Z. Tronick, 1989).

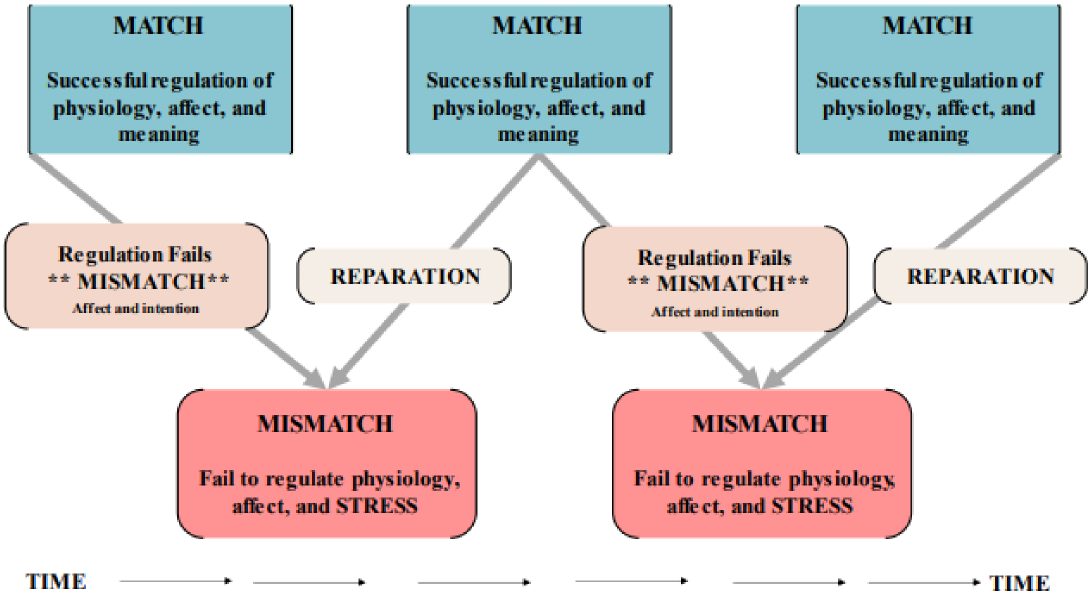

Figure 1*: schematic representation of the process through which the dyad manages its mismatches getting back to a preferable state of matching, in a constant fluctuation between the two phases (Tronick, 2009).*

Research by Tronick and Cohn (1989) revealed that only 30% of face-to-face interactions between mother and infant are characterized by coordination, indicating that the dyad frequently transitions between positive and negative affective states. Mismatched states are likely more common than matched states due to the frequent misalignment of intentions between the partners during interactions (E. Tronick & Beeghly, 2011). Possible reasons for this lack of predictability include fluctuations in attention, shifting intentions, the rapid pace of interactions, and the infant's developmental immaturity (E. Tronick, 2005; E. Z. Tronick, 1989).

Despite the prevalence of uncoordinated states, Gianino and Tronick (1988) found that reparation typically occurs immediately following a mismatch in 70% of the trials. This indicates that usually interactions evolve quickly, with interactive errors being swiftly corrected through repair processes (E. Z. Tronick, 1989). Consequently, episodes of negative affect are generally short-lived, as the dyad rapidly restores coordination. This is the core of

Tronick's observations: missteps do occur but are readily corrected, impeding micro-stressors to damage infants' development (DiCorcia & Tronick, 2011).

The infant learns that mismatches can be repaired if, during the interaction with the caregiver, these ruptures get consistently repaired with appropriate and contingent responses from the parents (E. Tronick & Beeghly, 2011). This process fosters in the infant a sense of reliability, both in their own ability to regulate their behavior and in the dependability of others, leading them to view themselves as capable and the parent as someone to be trusted (E. Z. Tronick, 1989). Over time, this contributes to the formation of a secure attachment with the parent (e.g., Cohn et al., 1991) and a stronger sense of agency (Brazelton, 1992). Moreover, understanding that interactions can be repaired cultivates a generally positive emotional outlook in the infant, helping them establish well-defined borders between themselves and others. As a result, the infant is more likely to approach future interactions with openness and a positive bias, even in challenging situations (E. Tronick & Beeghly, 2011). So, we could say it is the steady and fast reparation (or its failure) of mismatches that contributes the most to the development of the child.

Not all dyadic interactions have a positive outcome. When synchrony between the caregiver and the infant is low, negative emotions overshadow positive ones. Brazelton and colleagues (1974) showed the difference between successful and unsuccessful repairs in caregiver-infant interactions by providing two examples. In the first example, while playing with the mother, the infant turns away and starts sucking their thumb, displaying a common self-soothing behavior. The mother observes without intervening, and when the infant is ready to re-engage, he/she turns back to the mother, who responds with a smile, resuming and involving the child back in the interaction. This interaction is marked by positive emotions and an effective repair of mismatches. In the second example, after the infant turns away and begins thumb-sucking, they do not return to the mother. The mother, becoming more intrusive in her attempts to regain the infant's attention, inadvertently causes the infant to withdraw further. This interaction is denoted by more negative emotions and exchanges and difficulty in repairing mismatches. Regardless of who caused the interaction to "fail", something didn't go as expected in the second scenario (Brazelton et al., 1974).

Atypical interactions are often marked by longer negative emotional experiences and fewer shifts from negative to positive affectivity. The caregiver and the child appear to be trapped in negative, uncoordinated exchanges, with significantly reduced emotional synchronization between the infant and mother (E. Z. Tronick, 1989). Depending on how much control they believe they have in fixing the interaction, infants, sensing that the goal of establishing a positive connection with the caregiver has not been met, may feel angry or sad. If infants feel capable of overcoming the challenge, anger arises, motivating them to take action; if they feel powerless, sadness takes over, leading to disengagement. In both scenarios, infants focus primarily on regulating their negative emotions through self-directed behaviors. This intense focus on negative affect can cause the infant to neglect other crucial goals, like emotional closeness, potentially hindering their socio-cognitive development. If this sequence persists, this may cause the infant to see themselves as non-effective agents and their parents as non-trustworthy caregivers (E. Z. Tronick, 1989). Repeated failures in the dyadic interaction can contribute to the development of psychopathologies (E. Z. Tronick, 1989). When unsuccessful interactions dominate the mother-infant relationship, they can negatively affect the infant's development and their meaning-making process of what concerns themselves and their social interactions. This perspective tracks down the origin of psychopathologies in early negative experiences, attributing a great role to those that have to do with success, the repair of failures, and the transformation of negative emotions into positive ones (E. Z. Tronick, 1989).

But, as already said, typical interactions are characterized by frequent fluctuations in dyadic synchrony.

1.6.4 – Factors influencing dyadic synchrony

1.6.4.1 – Infant characteristics

A study by Tronick and Cohn (1989) found that mother-son pairs were 50% more synchronized with respect to mother-daughter pairs.

Beyond gender, differences in infant temperament, such as sensitivity to external stimuli or proactivity in the interaction, have also been shown to affect synchrony while the partners interact (E. Z. Tronick, 1989).

The degree of development of infants can play a role as well. For example, in his Model of Dyadic States of Consciousness, Tronick suggests that around 5 to 6 months of age, the interaction between mother and infant organizes differently. This new organization is called Dyadically Expanded States of Consciousness (DEC). This means that the mother and the infant can integrate the partner's emotional states into their own, increasing the complexity of the dyadic exchanges. The emergence of this process is supported by a growing awareness of both the individuals about the other's mental states. The dyad is made of two independent regulatory systems that are open to external regulation. Thus, moments of alignment increase the complexity of each system, thereby broadening the awareness of each of them at the dyadic level (E. Tronick, 2008)

Tronick argues that this connection is the foundation of new abilities that would not be able to emerge if it weren't for the interactive processes. For example, a child's capacity to gesture is thought to stem from the dyadic system. That is because the mother supports the child's body and controls their posture, enabling free arm movement (E. Z. Tronick, 1989). So humans don’t limit themselves to establishing interactions with others but also aim at creating shared dyadic mental states. These states serve as organizers, enhancing internal coherence and complexity.

1.6.4.2 – Maternal characteristics

Maternal sensitivity and availability are crucial for infants’ socio-emotional development. For example, it was demonstrated that when dyads experience vocal and affective synchrony, their biological synchrony, in terms of heart rate, increases as well (Feldman et al., 2011). This means that the mother’s ability to catch and respond appropriately to her infant’s signals can enhance dyadic synchrony.

Maternal depression or anxiety can negatively impact dyadic synchrony. Depression causes mothers to be less expressive and interactive. For example, it was demonstrated how dyads in which the mother has a depression diagnosis display less shared gaze and interaction sequences. On the other hand, anxious mothers tend to overwhelm their infants with social behaviors like smiling or vocalizations, ignoring their signals expressing a wish for less stimulation (Feldman et al., 2009).

1.6.4.3- Cultural Factors

Not only individual factors but also cultural ones play a role in shaping emotional regulation in the dyad and their match-mismatch-reparation process. LeVine (1990) provided an example from the Gusii community, an agricultural society in Kenya, where mothers often disengage from eye contact and smile at their infants, signaling a lack of interest in such interactions. Consequently, children raised in such an environment will be prone to avoid overt expressions of positive emotions. These findings highlight the influence of social and cultural norms on mother-infant interactions, which are to be defined and observed in a manner that takes into consideration the culture in which the dyad is acting.

In essence, various factors, both cultural and individual, can shape the dynamics of caregiver-infant interactions, leading to a huge spectrum of developmental outcomes. The skills that infants develop inside the dyad, such as emotional regulation and effective communication, will be crucial throughout life and significantly shape the person that the child will become in the future (Stern, 1985).

1.7 - Still-face procedure

While we go deeper and deeper into Tronick's research, we meet one of the most influential and used paradigms in infant research. In 1978, Tronick introduced this new experimental setting that would have a huge impact on how we study and observe mother-infant dyads. The Face-to-Face Still-Face Procedure (SFP; E. Tronick et al., 1978).

In his earlier experiments (E. D. Tronick et al., 1977) Tronick could observe how caregivers and infants actively regulate their emotions through the reciprocal feedback they provide each other during interactions. To further explore how infants manage their emotions during social exchanges, Tronick came up with an experimental design that intentionally distorted the feedback typically received from the mother by the child. In the first study from 1978, the SFP was structured into two subsequent episodes, each lasting 3 minutes, with a 30-second interval in between (E. Tronick et al., 1978). The initial episode just resembled a free interaction, without any limit or rule, in which the mother was instructed to play with her infant as she usually would. After 3 minutes had passed, she had to disengage from the infant for 30 seconds, before engaging the infant in the Still-Face episode, which would last 3 minutes as well. During this time, the mother had to sit in front of her infant, be unresponsive, and maintain a neutral, unexpressive face. During the whole paradigm, the infant had to remain seated in an infant seat, while the mother sat across from her child. This specific setting was required so that the entire interaction could be effectively recorded using two video cameras—one recording the infant and the other one recording the mother. These recordings were later used to code the behaviors of both the mother and the infant (E. Tronick et al., 1978).

In their initial analysis, Tronick and his team identified five key phases along which a typical dyadic interaction would develop: initiation, mutual orientation, greeting, play-dialogue, and disengagement. However, these phases were absent during the Still-Face episode, as the mother's unresponsiveness led the infant to withdraw rather than engage the partner. These findings underscored the active role infants play in the relationship with the caregiver and their sensitivity to changes in their partner's behavior, which is crucial for establishing and maintaining an interaction. The infant's immediate reaction to the lack of reciprocity demonstrated their awareness of what was happening in the interaction and how it could have an impact on their emotional states. According to Tronick and his colleagues, the Still-Face effect may be explained by a breakdown in mutual regulation, a phenomenon that can also be observed in everyday interactions between the dyad. During the Still-Face episode, the caregiver's contradictory behavior creates a confusing experience for the infant, making them feel trapped (E. Tronick et al., 1978).

After Tronick and colleagues published their initial study in 1978, numerous research teams began incorporating the Still-Face Paradigm into their experiments. The Still-Face effect quickly gained the scientific community's interest due to its ability to provoke a significant response in infants and its usefulness in revealing how infants manage their behavior during stressful social situations (Adamson & Frick, 2003). Over the years, the

SFP was adapted, leading to the creation of several variations. Unfortunately, some of these versions were never empirically validated (Mesman et al., 2009). One key modification involved shortening the duration of the episodes (making it 2 minutes long instead of 3 minutes) (Adamson & Frick, 2003) and expanding the procedure from two to three phases. This revised version has become the standard and is widely used in many studies (see **Figure 2)**. The first phase, known as the Play episode, is marked by a free interaction between the mother and the child: she is instructed to interact with her baby as she would normally do at home, such as by singing, playing (typically without toys), or through verbalizations. After 2 minutes of free interaction, the researcher signals the mother to begin the Still-Face episode, during which she must maintain a neutral, unexpressive facial expression and be unresponsive, avoiding any interaction with the infant for 2 minutes. Once this phase ends, the mother is allowed to return to her usual interactive behavior with the infant in the one that is called the Reunion episode, which also lasts 2 minutes (Mesman et al., 2009).

Figure 2*: each frame is taken from one of the three episodes that compose the SFP. In the Still-Face episode it can be seen that the baby reacts with a negative emotion display as the interaction is "turned off" " In the other two episodes, Play and Reunion, the baby will most likely be more relaxed as the mother will be fully available.*

While most research groups adhered to this last version of the SFP, the paradigm went through some other modifications that were introduced in order to make the SFP feasible for the exploration of the impact of specific factors on the interaction or to examine its effects on clinical populations, such as preterm infants (e.g., Segal et al., 1995), children with developmental delays (Carvajal & Iglesias, 1997), and children in the autism spectrum (Nadel et al., 2000). Additionally, although most SFP studies have focused on mothers, there is a growing interest in examining the father-infant relationship as well (e.g. Braungart-Rieker et al., 2001, 2014)

1.7.1 - Behavioral response to the SFP

In the initial version of the Still-Face Paradigm (SFP), the infant's behavior was analyzed through the observation of variables such as verbalizations, gaze direction, head orientation, body and head position, facial expressions, and movements. The mother's behavior was similarly coded, with attention given to her vocalizations, body and head position, the way she handled the infant, gaze direction, and facial expressions (E. Tronick et al., 1978). Later, Tronick introduced four behavioral coding systems: the Modified Monadic Phase Scoring System (MMSS; E. Tronick et al., 1980), the Mother Regulatory Scoring System (MRSS; (E. Z. Tronick & Weinberg, 1990b), the Infant Regulatory Scoring System (IRRS; (E. Z. Tronick & Weinberg, 1990a; Weinberg & Tronick, 1994), and the Infant and Caregiver Engagement Phase (ICEP; E. Z. Tronick et al., 2005). The IRRS specifically emphasizes the emotions expressed by infants and their ability to use both self and other-directed regulatory during a stressful situation such as the SFP.

This coding system was derived from the Modified Monadic Phase Scoring System, which, in turn, focuses specifically on the mother's behavior and the strategies she uses to regulate the infant's emotions. A further contribution was given by the observations made by Brazelton and colleagues on infant coping behaviors (Brazelton et al., 1974). The Infant and Caregiver Engagement Phase further expanded the analysis to include different variables of facial expressions, gaze direction, and vocalization types in both the caregiver and the infant. Various research teams have also developed their own behavioral coding systems for the SFP. While these systems differ in some aspects, they have in common the examination of the infant's gaze direction and emotional expressions. Some studies have also incorporated analyses of complex behavioral clusters (e.g., Braungart-Rieker et al., 2001) or very detailed micro-coding of facial expressions (e.g., Carvajal & Iglesias, 1997). Generally, the microanalytic approaches introduced by Stern (1971), are the most diffused in mother-infant interaction studies because they allow for second-by-second behavior scoring. Although consuming a lot of time, this method reduces the need for theoretical assumptions and interpretation by the observer, enhancing the reliability of the coded results as they are more objective.

Let's now go more in detail into the remarkable behavioral patterns that can be observed in infants while ongoing the SFP.

1.7.2 - The Still-Face effect

The so-called *Still-Face effect* refers to common behaviors that the infant displays during the Still-Face episode. Tronick (1989) reports that three-months olds usually display a wide range of behaviors, such as hand gestures or vocalizations, that have the function of communicating their discontent, caused by their mother becoming unresponsive. In order to get their mothers' attention back, they will most likely repeat those behaviors they experience in typical interactions with the caregiver, such as familiar games, gestures, or smiles. These efforts to reconnect with the mother demonstrate the infant's strong sense of agency and confidence in their own abilities. However, as time goes by and mothers remain unresponsive, infants begin to lose their feeling of effectiveness in forming a meaningful emotional connection. When they realize that these other-directed behaviors won't achieve their goal of closeness, they start to engage in self-regulatory behaviors to cope with the rising negative emotions (E. Z. Tronick, 1989). As a result, they exhibit a noticeable increase in negative affect between the Play episode and the Still-Face episode, showing more signs of wanting to be picked up, sadness, anger and being agitated (Toda & Fogel, 1993; Weinberg et al., 1999). Numerous studies have also reported that, during the Still-Face episode, the display of gaze aversion is significantly higher, while smiling is significantly lower if compared to a normal caregiver-infant interaction (e.g., Gusella et al., 1988).

Researchers have proposed various interpretations of the Still-Face effect, with some of the most prominent explanations coming from Tronick's model of caregiver-infant interaction. According to the Mutual Regulation Model (Gianino & Tronick, 1988), the Still-Face episode represents an exaggerated form of a typical mismatch within the dyad. The reason why it is considered an extremization is that infants will keep failing to reconnect with the caregiver, who will remain unresponsive for an unusual amount of time. Another model of his, the Dyadic Expansion of Consciousness Model (E. Z. Tronick et al., 1998), views the Still-Face effect as a failure to establish a dyadic state of consciousness between a mother and her infant. This failure occurs because the infant cannot process the mother's unresponsive behavior (E. Tronick, 2005).

But Tronick wasn't the only one who proposed some models for the interpretation of the Still-Face effect. An alternative explanation comes from Fogel and colleagues (1982). He suggests that the infant's behaviors during the Still-Face episode, such as smiling or laughing, serve as a way to release tension. He argued that the Still-Face Paradigm is governed by a tension-release cycle, which is disrupted by the mother's unresponsiveness, leading the infant to exhibit withdrawal behaviors. Field (1994) offered another perspective, emphasizing the caregiver's role in modulating the infant's emotions. During the Still-Face episode, the caregiver's unavailability fails to regulate the infant's negative emotions.

According to all these models, the key factor for the interpretation of the Still-Face effect is the caregiver's inability to regulate infants' emotions, causing the infants' self-regulation to depend on their immature abilities.

1.7.3 – The Reunion effect

The Reunion Effect was only acknowledged in 1996 by Weinberg & Tronick (Weinberg & Tronick, 1996). The Reunion episode is particularly delicate for the infant who has to engage in complex regulatory functions and manage mixed emotions while the mother resumes the interaction (Weinberg & Tronick, 1994). The difficulty arises from the conflicting signals from the caregiver: while the mother has returned to her normal behavior, the negative emotions triggered by the Still-Face episode persist.

During the Reunion episode, infants often show a *carryover effect* (Mesman et al., 2009), which means they continue to exhibit negative emotions and ambivalent behaviors, characterized by both approach and avoidance. This is important as it informs us of the fact that infants do not rely solely on current external stimuli for emotional regulation. Instead, they appear to internalize the negative experience that occurred during the Still-Face episode, anticipating the recurrence of another unpleasant experience even after the interaction has resumed.

Several studies have supported the idea that infants experience mixed emotions when re-establishing normal interaction with their mothers. In their pioneering study, Tronick and colleagues (1978) observed how infants often displayed anger as soon as the mother was again available for interaction, indicating that they did not immediately "forgive" the mother for her unresponsiveness during the Still-Face episode. Similarly, research by Field and colleagues (1986, p. 198) and Fogel and colleagues (1982) noted an increase in crying and overall distress in the baby during the Reunion episode. However, not all studies have replicated evidence of a carryover effect. For instance, Gusella and colleagues (1988) reported that the infant looked more often at the mother and smiled more during the Reunion episode.

In conclusion, what appears from the literature investigating this last episode of the SFP, is that children experience both positive and negative emotions when the mother becomes available again, but results are mixed and couldn't be replicated in all the studies (Weinberg & Tronick, 1996).

1.7.4 – Different styles of reparation

When interpreting the Still-Face and Reunion episodes, it's crucial to recognize that the reparation processes differ for each parent-infant dyad, as they are shaped by the unique interactions between individuals in various contexts. These differing reparation processes can lead to distinct dynamics and potentially influence the progression of a child's development (E. Tronick & Beeghly, 2011).

Infants do not all react uniformly to their mothers becoming unresponsive. Gianino and Tronick (1988) observed that infants accustomed to frequent reparations while interacting with their caregiver were more likely to seek out their typical behavior during the Still-Face episode. This may be because these infants have a well-formed internal understanding of their mother's usual behavior and how to restore interaction. In contrast, infants who are less used to effective reparations in their regular interactions were less inclined to seek their mother's engagement and more likely to withdraw. These infants often relied more on self-regulatory strategies to manage their negative emotions.

Variations in behavior during the SFP are generally considered individual differences, as long as they are not extreme. However, some studies have found correlations between the behaviors observed during the SFP and the quality of parental caregiving (e.g., Tarabulsy et al., 2003). These behaviors can also predict future developmental outcomes, like attachment quality (e.g., Braungart-Rieker et al., 2001) and potential behavioral problems (Moore et al., 2001).

In summary, Still-Face Paradigm's reliability for exploring the dynamics that characterize parent-infant interactions has been assessed by numerous studies. What is clear is that it offers valuable insights into how infants cope with stressful situations and how well the dyad can restore a positive interaction following a disruption, which will, in turn, have an impact on the child's socio-emotional development.

Through everything I just explained, infant research has overturned the frame that saw the infant as a passive recipient of external stimuli. The active role that the infant plays in the relationship with the caregiver, especially in the socio-emotional dimensions, is now well-assessed. The interaction with the parent gives infants the possibility to give meaning to what happens in the environment that surrounds them, while the feedback they receive from the caregiver helps them to give meaning to their emotions, which provides them with the abilities that occur to regulate them.

Chapter 2 –EEG in Early Dyadic Interactions

Despite the huge amount of evidence in the literature assessing the importance of parent-infant interaction for the infant's socio-emotional development, until not long ago there was a huge gap in the research.

Constructs like social attention or the way we see and understand other people used to be studied by designing paradigms that focus on one's own individual capacity to process social information. It means that social constructs were studied in contexts that were very distant from the social one. Most of the studies assessing the early mechanisms of social attention, like gaze, were designed with paradigms that used to put a lonely participant in front of pictures or videos featuring people or fictional characters (Grossmann et al., 2013; Grossmann & Johnson, 2010; Michel et al., 2015). Moreover, in most of these empirical studies, only infants' parameters were recorded (Hoehl & Markova, 2018).

This means that what researchers have measured until a few years ago was not the result of an immersive mutual social interaction. What Schilbach and colleagues argue (2013) in order to support the necessity for what they called "a two-person approach" is that the only way we can understand and interact with someone else is through an active social engagement that puts us in front of another mind. It is interesting to point out the discrepancy that arose between what was already well assessed in the literature through decades of investigations, (for example, the undisputed role of a well-functioning parent-infant interaction for the socio-emotional cognitive development of newborns) and the scientific paradigms that until not many years ago were still ignoring the dyadic interaction, investigating the individual outside of social contexts.

In the last few years, a new methodological approach has arisen. The hyperscanning paradigm is the research approach that allows the recording of simultaneous brain activities in two participants (Montague et al., 2002). The introduction of this technique made it possible to measure the so-called inter-brain synchrony (IBS; Dumas et al., 2010). Before getting into detail of this methodology, let's explain something about synchrony

2.1 - Synchronization

Synchrony has been defined as a process that coordinates the continuous mutual flow of sensory, hormonal, and physiological stimuli between parent and child when they interact, which represent the foundations for an infant's socio-emotional growth and development (Feldman, 2007b). This means that is not about synchronous oscillations of the systems involved, but rather how they adapt to each other (Tass et al., 1998). Among all the constructs that are used to describe the dyadic interaction's quality, such as attunement and sensitivity, synchrony is the only one that stresses the time-based component and the continuous structuring of social interactions into repetitive and synchronized patterns (Bernieri & Rosenthal, 1991).

This synchrony and its precursors appear in the parent-infant interaction a few hours after the infant is born, suggesting the human biological predisposition for socially coordinated interactions (Feldman, 2007b).

Right after birth, the mother stimulates the baby during alert states through a set of social cues, such as gazing at the infant's face, vocalizations characterized by an acute tone, the so-called *motherese*, and affectionate touch. This offers the baby its first experience of a connection between its internal state and how it can affect parental behavior (Feldman, 2007b).

Around 3 months of age, infants engage in face-to-face interactions and can respond to social cues from the parents through gaze, facial expressions and vocalizations. These coordinated interactions that provide critical inputs for the maturation of the social brain (Feldman, 2007a) require a turn-taking that is characterized, as Tronick (1989) suggested, by oscillations between moments of interactive and affective misattunement and interactive reparation.

The second half of the first year is characterized by an increase in shared attention and mutual responsiveness (Feldman et al., 1999), but also a decrease in mutual gaze and vocalizations (Feldman, 2007b). Synchrony here is related to stress regulation both at a physiological and behavioral level (Feldman, 2012). The emergence of good levels of synchrony in the dyad has been found to correlate with maternal availability, as supported by Feldman and Eidelman (2003). They found that conditions that decrease maternal responsiveness such as being born premature or postpartum depression decrease maternal contingent response and vagal tone in the infant. These results, together with the findings that dyadic synchrony in humans is achieved mostly through signals that are conveyed through the face rather than touch (Feldman et al., 2011). An early well-functioning parent-infant synchrony is quite fundamental for the infant's socio-emotional development as its long-term effects were demonstrated (Feldman & Greenbaum, 1997). Synchrony at 3 and 9 months of age predicted self-regulation at 2, 4 and 6 years. Moreover, synchrony with both parents at 3 months predicted lower behavioral problems at 2 years, which could represent a defense against psychosocial distress (Feldman & Greenbaum, 1997). It also seems that synchrony at 3 months could predict empathy capacities in 13-year-old adolescents. These results make clear how certain areas, such as empathy, self-regulation and other complex social processes, require an early dyadic matching between mother and infant in order to determine an ideal development.

2.2 – The advent of Hyperscanning

What I’ve been discussing until now was synchrony from a behavioral and physiological perspective. Nonetheless, recently, a new tool for investigating synchrony has been validated and is now widespread in the field of parent-child developmental research. Electroencephalography (EEG) hyperscanning is a two-person paradigm that allows measuring simultaneously mothers' and infants’ brain activity (Montague et al., 2002). What is innovative in this technique is that it allows us to observe and link both neural processes and behaviors (Turk et al., 2022). Moreover, instead of recording with standardized screen-presented stimuli, it measures EEG signals in the dyad during free interactions (Wass et al., 2020). The analysis could focus on behavior-to-behavior, brain-to behavior or brain-to brain associations. In the case of brain-to-behavior relation, it is assessed by aligning EEG data to the behavioral recordings after they are coded. Brain-to-brain association refers to the coordinated activity occurring in the brains of multiple individuals (Turk et al., 2022).

When it comes to brain-to-behavior studies, they help to highlight and better understand what dyadic behaviors are associated with a neural response, and the way these exchanges contribute to the infants’ socio-emotional development (Turk et al., 2022). These constructs are usually investigated in the context of different interactive settings between parents and infants. This is the case, for example, of the studies from Atzaba-Poria (2017) and Perone (2020), which will be disclosed more in detail in the next chapter, that investigated frontal alpha asymmetry in interacting dyads.. These pivotal studies demonstrated a strong relation between frontal region activity and brain-to-behavior synchrony during emotion-eliciting tasks.

Another example is the investigation by Wass and colleagues (Wass, 2014) that shows the duration of infants' look at an object was affected by the presence of the caregiver, being longer while they were playing together rather than when the baby was playing alone. Interestingly, the amount of time that the baby spent looking at the object was also correlated to maternal neural responses.

Brain-to-brain synchrony investigation can help in understanding how social exchanges are represented in the brain (Turk et al., 2022). It is assessed that social attentional cues lead attention and learning already in early infancy (Wu & Kirkham, 2010). A study by Leong and colleagues (2017) demonstrated how joint-directed gaze enhanced synchrony, which was further enhanced by an augment of children's vocalizations. Another study by Leong et al. (2019) correlated dyadic brain synchrony to better social learning in the infant, which was in turn associated with more gaze and vocalization production from the mother. These results altogether suggest that gaze (Leong et al., 2017), emotional display (Atzaba-Poria et al., 2017; Perone et al., 2020) and vocalization (Leong et al., 2019) are associated with brain-to-brain synchrony, which is foundational for ideal dyadic interactions and children's socio-emotional development.

What is important to make clear here is that brain-to-brain synchrony isn't only achieved through an exchange of information (Burgess, 2013). Especially when talking about hyperscanning settings, the synchronization between the brains of the participants could be provoked by exposure to similar and contemporary external stimuli (Hasson et al., 2012). Another case is the one in which one of the subjects is able to influence the other one. Finally, there could be a coincidental synchrony, which usually only means that the individuals have a similar brain activity at the moment.

In general, until now, hyperscanning helped researchers in gaining important insights into many social factors that characterize dyadic interaction. Joint attention, social learning, and even maternal chemosignals (e.g. the odor of the mother) have all been investigated in order to see how they influence inter-brain synchrony, and how inter-brain synchrony affects them.

In the last three decades, a new EEG analysis method has been adapted to the study of interactional contexts using the hyperscanning technique. Frontal Alpha Asymmetry (FAA) has been argued to be a reliable measure for emotion regulation and motivational processes.

The next chapter will be dedicated to illustrating this construct.

2.3 – EEG in emotion and motivational processes

The EEG signal captures the frequency and amplitude of the electrical activity produced by the brain, which oscillates between 1 and 100Hz. Five frequency bands in this spectrum have been associated with specific states or functions in the brain.

Delta waves (1-3 Hz) are typical of deep sleep and therefore are not usually present during wakeful states. Theta waves (4-7Hz) are usually recorded during light sleep. Alpha waves (8-12Hz) and beta waves (13-30Hz) are typical of awake states and are respectively associated with relaxation and concentration. The last ones, gamma waves (more than 30Hz), are related to higher-level cognitive functions (Abo-Zahhad et al., 2015; Malik & Amin, 2017).

EEG allowed researchers to study the activity in specific regions and their functionality. Specifically, these studies were aimed at the investigation of cognitive and emotional processes. The alpha band has been associated with emotional processing, emotion regulation and social cognition in both adults and infants (Coan and Allen, 2004). Furthermore, emotional processes have been consistently associated with asymmetry in EEG signals (Davidson, 1988). Alpha frequency has been proven to be inversely related to the cortical activation of the brain, suggesting that when an emotion is elicited, alpha power increases and the activity in the hemisphere is reduced. It is therefore important to differentiate two concepts that, if used improperly, can mislead the interpretation of alpha power recordings. Activity refers to the recording of cortical activity in a given time point or duration. Activation, in contrast, refers to changes in EEG activity in response to tasks or stimuli. In other words, activity refers to the level of electrical oscillations recorded, and activation refers to the neural engagement of the brain region. Since alpha waves are inversely related to cortical activation, if we record a lower level of alpha oscillations (activity), it suggests that the region is more active (activation).

The idea that the two hemispheres have different roles in emotion processing has arisen many years ago from studies on brain lesions. Through lesional studies, researchers could observe the prevalence of negative affect in patients with unilateral left hemisphere damage, while patients with unilateral right hemisphere damage would mostly display positive affection (Alford, 1933; DENNY-BROWN et al., 1952) . Other studies moved the focus toward frontal lobe asymmetries by finding, for example, that lesions in the left hemisphere would result in depressive symptoms, and that the severity of these symptoms was associated with the distance of the damage from the frontal lobe. Instead, patients who had damage to the right frontal lobe would develop mania (ROBINSON et al., 1984). The association of the two frontal hemispheres to motivational stances is old as well. The left frontal region has been associated with intention, self-regulation and planning by

Luria in 1973 (Luria, 1973). Moreover, patients with left frontal damage usually experience deficits in approach behaviors such as loss of interest in people and objects (Davidson, 1992). The selective activation of frontal and temporal areas when researchers elicit withdraw-related emotions in participants during EEG measurement paradigms is the evidence that associates the right frontal hemisphere with withdrawal (Davidson, 1992).

All these findings have brought researchers to build and further investigate the construct of Frontal Alpha Asymmetry.

2.4 – Frontal Alpha Asymmetry (FAA)

Frontal Alpha Asymmetry is a measure of the EEG activity that refers to the imbalance of brain activation between left and right frontal areas. Alpha waves are associated with a decrease in cortical activity (Coan & Allen, 2003). This means that an increase of alpha power in the left hemisphere corresponds to a decrease in left cortical activity. In order to calculate asymmetry scores, raw alpha power is first natural log-transformed. Then, the obtained relative right value is subtracted from the relative left value. Being that, as pointed before, high alpha activity denotes low cortical activity, positive scores will indicate a relative greater left cortical activity, or higher right alpha power, while negative scores will indicate greater right hemisphere activity, or higher left alpha power (Allen et al., 2004).

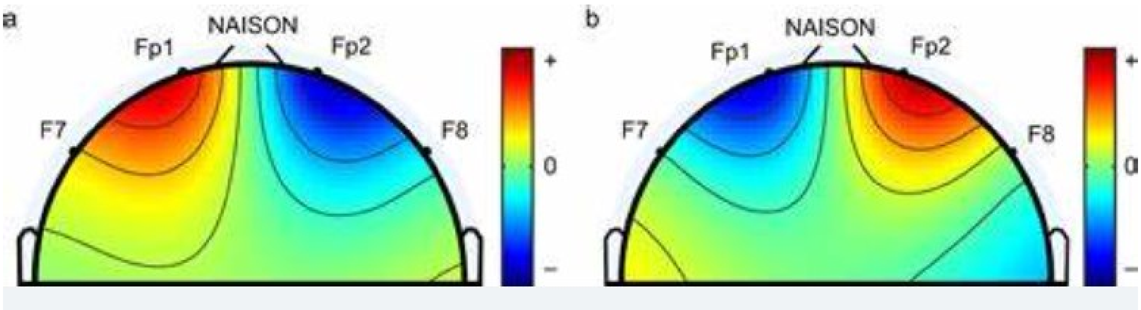

Figure 3: *The figure shows the different activity recorded in the frontal areas: red areas indicate an enhanced alpha power, or a decreased activity in the area.*

Frontal EEG asymmetry has a strong body of literature discussing its role in emotion regulation and motivational processes in many different settings and approaches. Most studies examine frontal asymmetry at rest, as a trait measure of psychological phenomena, or during emotionally evocative paradigms, as a state measure of current emotions or behavior.

2.4.1 - Models of interpretation

There's a quantity of existing models aiming at interpreting the results we find when measuring alpha asymmetry in dyads. Frontal EEG asymmetry is associated with both emotions and behavioral factors. As a matter of fact, the *valence model* and the *approach/withdrawal model* address these two aspects. The valence model posits that the asymmetrical activation of the left and right hemispheres is linked to the emotional valence of the stimulus: an increased frontal left activity corresponds to positive emotions, while greater right activity corresponds to negative emotionality (Davidson, 1998). Evidence supporting this model comes from studies like the one from Davidson and colleagues (1990). Participants were presented with emotion-eliciting clips: two were aimed at eliciting positive emotions; two other clips contained a negative emotional valence. Researchers measured their EEG signals and coded their facial expressions during the visualizations of the emotional films. Results showed that a greater activation in the right frontal lobe was associated with disgust and fear, while positive emotions, such as happiness, were related to a greater activation in the left frontal lobe. The approach/withdrawal model (Davidson & Irwin, 1999), instead, proposes that left frontal regions are responsible for the approach system, involved in approach-related and goal-directed emotions and behaviors; while right frontal regions respond to the withdrawal system, which activates in order to inhibit behavior and during negative affective states. For example, a study from Sobotka, Davidson and Senulis (1992) highlighted evident asymmetry during approach and withdrawal-related emotions during a game-like task which manipulated reward and punishment likelihood. The experimental session consisted of a series of trials. Half of them would give rewards if the task was completed successfully, with no repercussion in case of failure; the other half would inflict punishments in case of unsuccessful execution, with no reward in case of successful execution of the task. Researchers measured the EEG signal from the participants and found that during the punishment conditions subjects would showcase a greater right cortical activation and greater left activation during reward conditions. This shows how the manipulation of desirable and undesirable conditions, which are thought to elicit, respectively, approach and withdraw-related behaviors is reflected in EEG asymmetry.

Another aspect that has been widely discussed is whether FAA is a trait-like or situational construct

The *dispositional model* (Davidson, 1998) depicts alpha asymmetry as a trait. According to it, individuals tend to respond with either approach, correlated to a greater left FAA asymmetry, or with withdrawal, corresponding to a right shift in the asymmetry, across most of the situations. This model can be applied for example to interpret and understand the functioning of clinical populations, like depressed patients. A study comparing a depressed sample with a non-depressed one has shown that the clinical sample showed more right frontal activation at rest compared to the control group (Schaffer et al., 1983). In healthy populations, studies like the one from Wheeler, Davidson and Tomarken (1993) found that the resting values of asymmetry were related to the intensity of the emotional experience during the visualization of emotional clips. The opposite side is represented by *situational models* arguing that people's behavior is strictly related to the different contexts they come across. Studies that elicit emotional responses gave several evidence to sustain this model, assessing that provoking a shift of someone's emotional state will reflect in a shift in their FAA. An example is the study by Harmon-Jones and Siegelman (2001). Researchers measured participants' baseline EEG signal and then asked them to produce an essay on a social topic that was really important to them. Then, they pretended to give the essay to another fictional participant who would give an opinion on the essay. The opinions could be neutral or negative. Right after, researchers measured their EEG signals again and found that the subjects who were given a negative opinion about their topic had greater left frontal activity and a greater display of anger.

These two contrasting points of view merge in the *capability model* (Coan et al., 2006) which claims that individual differences in FAA come from an interaction between the emotional valence of the stimuli and the individuals' capacity to regulate their emotions. According to this theory, EEG asymmetry measures the ability to inhibit approach or withdrawal responses depending on the context.

According to this model, individual differences become more evident during emotionally eliciting tasks. This hypothesis can be tested with clinical populations. It has been assessed already that depressed patients display more negative values of FAA, and these individual differences should be reflected in tasks that provoke emotions. Stewart and colleagues (2014) measured EEG in participants divided into 3 groups: never-depressed, depressed patients with an ongoing Major Depression Disorder and patients with a history of depression but who were not diagnosed with mood disorders at the moment of the experiment. The EEG signals were gathered during baseline and emotion eliciting conditions, through a facial expression imitation task. The aim of the task was to imitate facial expressions that conveyed positive or negative emotions. After the "imitation session", participants were asked about their emotional experience while they were imitating the faces. Researchers demonstrated that individuals with a previous history of depression display more right frontal activation than people who never received a diagnosis while imitating faces associated with negative emotions. Moreover, results highlighted greater shifts in asymmetry in currently-depressed participants with respect to never-depressed participants during the emotional task compared to the baseline measurement. These findings highlight how individual differences get amplified in emotional situations.

2.4.2 – The application of FAA in mother-infant interaction

To my knowledge, not many studies have investigated mothers' FAA during their interaction with their children. Moreover, only a few have considered "live interactions". Some of these studies recorded alpha asymmetry in mothers while they were seeing images of their babies displaying different facial expressions and emotions (Killeen & Teti, 2012). Other papers investigated FAA during interactive task between mothers and their children (Atzaba-Poria et al., 2017). Only a couple of studies used the still-face procedure (Gartstein, 2020; Perone et al., 2020; Swider-Cios et al., 2024) and we will dwell on these as they are particularly relevant to this thesis The reason why SFP might be a great tool to combine with the measurement of FAA is that it is widely recognized as a reliable technique to investigate emotion regulation in the dyad while also introducing a stressful situation (E. Tronick et al., 1978). Such an experimental setting seems suitable to address how emotions and the role of the parent are highly dependent on the context and on the little predictability of the interaction, which is always subject to sudden changes and disruptions.

As mentioned before, FAA has been studied at first as a trait, measuring asymmetry while at rest.

Wheeler, Davidson and Tomarken (1993) found that people with relative left frontal activation at rest would report higher positive emotions in response to positive valence stimuli and less negative emotions in response to negatively valenced stimuli. On the other hand, people displaying greater right asymmetry at rest would report more negative emotions in response to negative stimuli and less positive emotions in response to positive ones. These results have been replicated multiple times in many different settings. Nonetheless, studies linking resting asymmetry to parents' behavior gave mixed results. One study that compared depressed and non-depressed mothers (T. Field et al., 2003) found that greater right FAA at rest was displayed in depressed mothers who were withdrawing during an interaction with their child. They were followed by depressed mothers displaying positive parenting and then by non-depressed mothers. Furthermore, it was found that mothers displaying withdrawn behavior had greater right FAA at rest compared to mothers displaying intrusive behaviors (Diego et al., 2001).

Other studies couldn't find associations between FAA and parental behaviors (Chen et al., 2015; Killeen & Teti, 2012). This might be due to the nature of resting frontal asymmetry, which is associated with trait-like emotionality, but emotions and parenting are strictly related to the context and the flexibility that allows one to adapt to the constantly changing demands. This is why studying state-related variance in FAA is more useful: it measures parental modulation of the asymmetry in response to emotional stimuli coming from their children.

Studies that imply the measurement of asymmetry during the elicitation of emotional responses confirmed robustly the correlation between positive emotional stimuli and left asymmetry and between negative valenced stimuli and right asymmetry. For example, Coan, Allen and Harmon-Jones (2001) asked people to produce facial expressions associated with emotions such as disgust, fear, joy, anger and so on. Results say that expressions associated with withdrawing behaviors (such as fear) provoked a right shift of FAA, while emotions associated with approach (like joy and anger) were related to a left shift of the asymmetry.

Another example can be made mentioning the use of emotionally valenced films: Davidson and colleagues (1990) found that subjects showed greater left asymmetry while watching positive valence films, while they showed greater right asymmetry when watching negatively valenced videos.

The study from Killeen and Teti (2012) took one step forward involving dyadic interactions and measures. Researchers measured FAA in mothers both at rest and while they were shown videos of their infants displaying both negative and positive affection. The research was articulated in three phases: in the first one, researchers video-recorded the infants displaying different emotions in order to create the emotional stimuli for the third phase. Moreover, mothers had to compile questionnaires and a report of internalizing symptoms. In the second stage, researchers recorded a free-play interaction between the mother and the infant during a second home visit. This was necessary in order to have some footage for behavioral coding. The last phase involved maternal EEG recording in the laboratory. During this protocol, the mother was shown her infant's emotional expressions recorded in the first stage. After that, she had to complete a self-report about her emotional reaction to the videos of her child.

This study in particular might show a fundamental weakness in the paradigms that don't measure asymmetry during dyadic interactions. The results report that mothers displayed greater right frontal asymmetry overall, independently from the emotional valence of the footage. This is most likely due to the impossibility of the mother to interact in any way with the infant. This might have translated into attenuated feelings of joy when seeing their children showing positive emotionality, which limited significantly left FAA shifts (Killeen & Teti, 2012). Moreover, a study by Light and colleagues (2009) found that low-level positive emotions without an approach orientation are associated with greater relative right asymmetry.

The study from Atzaba-Poria and colleagues is instead based on an interactive task (Atzaba-Poria et al., 2017). They studied how children's and mothers' behavior statistically predicted their partner's behavior during interactions. Mothers were instructed to help the child (aged between 37 and 42 months) complete a puzzle that was appropriate for older children. Results from this investigation support previous findings: children's display of negative feelings was associated with mothers' greater right frontal activation and vice versa. This important finding again highlighted the bidirectional nature of the influence between the mother and her own child.

As already pointed out, the literature combining SFP and FAA measures is really scarce. Nonetheless, apart from one study (Swider-Cios et al., 2024), they are in line with previous findings. Garstein (2020) examined dyadic quality interaction and infant temperament addressing them as plausible factors influencing asymmetry in 59 dyads. EEG measurements were run only on children during a double-SFP, which means that the Still-Face episode was repeated one time after the first one. Each episode (which followed in the sequence; play, still-face, play, still-face, play) was 2 minutes long. The interaction was also coded. The behavioral variables involved were maternal sensitivity, reciprocity, tempo, intensity and emotional tone. Analysis (EEG data were available for 50 children by the end of the study) confirmed that children who showed higher levels of positive emotionality responded with left frontal activation to the SFP. Greater right activation was associated with more intense interactions (i.e. loud vocal exchanges and parental exuberance) and low levels of positive affection.

Other important findings were featured in the study by Perone, Garstein and Anderson (2020). They measured asymmetry for both mothers and children during a double-SFP (2 minutes for each episode) controlling for mothers' responsiveness in 10 dyads. Results (see **Figure 4** for tables) show the dyad displayed a right shift in FAA during the recording. Mothers that were more responsive exhibited more relative left activation in respect to less responsive mothers, and so did their children. Moreover, children with more responsive mothers exhibited more variability during still-face segments, while infants with less responsive mothers showed more variability during play. Nonetheless, when FAA was normalized for baseline, a reverse pattern was shown. Responsive mothers' infants displayed a shift towards the right for asymmetry. This might be due to the fact that these children may experience a greater violation of their expectations as their usual experience is much different compared to the one experienced by infants with less responsive mothers. Mothers' variability, instead, increased over the course of the procedure and showed fluctuations, especially during the Play episode, prevalently in responsive mothers. The lower variability in mothers' FAA observed during the Still-Face episode is probably due to the request to be emotionally unavailable.

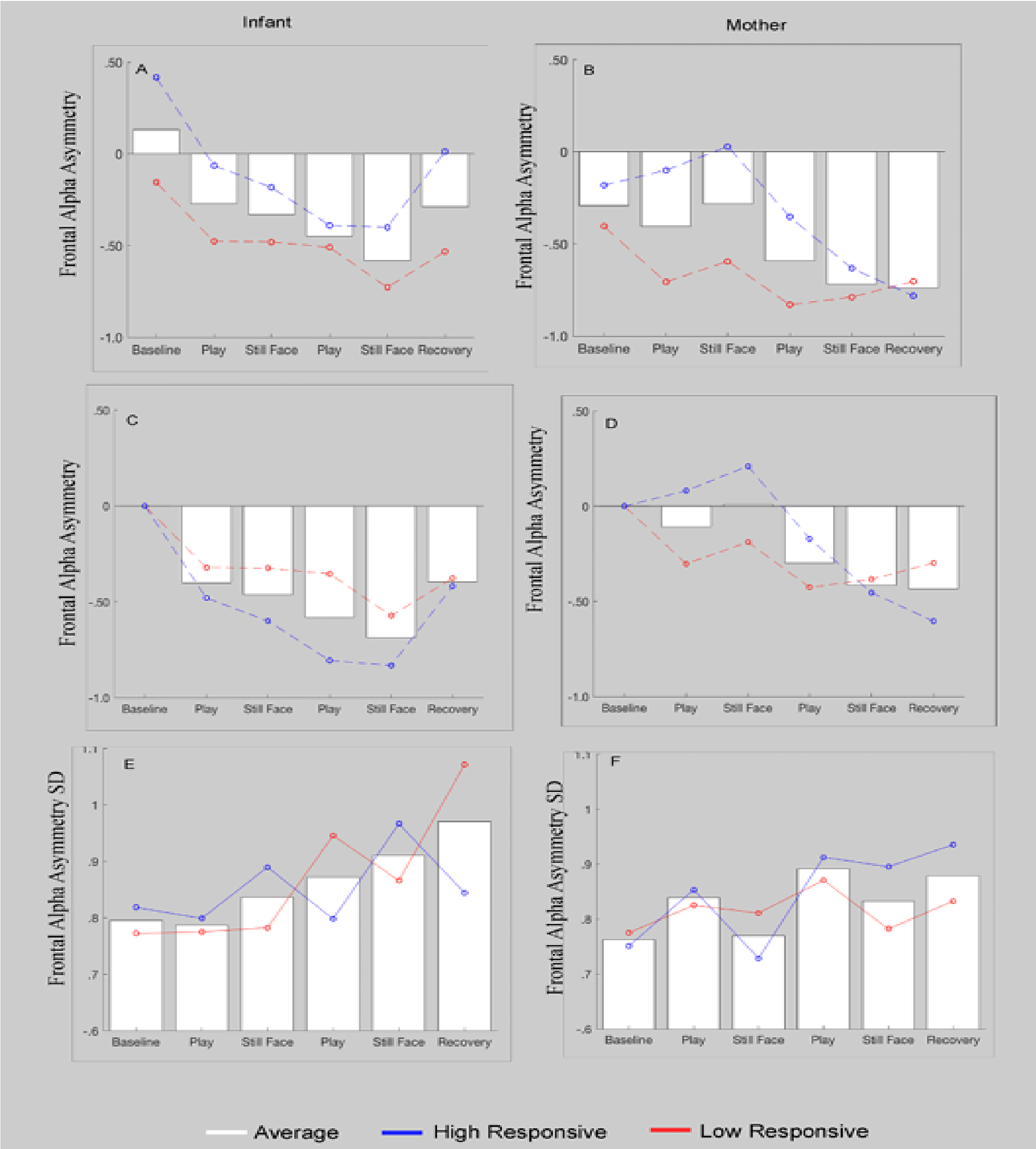

Figure 4: the graphs picture variations in dyadic FAA throughout the double SFP with the red lines representing the median scores of responsive mothers and the blue lines representing less-responsive mothers. A-B tables represent FAA scores from the baseline (Play episode) to the recovery (Reunion episode); C-D shows FAA scores normalized for baseline; E-F shows FAA variability during the SFP (Perone et al., 2020).

The most recent study that involved the SFP for studying FAA, is the one from Swider-Cios and colleagues (2024). More specifically, the 38 dyads recruited were administered an adapted double-still-face paradigm: during the aforementioned episode, mothers, instead of assuming a neutral facial expression, had to pretend they were using their phone in order to make the setting more ecological (Barr et al., 2020; Konrad et al., 2021; Myruski et al., 2018). What they found here was really interesting, as they highlighted an opposite trend with respect to the literature. Results show a positive correlation between children's negative affectivity and FAA in mothers during the play episode. This means that positive values in the asymmetry corresponded to higher negative affect in children. What they argue in the discussion is that these results might be interpreted according to the approach/avoidance model of asymmetry (Kelley et al., 2017). What it means is that upset infants may activate approach behaviors in mothers willing to engage their children in order to soothe them, which would translate into a positive score in maternal asymmetry.

Chapter 3 – The study

3.1 - Rationale

Human beings are defined as social animals. This awareness dates back in Ancient Greece, since Aristotle can be considered the first one who gave such a definition of us, in his work *Politics.* He specifically stressed the political nature of the humans, stating that we tend to create systems of governance, laws and systems of order within a community. To these days, his definition is still fitting and has been expanded in many different disciplines. Aronson, in his book *The Social Animal* (1972)(examines how our thoughts, feelings, and behaviors are influenced by the presence and actions of others. Despite it being done in different settings and with theoretical frameworks belonging to different disciplines, it could be the same type of investigations that were run from the godfathers of infant research in the last decades. Among the most complex functions that human beings display, there are social interactions (Hari et al., 2015). Trough the interactions with a primary caregiver capable of mirroring and being responsive very early in life, infants not only grow into individuals provided of an internal sense of the self (E. Tronick & Beeghly, 2011; Wang et al., 2018), but also their socio-emotional and cognitive development finds positive and adaptive outcomes (Bernier et al., 2016; Hane & Fox, 2006).

One of the most used and well-validated paradigms for the behavioral observation of dyadic interactions is the Still-Face paradigm (E. Tronick et al., 1978). The procedure is rooted into the match, mismatch, reparation cycle that the mother-infant interaction goes through (Brazelton et al., 1974; E. Tronick et al., 1979). These authors state that dyadic interactions aren't always synchronized, but rather characterized by frequent shifts from coordinated to uncoordinated states. A large number of studies in the last 40 years have investigated behavioral associations and synchrony between two individuals, also implementing the SFP (Moore et al., 2009). For a while, the neural underpinnings of social interactions have been studied only in individuals, far from a social context (Nam et al., 2020).

The introduction of hyperscanning gave researchers the opportunity to record at the same time the brain activity in two interacting participants (Montague et al., 2002). This technique allowed us to investigate the neural underpinnings of social exchanges in real time, right in the moment of the parent-infant interaction. The feasibility of hyperscanning and the SFP has already been validated to this day (Billeci et al., 2024; Perone et al., 2020). Despite that, no effort has been made in trying to associate micro-analytically coded behaviors to what happens at a neural level.

Through this paradigm, it is also possible to observe Frontal Alpha Asymmetry in the two participants. FAA measures the difference of activation in the frontal areas of the left and right hemispheres (Killeen & Teti, 2012; E. E. Smith et al., 2017; Swingler et al., 2014). When alpha power is high, it means that the cortical activity in that area is decreased (Coan & Allen, 2003). FAA has been studied as an important factor for emotion regulation and motivation. In general, greater left frontal activity is related to positive emotionality and approach behaviors, while right activity is related to negative emotions and withdraw from the interaction (Coan et al., 2006; Davidson, 1992, 2004; Perone et al., 2020). The great majority of the studies investigating FAA related to emotion regulation have again overlooked the interactive nature of this construct:

researchers studied asymmetry as a trait measure at rest (Wheeler et al., 1993), or implying paradigms that elicited emotions such as the reproduction of facial expressions (Coan et al., 2001) or videos that carried an emotional valence (Davidson et al., 1990).

The mother-infant interaction has been overlooked for a while but with Killeen and Teti (2012) we start to see an interest towards the mother-infant dyad. The problem with their study is that it still didn't measure brain activation during a live interaction with the child. In fact, the mothers' asymmetry was recorded while they were shown videos of their babies displaying different emotions. Only in the last years, online interactions were introduced in the FAA studies. The first study that measured FAA in both mothers and children during an interactional task is the one from Atzaba-Poria and colleagues (2017). What's really important for our study, is the implementation of the SFP to FAA paradigms, which is something that was investigated a very limited number of times. For our study, we decided to focus in particular on the mothers' FAA: this decision was led by the fact that parenting behaviors and reactions to their infants' signals are strictly related to the parents' emotional states. In turn, this will have a strong impact on the socio-emotional development of children. FAA seems to be a very appropriate paradigm in order to catch the neural processes that underline parenting. Moreover, it can be much more effective if combined with the SFP, which is very effective in eliciting strong emotional responses. SFP can reflect changes in FAA as a stressful situation has been seen to increase negative values of FAA due to the regulation strategies deployed (Perone et al., 2020).

Most interestingly, these few existing studies yielded contrasting results between them for what concerns the relation between maternal FAA and infant emotionality during the play episode (Gartstein, 2020; Perone et al., 2020; Swider-Cios et al., 2024). In this study, we proceed in the analysis of the association between maternal FAA and infant behaviors' to further investigate and interpret this interesting contrast in the literature.

Another thing to take into account is that available studies on the topic have usually associated only measures of maternal sensitivity or infant temperament to the changes in

FAA (Killeen & Teti, 2012; Perone et al., 2020). There's a gap in the literature for what regards the association between FAA changes in response to child cues and parenting behavior. Our study analyzed these associations for some micro-analytically coded behaviors (e.g vocalizations and touch) during the 3 episodes of the SFP and maternal FAA.

Another thing to argue, is the incredible variety of methodological and experimental settings that have been used throughout the history of FAA literature, which make it difficult to interpret the data sometimes (Hajal & Loo, 2021). This study joins the few ones that merge SFP and FAA contributing to the creation of a reliable way to study parenting

Furthermore, the association between maternal feelings and their FAA during the SF Episode has never been studied in the literature. The associations present in the literature usually regard the relation between infant emotionality and maternal FAA, but less attention has been given to parental reports of emotional experience. Assessing how the mother felt and how she perceived her infant's emotional states helps us better understand how parents react in relation to their infant's communicative signals.

3.2 - Aims of the study

Our study has two specific aims: observe the way maternal FAA fluctuates across the SFP; investigate the association between infants and mothers' behaviors with maternal FAA.

For our first aim, we expected maternal FAA to be less subject to fluctuations during the Still-Face episode. As hypothesized by other studies finding this pattern (Perone et al., 2020), it would be due to the specific request to the mother to control her behavior during that specific time. In general, we expected to observe a shift towards negative values across the SFP in the mother.

Our second goal was to find brain-to-behavior associations across the SFP. We expected infant affect to be associated to maternal FAA. Despite that, the contrasting results in the literature made us cautious in advancing further our hypothesis, as Swider-Cios and colleagues (2024) found infants' negative affect being associated to maternal left shifts in FAA, which is a result that goes in the opposite direction of the literature.

We further hypothesized that maternal rating of the experience would have been associated with their FAA: more specifically, we expected mothers with a negative FAA pattern to rate the experience as more unpleasant and their baby as displaying more negative emotions; while mothers displaying positive FAA values would have felt less guilty and at unease, reporting their children to be expressing more positive emotions.

In our analysis, we also included the investigation of behavioral changes in the dyad across the 3 episodes of the SFP.

According to the literature, we might expect an increase in negative emotionality across the SFP for infants, hitting its peak in the Still-face episode and slightly decreasing during the Reunion, but without getting back to the baseline levels recorded during the Play episode.

This study employed an EEG hyperscanning setting during a SFP. We later extracted FAA data from the mother and coded dyadic behaviors through the video recordings of the procedure. Since we needed clear enough EEG data during the Reunion episode, we opted for a 1-minute long Still-Face episode, rather than the usual 2-minutes one. This was because an excessive perturbation of the baby could have compromised the integrity of the signal. The 1-minute SF variation represents a fine compromise between having an effective disruption of the interaction (Tang et al., 2020; Yazbek & D'Entremont, 2006) and leaving enough chances to obtain clear EEG data.

3.3 - Methods

3.3.1 – Partecipants

Thirty-eight caregiver-infant dyads were recruited through Pavia's San Matteo hospital database and through pre-natal courses. Families were contacted telephonically and given all the information regarding the study. We didn't specify the caregiver's gender, but we asked for the parent that spent the most time with the child.

Inclusion criteria for babies' recruitment included being aged between 8 and 10 months, being born full-term with a normal birth weight, being healthy with no neurological or medical condition and intact vision and hearing. The babies' sample included 21 males and 17 females with a mean age of 9.1 months. The thirty-eight caregivers, which were all mothers, had a mean age of 35.1 years.

By the end of EEG data analysis, the remaining dyads were 20. 8 were excluded following the occurrence of inconvenient during the experimental procedure (e.g. the infant crying too much and making the observational or EEG data useless); 6 for technical problems (e.g. problems with the equipment for the measurement of the EEG signals or the cameras); 4 dyads were excluded because of their signal being non eligible for the analysis (e.g. too many interpolated channels or less than 30 1-s epochs with a clear signal);

All mothers gave written informed consent bot for them and for their children in accordance with the Declaration of Helsinki (BMJ 1991; 302:1194).

3.3.2 – Materials

3.3.2.1 - EEG equipment

To measure EEG activity in the participants we used the Smarting Pro (mBrain Train) system. The system is composed of two 32-channel EEG caps, one for each subject (caregiver and infant simulatenously), with respectively two different sizes each (44-46) cm of head circumference for the infant and 54-56 cm for the mother). Both EEG caps were connected through their Bluetooth amplifiers to a computer running the mBrain Train Streamer program, on which we could visualize the state of each electrode in order to adjust it and, later, the flow of the signal. The two computers were wired together so that we could record both signals on only one of the devices.

3.3.2.2 – Maternal SFP Experience Questionnaire

Right after the experiment, the mother compiled a questionnaire regarding her emotional experience and how she perceived the baby's emotional experience during the Still-Face episode. In particular, she was asked to report how much she felt calm, agitated, worried and guilty during the Still-Face episode, scoring the items on a scale from 1 to 10. After that, she was asked to answer the next questions from the infant's perspective and to report how much, according to her, the infant felt angry, sad, calm and frustrated when she stopped the interaction, scoring the items from 1 to 10.

The Maternal SFP Experience Questionnaire's items were then reduced to four mean scores. Two items for the emotional experience of the mother (mother positivity and mother negativity) and two other items for evaluation from the infant perspective (infant positivity and infant negativity).

3.3.3 - Setting and procedure

Experimental sessions were run in a laboratory room at IRCCS Mondino, Pavia. The participants met with one of the researchers at the entrance of the hospital. Once in the laboratory, in order to help infants acclimate to the environment, they were put on a play mat with some toy. During this little playtime, while a colleague is distracting the baby, an experimenter provided the mother with an overview of the study's goals and procedures. After that, parents sign the informed consent and privacy forms. The mother is instructed about the Still-Face Procedure functioning. The whole procedure is going to last 5 minutes in total: for the first 2 minutes (the Play episode) she is seated in front of her baby placed on a highchair and she has to play in the most spontaneous way with her child, possibly without toys. During the Still-Face episode, she has to quit interacting verbally and physically with the child, while staring at him/her with a neutral facial expression. This phase will last 1 minute, but, if the child gives signals of an heavy distress, it will be interrupted earlier. In the Reunion episode, the mom can resume the free interaction with the child. This last stage will last again 2 minutes.

After giving instructions, experimenters prepare the dyad. This procedure usually starts from the mother so that the child can see what happens and familiarize with the events. Mother and baby’s head circumferences are measured and then EEG caps are applied. A gel that enhances skin conductance is placed in every electrode in order to help with the recording of the signal. Caps are then connected to their respective amplifiers and to the computers. Once the impedances level and the signal are set to the desired values, the child is put in a baby seat in front of the mother sitting on a chair. The two video cameras are set so that one records the face and the body of the baby, and the other one records mother’s hands and face. Before beginning the experimental session, experimenters leave the room after starting the video recording. Only one colleague stays in the laboratory in order to give the voice signals to the mother and to record the EEG signals on the computer. This person is hidden from the dyad by a cardboard panel so that the baby isn't distracted by his/her presence. Once the instructions are repeated one last time to the mother, the experimental session starts. At the end of it, the mom and the baby are helped removing the caps and get the opportunity to wash away the conducting gel from their hair, if they want. As soon as it is done, the mother is given a questionnaire about her and her infant's perceived emotional experience during the Still-Face episode. At last, she will receive a further brief questionnaire via email when she'll get home.

3.3.4 - EEG recording and pre-processing

The EEG signal was acquired and recorded on one predefined computer onto the mBrain-Train Streamer program. While recording, the signal was sampled at 250 Hz and the different epochs were defined through a keypress. Data of the dyad were separately offline pre-processed through MATLAB's toolbox EEGLAB using an automated pipeline which is completely ran by algorithms and criteria inserted in the code. First step is applying a band filter with frequencies between 1-30Hz. The reason behind this is that we are more interested in lower frequencies: theta and low alpha bands are implied in social interactions and elaboration of emotional stimuli, while higher frequencies are more likely to be noise deriving from movement or signals from devices in the surrounding environment. A graph showing all the electrodes is obtained. By running the CIT Algorithm, 3 artifacts can be detected: flat electrodes, activity deriving by noise and outliers. Noisy data is rejected with ASR algorithm that removes high frequencies and interferences. Next step is decomposing the signal in all its single components performing the Independent Component Analysis (ICA). Every element will be categorized based on its activity pattern. The algorithm shows the probability for every component to be part of one of these categories of activity: brain, ocular, muscular, line noise, other noises. Components with more than 50% of eye activity are rejected. This is done in order to work on data as clean as possible that are mostly composed by signals from the brain. Consequently, flat channels are interpolated with NEAR plugin: their activity will be reconstructed based on the mean activity of neighboring electrodes.

Now the signal is re-referenced to the average of the all the electrodes and the signal is split in three trials in order to analyze them separately: Play, Still-Face and Reunion. This is done in order to be able to compare the brain synchrony of the dyad in the three phases. To do so, the trials are further split in one-second epochs. The 2 signals are then merged in one plot and epochs with signal that exedes +/- 150 micro-Volts are rejected from both mother and child's tracks. If more than 30 epochs are kept, the signal can be further analyzed.

3.3.5 - FAA computation

As found in the literature, FAA was computed in the 8-13 Hz ranges for mothers (e. g., Atzaba-Poria et al., 2017; Hane & Fox, 2006; Swider-Cios et al., 2024; Swingler et al., 2017).

Data from the two frontal electrodes F3 and F4 from mothers and infants during the three episodes of the SFP were extracted for further analysis. FAA values were computed for each of the phases by subtracting natural log-transformed alpha at left site F3 from right site F4 (Perone et al., 2020). Being alpha band inversely related to brain activity, a greater score will reflect greater left frontal activity, which, in turns, is indicated by positive values in data (E. E. Smith et al., 2017).

3.3.6 - Videotaping

The SFP was video recorded using two video cameras. The videos obtained were then moved into the Movavi Video Suite 2020 softwareand subsequently edited in order to delete the parts that couldn't be used for the behavioral coding

3.3.7 – Behavioral coding

The behaviors of interest displayed during the SFP by infants and their caregivers were micro-analytically coded from the recordings of the interactions by trained coders via *Noldus The Observer TX* software. An ad-hoc coding scheme was created by adapting the *Parent-Infant Coding Scheme Version 4.0*. Measures were adapted as time percentages for each episode of the SFP in order to account for the little variations in the length of the episodes that might have occurred both between and within dyads.

The behavioral variables of interest are better described in Table 1.

Table 1: description of the behavioral variables coded for later analysis.

Variable	Levels	Description
Emotional state	*Negative*	Explicit display of negative emotionality (e.g., eyes, mouth, general movements of the face or the body, and other vocal or non-vocal signals) including fussing and crying.
	Positive	Explicit display of positive emotionality (e.g., eyes, mouth, general movements of the face or the body, and other vocal or non-vocal signals) including smiles and laughs.
Vocalizations	*Affective*	Vocal comments that convey playful and social engagement such as singing, laughing, playing nursery; express appreciation or acceptance of infants' behaviors or state or are finalized to sooth infants' stress. These also include mind-related comments (e.g., "you think", "you want") and mirroring of infants' communicative bids.
	Cognitive	Vocalizations expressing direct requests for specific behaviors (do this, take that) or used to get infant's attention (the parent requests the child to look toward the parent herself). Explicit explanations, object naming (this is a telephone), object characteristics , object affordances (you can open it with this).
Touch	*Affective*	Tactile stimulations that convey playful and social engagement such as tickling, squeezing; finalized to sooth or regulate the behavioral state of the interactive partners and conveying a sense of affective closeness such as stroking, kissing, massaging.
	Pragmatical	Touch used to accomplish non- relational task (e.g., removing infants' hands from the mouth, adjusting infant's position on the infant-seat, adjusting infant's dress, cleaning the mouth of the child, etc.) OR, usually accompanied by attention getting vocalizations, touch used to get the infant's attention (e.g., tapping, patting, squeezing, pinching, stroking, etc.).

Note: *It must be specified that the* ***emotional state*** *variable was coded for both mothers and infants, while* ***vocalizations*** *and touch were coded only for the mother.*

3.3.8 – Statistical analysis

Statistical analysis were done using Jamovi and setting alpha to .05.

As a preliminary analysis, changes in behavioral responses across the SFP in mothers and infants were assessed. In order to test if infant emotionality (positive and negative) changed between SFP episodes a repeated-measures ANOVA was performed. This analysis is particularly useful when measuring the same subjects multiple times at different points in time. Post-hoc pairwise comparisons were used to investigate significant differences between episodes. A paired sample t-test was employed in order to verify the differences in maternal behavior during play and reunion. In order to verify the association between infants' emotionality and maternal behaviors, we used a Pearson correlation test. The analysis was carried out between infant emotionality (positive or negative) and maternal behaviors (affective touch, pragmatic touch, affective vocalization, cognitive vocalization).

For aim 1, in order to assess changes in maternal FAA across SFP, a repeated-measures ANOVA was performed. To gain further insights into how much the variables differed across specific episodes, post-hoc pairwise comparisons and estimated marginal means were analyzed.

For aim 2, Pearson correlation tests were computed in order to investigate the association between maternal FAA across SFP episodes and infants' emotionality, as well as the association between maternal behavior and maternal reported emotions during SF.

Pearson correlations are very useful in order to explore linear relationships between variables, determining also the strength and direction of the associations.

3.4 - Results

3.4.1 - Behavior across SFP

Our preliminary analysis regarding maternal and infants' behavior across the 3 episodes of the Still-Face procedure generally confirmed the already well-assessed findings present in the literature.

In order to see how infants' positive and negative emotionality varied during the episodes, an ANOVA repeated measures was run. Looking at infants' negative emotionality a significant effect of episode $F(2,36) = 8.69$; $p < .001$ emerged. This suggests the presence of a statistically significant variance of children's negative emotionality across the episodes. Evidence support the presence of a statistically significant episode effect for infants' positive emotionality as well (F = 6.20; p = 0.005).

Post hoc tests were run in order to see which episodes differed between themselves and how much. Results showed a significant increase in negative emotionality between play and still-face episodes $t(19) = -4.37$; $p < .001$. For positive emotionality, there was a significant decrease between play and still-face ($t(19) = 3.733$; $p = .004$) and a significant increase between Still-Face and Reunion ($t(19) = -2.83$; $p = .028$).

Estimated marginal means (**Figure 5**) gave further insights into how much episodes differed. For negative emotionality, it can be seen that the highest value belongs to SF, followed by Reunion and Play episodes.

For positive emotionality, we can observe a specular pattern: the highest estimated marginal mean belongs to the Play episode followed by Reunion and SF.

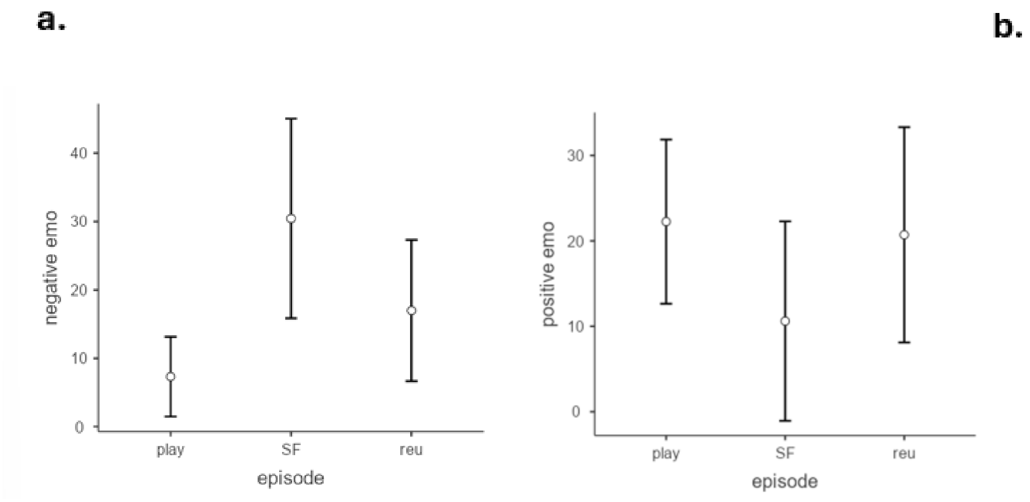

Figure 5: the 2 graphs show the estimated marginal means for negative emotionality (**a.**) and for positive emotionality (**b.**)

A paired-sample t-test was run in order to verify if there were differences in maternal behaviors' means during Play and Reunion (Figure 2). The results suggest there is no significant difference between episodes in maternal behaviors.

Table 2: the table shows the paired-sample t-test results.

	Play	Reunion		
	M(SD)	**M(SD)**	**t**	**p**
Pragmatic touch	7.48 (13.00)	13.46 (28.90)	-1.18	.254
Affective touch	24.05 (22.9)	21.09 (25.2)	0.49	.632
Cognitive vocalizations	21.84 (23.1)	21.54 (23.5)	0.06	.952
Affective vocalizations	32.24 (29.6)	30.34 (28.2)	0.34	.737

3.4.2 - Dyadic behavior association across SFP

Correlations between mothers' behavior and infants' emotionality during reunion are presented in Table 2. Mothers' cognitive vocalizations were found to be negatively correlated with infants' negative emotionality (R = -0.453; p = 0.045). Mother's affective vocalizations were found positively correlated with infants' positive emotions (R = 0.502; p = 0.024)

Table 3: correlation matrix between mothers' behavior and infant emotionality.

	Pragmatic touch	Affective touch	Cognitive vocalizations	Affective vocalizations
	R (p-value)	**R (p-value)**	**R (p-value)**	**R (p-value)**
Positive emotionality	0.044 (.855)	0.235 (.318)	0.096 (.687)	0.502 (.024) *
Negative emotionality	0.206 (.383)	0.191 (.419)	-0.453 (.045) *	-0.128 (.592)

3.4.3 - Changes in maternal FAA across SFP

In order to investigate the variance of mothers' FAA in the 3 episodes, a repeated measures ANOVA was run. Results report the absence of an episode effect $F(2,38) = 0.322$; $p = .727$. on maternal FAA.

Table 4: estimated marginal means results for maternal FAA variability. They represent the mean FAA values for each episode

	Mean	**SE**
Play	0.024	0.105
SF	0.028	0.142
Reunion	0.029	0.80

3.4.4 - Brain-to-behavior associations across SFP

One other aim was to investigate if and how mothers' and infants' behavior is associated with the variance in FAA levels across episodes.

Pearson's correlations found that the only statistically significant association was the one with infants' positive emotionality ($r = 0.467$; $p = .038$) in the play episode. A moderate positive association tending to significance ($R = 0.307$; $p = .189$) was found with positive emotionality during the SF episode meaning that the more children showed positive emotions, the more mothers' asymmetry shifted through positive values

Table 5: correlation matrix for the association between infant emotionality and maternal FAA during play and SF episodes.

	Positive emotionality	**Negative emotionality**
	R (p-value)	**R (p-value)**
Play	0.467 (.038)*	-0.187 (.429)
SF	0.307 (.189)	-0.167 (.480)
Reu	-0.084 (.725)	0.120 (.613)

The association between mothers' behavior and their own FAA was also tested during both play (Figure 4a) and reunion (Figure 4b). Still-face was not considered for these analysis because the mother, for the seek of the experimental design, didn't have to display any behavior. Despite not finding significant associations, an interesting trend could be seen. There was a weak negative correlation ($r = -0.278$; $p = .235$) between affective vocalizations and mothers' FAA during play and a weak positive association ($r = 0.356$; $p = 0.356$) between pragmatic touch and mothers' FAA. This means that the more the mothers' FAA shifted towards negative values during the still-face, the more they produced affective vocalizations, while, the more their FAA was positive, the more they used pragmatic touch.

A moderate positive correlation between FAA and cognitive vocalizations ($R = 0.384$; $p = .095$) emerged during reunion episode, suggesting that mothers displaying more positive asymmetry used more cognitive vocalizations. Another moderate negative correlation ($R = -0.361$; $p = .118$) emerged between FAA and affective vocalization, suggesting that mothers displaying more negative asymmetry during the reunion episode tended to use more affective verbalizations. These associations did not reach statistical significance. No significant associations were found between mothers' FAA levels and children's emotionality.

Table 6: correlation matrix between FAA and maternal behavior during play and reunion episodes

	Affective vocalizations	Cognitive vocalizations	Pragmatic touch	Affective touch
	R (p-value)	**R (p-value)**	**R (p-value)**	**R (p-value)**
Play	-0.278 (.235)	-0.031 (.898)	0.356 (.123)	-0.159 (.502)
Reunion	-0.361 (.118)	0.384 (.095)	0.276 (.239)	0.153 (.519)

3.4.5 - The role of maternal reported feelings during SFP on FAA variability

The results of the correlation matrix to investigate the association between maternal still-face experience reported emotions and their FAA gave no significant results. Nonetheless, a weak negative correlation was found between asymmetry and mothers' reported unease during the still-face episode (R = -0.213; p = .397), meaning that the more they displayed negative emotionality, the more the rating of the experience tended to be negative and unpleasant. On the contrary, a weak positive correlation was found between reported positive infant emotionality and mothers' asymmetry (R = 0.254; p = .309). This means that mothers' displaying positive asymmetry reported their children as displaying more positive behavior during the still-face episode.

Table 7: correlation matrix to investigate the association between maternal SF experience and their FAA

	Maternal negativity	Infant negativity	Maternal positivity	Infant positivity
	R (p-value)	**R (p-value)**	**R (p-value)**	**R (p-value)**
FAA during SF	-0.213 (.397)	-0.150 (.553)	0.179 (.397)	0.254 (.309)

Note: The questionnaire was composed of 1 positive item and 3 negative items both for the child and the mother ratings. Negativity scores were calculated as the mean score for the 3 items with negative emotional valence

Chapter 4 – Discussion

The present study aimed to explore the dynamics of maternal and infant behavior across the Still-Face procedure, focusing particularly on emotional responses and their association with maternal frontal alpha asymmetry as a measure of emotional regulation. Hyperscanning and FAA are very useful paradigms that help study the neural substrates and dynamics of the mother-infant interaction, especially when merged with the SFP that is able to create a stressful situation that requires the dyad to adapt and regulate their emotions and behavior. Our study examined maternal FAA during the SFP, and how it associates with both maternal and infants' behaviors and emotional display. The aims of the study comprised the assessment of behavioral changes in mothers and children across the SFP, as well as maternal FAA. At last, we tested the association between the dyadic behavioral dynamics and maternal FAA.

4.1 - Emotional Variability Across Episodes

For what concerns infants' emotionality, this study revealed significant differences in infants' emotional responses across the three episodes. Both positive and negative emotionality showed statistically significant episode effects, indicating that the structured changes in the experimental conditions elicited varying emotional responses from the infants. Specifically, the marked increase in negative emotionality from the Play to the Still-Face episode and the significant rise in positive emotionality during the Play and Reunion episodes underscore the sensitivity of infants to maternal engagement and withdrawal. These findings align with previous research, such as Tronick et al. (1978), who demonstrated the robust impact of the still-face paradigm in eliciting distress and negative emotionality in infants.

Findings suggest the presence of a gradual adjustment of infants' emotionality during the Reunion episode. The significant increase in positive emotionality from still-face to reunion might reflect a delayed emotional response, where infants begin to recalibrate their emotional state after the distressing Still-Face episode. This pattern of emotional recovery is consistent with the idea of emotional regulation, where infants gradually adjust their affective state following a period of distress (Mesman et al., 2009). Moreover, children's negative emotionality during the Reunion episode didn't show significant differences with respect to both Play and Still-Face episodes. We also found that the values of emotional negativity displayed by children during the Reunion episode were between the values registered during the other two episodes of the SFP. These findings suggest that during the Reunion episode infants didn't get back to the baseline levels of negative emotionality. This again suggests that this process of regulation is not sudden, but it requires time. Other papers have already found a carryover of negative emotions across the Reunion and Still-Face episodes (Mesman et al., 2009; Swider-Cios et al., 2024; Weinberg & Tronick, 1996). These findings were replicated in our study even though we didn't use a double-Still-Face paradigm, reinforcing the idea that a 1-minute long Still-Face episode might cause enough stress to obtain valid results.

For what concerns the analysis of maternal behavior during Play and Reunion episodes, we found no significant differences in the frequency of the use of touch and vocalizations. This suggests that mothers didn't change their interaction strategies after experiencing a stressful situation.

4.2 - Maternal Behavior and Infant Emotionality

Our research also explored the relationship between maternal behaviors and infants' emotionality during the reunion episode. The correlation analysis revealed that maternal cognitive vocalizations were negatively correlated with infants' negative emotionality, while affective vocalizations were positively correlated with infants' positive emotions. These findings suggest that mothers' verbal strategies might play a crucial role in modulating infants' emotional states.

4.3 - Frontal Alpha Asymmetry and Dyadic Behavioral Dynamics

The investigation of maternal FAA across episodes did not reveal significant episode effects, as indicated by the lack of variance in FAA values across the Play, Still-Face, and Reunion episodes. This suggests that maternal emotional regulation, as indexed by FAA, remained relatively stable despite the emotional demands of the different episodes. This result contrasts with some studies that have found FAA to be sensitive to situational emotional challenges (Allen et al., 2004). While Perone and colleagues (2020) did find a still-face effect, the study from Swider-Cios and colleagues (2024) didn't find any. The reason behind this might be the shortened duration of the Still-Face episode that we employed, which is 1-minute long instead of 2, thus reducing the stressful load on both the mother and the infant. Nonetheless, we reported a decrease in maternal FAA variability during the reunion episode. This pattern is different from what has already been found in other studies (Perone et al., 2020) and it could be related to an effort from the mothers to exert more control over their emotions to try to soothe their children after the stressful situation of the Still-Face episode.

However, our second aim was to investigate the correlation between behaviors displayed by the dyad and maternal FAA. The correlation analysis revealed a significant association between infants' positive emotionality and maternal FAA during the play episode suggesting that mothers whose babies displayed positive emotionality had positive FAA values. A moderate positive association, although not significant, was found between maternal FAA and infants' positive emotionality during the SF episode as well. Similar patterns can be seen for negative emotionality. These results are in line with the study from Perone and colleagues (2020), but they go against the pattern highlighted by Swider-Cios and colleagues (2024). They found maternal FAA and children's emotionality during the Play episode to be inversely related. According to them, mothers would exhibit positive values of FAA when their children would display negative emotionality. What they argue is that mothers who see their children in distress would activate approach behaviors that would overcome the negative feelings and cause a shift of the asymmetry towards the left (Swider-Cios et al., 2024). Although interesting, we couldn't replicate these findings with our study, which tends to confirm again the correlation between approach-related emotions and relative left frontal activation.. Anyway, this might be due to the limited size of our sample.

These findings also highlight the potential bidirectional emotional influence that takes place in the dyad and the power of mirroring processes. Being able to control our emotions to cope with stressful situations is a skill that is already crucial in the first months of an infant's life (Sroufe, 1996). According to the Dyadic States of Consciousness Model (DSCM; E. Tronick, 2005), infants depend on their interactions with their caregivers and on the mutual intersubjectivity for the to construction of meaning and their emotion-regulation abilities. This shared meaning is essential for infants to sustain an integrated state of awareness of the self, which in turn supports an optimal physiological state. If a mother is unresponsive, she will violate her infant's anticipation. This will lead the baby to try engaging the mother back and, if the infant doesn't succeed, it will cause strong distress (E. Tronick et al., 1978). Field (1994) tried to explain the Still-Face effect differently. According to him, when the mother quits the interaction, the infant loses an external landmark for emotional and behavioral regulation. Without it, infants lose their possibility to interact with the environment and to control negative feelings. The distress and negativity they feel can be measured both at a behavioral and physiological level.

Interestingly, while no significant associations were found between maternal FAA and their own behaviors, trends in the data suggested that mothers with more negative FAA were more likely to use affective vocalizations during reunion, potentially as a compensatory mechanism to manage their own negative emotional states, or to help reduce the distance that originated between her and her infant during the Still-Face episode. Conversely, more positive FAA during the Reunion episode was associated with increased use of pragmatic touch and cognitive vocalizations, which may reflect a more relaxed and confident maternal approach. This being said, although these trends did not reach statistical significance, they suggest a complex relationship between maternal emotional regulation and behavioral strategies, warranting further investigation. To our knowledge, no previous study tried to associate behaviors that were micro-analytically coded to the direction of FAA shifts (previous investigations employed constructs such as maternal sensitivity to the infant's emotions; e.g. Perone et al., 2020), but this more fine-grained approach might help better detect and understand what kind of strategies and behaviors are usually deployed by the dyad to cope with stressful situations.

For what concerns the impact of maternal reported feelings on their FAA, results didn't reach significancy. Nonetheless, associations were found in the expected direction according to FAA literature that correlates negative emotional experiences to negative shifts in FAA and positive emotional experiences to positive values of asymmetry (Davidson, 1998). Maternal asymmetry and self-reported negative emotions were weakly negatively correlated, so that mothers who experienced more distress during the Still-Face episode, would display a shift in FAA towards the right and would rate the procedure as much more unpleasant. On the other hand, reported infant positive emotionality was found weakly positively associated with FAA. Mothers who reported their children as displaying more positive emotions during the Still-Face episode exhibited more positive values of FAA.

These results are really important in light of what was discussed before. This pattern confirms the association between infant positive emotionality and maternal positive values of asymmetry, as it reports an association between maternal left FAA and mothers reporting their child to display positive emotions. Following this line of explanation, we might hypothesize that the association between self-reported maternal negativity and their own FAA values might be mediated by seeing their children displaying more distress, which caused more negative values in maternal FAA. Unfortunately, we didn't analyze if the children of mothers rating the experience as more negative displayed more negativity during the Still-Face episode, so this is only a possible explanation that should be tested by future research.

4.4 – Limitations

Despite the interesting findings, our study has several limitations to be acknowledged.

First thing, as already mentioned, our sample size was relatively limited, therefore reducing the generalizability and representativeness of our results, as well as their statistical power.

Another limitation could be the short duration of the procedure overall. Although necessary in order to obtain clear EEG data, the 1-minute variation of the SFP might not cause enough stress to catch variability in FAA.

The lack of a baseline recording represents another limitation: a baseline correction in these kinds of paradigms has been employed almost every time and it allows us to tell whether brain activity is related to the construct that is being studied or to resting brain activity (Hu et al., 2014), but it can also offer more insights in the phenomenon by unveiling other patterns when the results are normalized to baseline (Perone et al., 2020). In this last case, baseline levels of FAA were recorded while the mother and her infant, separated by a curtain, were watching a video. This procedure might be implemented in future studies, even if the whole procedure required to prepare the experimental setting might be already too long, causing enough distress in infants to make the measurement of baseline FAA values useless, as they would not reflect baseline levels of brain activation.

The whole preparation procedure is another intrinsic limitation of the study. Getting the EEG caps ready is a procedure that usually takes a long time and is something new to the infants, that, most likely, have never experienced the application of such a cap and the conductive gel. Despite trying to help the infant familiarize with the situation by preparing the mother first, and our attempts to be as fast as we could in this procedure and leaving all the time that the infant needed to settle down in case they got nervous, our precautions didn't always succeed in preventing infants from becoming fussy. As a result, we had to exclude 4 infants from the data analysis. Unfortunately, this limitation is strictly related to the nature of EEG recordings which is impossible to bypass at the moment, even using a mobile EEG technology that allows infants to maintain their freedom of movement. It is appropriate to highlight again that this isn't a limitation that is strictly related to our study in particular, but rather to the methodology we employed.

In this study, we didn't consider infants' FAA. Doing so might unveil many other associations and patterns between dyadic asymmetry, or between mothers' and infants' behaviors and their own FAA, clarifying also what kind of self-soothing behaviors the infant might display when distressed, for example. Future research should consider children's FAA measures as well in order to further investigate all the associations aforementioned.

4.5 - Implications and Future Directions

These findings have important implications for understanding the intricate emotion regulation and behavioral dynamics between mothers and infants. The differential emotional responses observed across episodes highlight the need for further research into how specific maternal behaviors can buffer or exacerbate infants' emotional reactions in challenging contexts such as the still-face paradigm. As already said, it would be interesting to try to investigate the association between infants' FAA, their own behavior and the maternal one. This would help understand what kind of self-regulatory behaviors the infant can display and their effectiveness, giving further insight into what happens in the child when important regulatory support, like the one that the caregiver offers, is missing. Longitudinal studies could also investigate age-related differences through frequent assessment. This would be needed as infants go through a very fast development that involves all the areas from the cognitive to the motor ones. All of these changes may exert a big influence on emotion regulation strategies and the behaviors deployed in the dyadic context.

Future research could benefit from exploring the underlying mechanisms driving the observed correlations between maternal FAA and their specific behaviors, as well as expanding the sample size to confirm the trends noted in the present study.

The insights that we can obtain by implementing SFP in studies investigating FAA dynamics and its relation with emotion regulation and behaviors in the mother-infant interactions could be really important for the investigation in at-risk populations like preterm babies and to design better interventions that can fit better the needs of such peculiar conditions. Preterm infants go through an early separation from their mothers in order to receive the care they need in the NICU. This deprivation of the mother's closeness can affect negatively the outcomes of their interaction with her, even though it doesn't mean that their interaction quality will always present negative outcomes (Korja et al., 2012). The measurement of FAA in the first year of life may help detect those infants who are more at risk for the development of psychopathologies or dyads whose interactions are less adaptive, hindering the socio-emotional development of the infant. The problem here is that, despite the relation between FAA and what happens within the dyad is well assessed, directions of the effects and patterns are sometimes inconsistent and unexpected. In order to be able to interpret these results correctly and to consider FAA as a reliable marker of emotion regulation and motivational processes, we need more research to clarify these aspects.

Moreover, it could be interesting for future research to investigate the same dynamics in father-infant interactions. Cabrera, Karberg, Malin and Aldoney (2017) have already assessed the important role that fathers have in helping their children to develop their self-regulatory skills. Thus, father-infant dyads might show different synchrony patterns, giving their own distinct contribution to the emotion-regulation development.

One last thing worth acknowledging is that this study contributes giving further validity to the feasibility of the measurement of FAA during SFP. This is important for FAA literature which has explored the construct along a wide number of different settings and methodologies, which sometimes made results difficult to interpret. The few studies employing the use of SFP are contributing to the collection of more coherent and easy-to-interpret results that will surely benefit the understanding of the construct with the definition of a clear and reliable methodology.

In conclusion, this study sheds light on the complex interplay between maternal and infant behaviors, emotional responses, and neurophysiological measures like FAA, giving further validity to the already existing literature, but it also leaves some open questions and shows that it might be possible to investigate further the associations between the display of certain behaviors during tasks that elicit emotions. For example, it might be interesting trying to understand more deeply the influence that motivational aspects (e.g. approach and withdrawal) have on the interaction and on EEG asymmetry. Such investigation would probably require a more appropriate paradigm than the SFP, as the setting for this procedure requires participants to stay at a certain distance and not move too much.

Epilogue - Thinking back on infant research

Before ending, I would like to spend some lines to talk about a little reflection that I made while writing this thesis.

I would like to begin by telling an anecdote I heard from Alessandro Barbero, an Italian historian and popularizer. In one of his lessons, he talks about Federico II di Svevia and his ambiguous reputation. He tells about this story that Salimbene da Parma, an important ecclesiastical of those times who spent some time at his court, refers to us through his writings. Federico II was a very curious man, extremely open-minded for his time. This characteristic of his brought him also to do weird experiments, of dubious moral values. Once, he was wandering which of the many present in the world was the primordial language, the one with which the man was created. In order to discover it, he ordered to grow some infants without ever telling them a single word. I guess he thought that this way babies would have not been influenced by the language that was spoken around them and the one that was written in the genetic code (or whatever they would have ascribed it to at those times) would have arisen at a certain point, giving him the answers he was looking for. There's no need to say that, of course, all these babies died, and he never found out. I'm going to overlook this interesting intuition, even if implicit, from a man who lived 800 years ago about the interaction between genes and environment, in order to dwell on Salimbene's comment about this fact. He says that "it is obvious that they all died, as a child can't live without the chit chats and loveful cares of a mother" (Barbero, 2017). What I found striking here is that a monk from the 13th century, as well as a cruel experiment from a curious man, fully anticipated what would have been taken up again centuries later: the development of the infant cannot ignore the interaction with a caregiver.

Now, what does this have to do with this thesis ?

While working on the introduction, I had to scroll through infant research literature to briefly track its path from the beginning of the discipline until nowadays. While doing so, I came across a pattern that I already touched on. What I'm talking about is the tendency of infant research and social construction investigations to ignore the mother-infant dyad or in general the social context when studying certain constructs, especially when beginning to apply new methodologies and paradigms. I would like to try to break down this phenomenon a little bit here.

As already told, at the beginning of experimental psychology, the mother-infant dyad was totally overlooked as researchers thought that babies were just too immature to be informative in any way to how human beings function. There wasn't any effort from the research to try and adapt all the paradigms that were employed back in those days to the cognitive abilities of children in order to try to grasp something of their functioning. For someone to manifest any interest in the development of children, we have to wait for Piaget. With his work "*The Origin of Intelligence in Children"*, dated 1952, Piaget laid the foundation for understanding how children develop cognitive abilities from infancy through adolescence. Still, despite acknowledging the importance of social interactions in learning, we will have to wait for the 1970s for authors to really stress the importance of the interaction between the mother and the infant for infants' socio-emotional development.

As already said, despite the groundbreaking and impactful works of researchers like Trevarthen, Bowlby, Sanders and Tronick that made us aware of the fact that infants' development can't be considered outside the mother-infant relationship, the neuroscientific approach that developed in later years looked for the neural correlates of social attention and the processing of social information ignoring the mother-infant dyad, studying the individual outside the social context, employing paradigms that relied on the presentation of pictures or videos with characters looking at objects, for example. This happened until the hyperscanning technique was invented.

A similar pattern can be seen in the study of FAA. In this case, as well, the first studies on infants were run outside social contexts, same things for adults. The first paradigms simply measured FAA at rest, and only later implied some emotion elicitation tasks that were still without live interactions. Of course, emotion regulation processes are not only activated in social contexts, but the problem here stands in the fact that researchers tried to translate these non-interactive paradigms in the study of the parent-infant dyad. Of course, this means that, again, before the relation between FAA in mothers and children and the interactive dynamics could be studied appropriately, a lot of years passed, and only in 2017 we had the first FAA paradigm that employed the EEG asymmetry measurement during an online interactive task between the mother and her infant, thus acknowledging again that the development of the infant can't be studied outside from its primary environment: the interaction with the mother.

Now, I don't have the means to understand why researchers insisted on studying dynamics that belong to interactive contexts outside of them, but thanks to my background I can acknowledge now that if the infant doesn't learn where to pose his gaze and what social cues are more salient from a screen (at least for now), then it doesn't make sense to study how he learns that and how these processes are represented in the brain putting the child in front of a screen. What impresses me the most is that this awareness was present already 800 years ago, before the advent of infant research, so I was left as confused as curious about this troubled path that led us to slowly adjust the methodologies to the theoretical accounts.

The reason behind this contradiction might just be the background of all the different researchers, maybe not used to working with parents and infants, but rather with individuals, or just the fact that they also found themselves in the middle of all the great technological advances of the last century, and understanding the best way to use them and apply them to the theoretical models and views is never easy.

To conclude, I would like to make clear how this whole thing contributed to my education as a psychologist and a researcher. Professor Livio Provenzi insisted a lot during class on the fact that, in order to understand people (and to help them, in the case of the therapist), the most important thing is having clear in mind what the Human Being is for you. This travel along infant research showed me what can happen when this awareness is set aside. Writing this thesis gave me a better understanding of what my professor tried to teach us, and I think it showed me what can happen if I forget the essence of what I'm studying and that I have to stick to it if I want to be effective in my research.

Keeping this in mind forever, I will try to do my best to contribute to science.

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