UNIVERSITY OF PAVIA – IUSS SCHOOL FOR ADVANCED STUDIES PAVIA

Department of Brain and Behavioral Science (DBBS)

MSC in Psychology, Neuroscience, and Human Sciences

Autonomic Regulatory Interaction in Early Life:

The impact of technoference on mother-infant co-regulation processes: an Infrared Thermal Imaging exploration

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Contents

Abstract

Mother-infant interactions are crucial for newborns to achieve self-regulation through finely tuned-coregulation. In modern life, the pervasive use of smartphones and social media influences these interactions, consequently affecting coregulation. This thesis has investigated the impact of technoference and paper-ference on maternal and infant thermal and behavioral responses during dyadic interactions.

Applying infrared thermal imaging (ITI), the study examined how maternal distraction by smartphones (technoference) and paper-based tasks (paper-ference), which are modified versions of the still-face paradigm, affected thermal and behavioral expressions and dyadic attunement between mothers and infants.

Results indicated distinct patterns in maternal and infant thermal and behavioral responses across episodes. Infants showed a decrease in forehead temperature compared to baseline while no variation was observed in infants' nasal temperature. A decrease in maternal forehead temperature was observed during technoference and paper-ference with a full recovery during the reunions. The thermo-behavioral coregulation findings indicated a negative correlation between maternal touch and infant negative affect during the reunion following the paper-ference. Interestingly, mothers showed an increase in nasal temperature during the experiment episodes compared to baseline. We also found an increase in infant negative affect and a decrease in infant positive affect. Furthermore, a thermal coregulation was found in nasal temperature during the reunion following technoference.

The findings underscore the complex interplay between technological distractions, maternal caregiving behaviors, and infant emotional responses. This research contributes to understanding the physiological and behavioral dynamics of mother-infant interactions in today's digital contexts.

Keywords: Coregulation, Infrared Thermal Imaging, Technoference, Peper-Ference, Still-Face, Forehead temperature, Nasal Temperature, Thermo-Behavioral Coregulation, Infant Affect, Maternal Touch

Prologue

All our endeavors in life are intended for one goal: achieving a sense of safety. As Dr. Stephen Porges wisely stated, “if you want to improve the world, start by making people feel safe”. We cannot be anchored in a state of safety unless we identify the stressors in our environment and try to mitigate or reduce them. This fundamental goal drove my first decision to initiate this project. A sense of safety can be experienced from infancy onward.

Differently from reptiles, mammalians need extensive postnatal caregiving (Abney, daSilva, et al., 2021; Neff, 2011; Porges, 2003a, 2003b) and among mammalians, the brain of human newborns is particularly immature and needs a supportive caregiving environment to properly grow and develop (Provenzi et al., 2018). In this sense, parents, through the bidirectional interaction with the infant, have a key role in the bio-psycho-socio-emotional development of their children (Montirosso et al., 2010).

Face-to-face mother-infant interaction is essential for the infant to reach mutual regulation and consequently, self-regulation which is obligatory for adopting an adaptive coping style (Swider-Cios et al., 2024). Previous studies have indicated that less mutual regulation is related to lower self-regulation and later limited capacity for coping with stressful conditions (Montirosso et al., 2010). During the infancy period, reciprocal synchrony is shaped through the social interaction between mother and infant which has sometimes been referred to as the “mother-infant dyadic dance” (Provenzi et al., 2018) which occurs in the level of behaviors, emotions, and physiological rhythms (Swider-Cios et al., 2024). This synchrony is considered the basis of a variety of neurodevelopmental behaviors (Feldman, 2007a, 2007b).

Nowadays with the prevalence of technology usage, every aspect of life is influenced. Using the smartphone while caregiving an infant might have an impact on mother-child interaction. There is an increasing amount of research that demonstrates the interruption of mother-child synchrony due to the usage of smartphones (Zivan et al., 2022). One of the reliable as well as secure experimental procedures to explore the early mother-infant dyadic interaction is the Still Face Paradigm (Provenzi et al., 2016).

As we were eager to realize how smartphones can affect early dyadic interaction, we adapted this paradigm to investigate the impact of disruptions during the interaction related to smartphone use. We also compared this condition to a disruption related to paper use to highlight the potential specificity of maternal smartphone use while interacting with an infant.

While distorted mother-infant communication brings about various future challenges for newborns, it is important to emphasize that it affects the current autonomic and behavioral system of both mother and child, as well (McFarland et al., 2020). It is indicated through different research studies that there is an autonomic co-regulation even if the behavioral responding is interrupted by some reasons such as still-face or smartphone-adapted still-face (Ham & Tronick, 2006; Swider-Cios et al., 2024; Zivan et al., 2022).

This mother-child coregulation can be explored by use of infrared thermal imaging (ITI), a unique and useful physiological measuring method by which we can explore not only the autonomic co-regulation of child and parent (Nazzari et al., 2024) but also the change of a single person's autonomic system (Ioannou et al., 2014).

Although numerous studies using the still face have assessed links between the child's behaviors in stressful situations and maternal responsiveness, few studies have explored autonomic co-regulation between mother and infant. By usage of thermal imaging, we aimed to understand how behaviors are synchronized with the autonomic changes in skin temperature. In addition, we tried to understand if there is any behavioral and autonomic co-regulation among mothers and babies and how this might be impacted by technoference.

Chapter 1. The early mother-infant dyadic dance: from theory to research

1.1 The mother-infant dyad as a dynamic system

Theories that consider the interaction of mother and infant mainly assume that both mother and infant are active (and not passive) through communication (Kahya et al., 2022). There are a variety of terms to refer to the dyadic interaction; coherence, concordance, contingency, mutuality, reciprocity, synchrony, maternal responsiveness, maternal sensitivity attunement, coordination, and so on (Bornstein & Esposito, 2023; Kahya et al., 2022; Mesman, 2010; Provenzi et al., 2018). Provenzi and colleagues (2018) in a systematic review noted that the terms "reciprocity" and "mutuality" evolve as broad constructs whereas the other terms mainly explain certain procedures. In keeping with Stephen Porges (2021), in the current thesis, we will use mostly the term "co-regulation". Coregulation and all other terms mentioned above can be described as a type of mother-infant dyadic dance (Provenzi et al., 2018). In the following sections, we will provide a more detailed description of the, highlighting the main theories and contributions.

The early mother-infant interaction has been frequently described as a "dyadic dance". Besides the scientific concept, we can consider the aesthetic aspects of scientific terminology. Dyadic dance is a metaphor to indicate the mother-infant interaction in a fine synchrony. Dyadic dance is coined to refer to the spontaneous patterns of macro and micro expressions (Hoch et al., 2021) which can be relevant to different aspects of social interaction including physical (behaviors), psychological (emotions), biological (autonomic nervous system), and neural (brain activity); while every aspect works independently, all of them are linked and can influence each other (Bell, 2020; Leclère et al., 2014). During interacting, mother and child can appreciate and respond to the micro displays of each other in a meaningfully integrated dispatch (Feldman, 2007a, 2007b). Behavioral coregulation can happen incidentally or due to a common objective. Accurate concordance between mother and infant is the basis for them to learn how to perform dyadic movements as well as personal motor skills (Feldman, 2007b); the most explicit instance is about dual dance "both partners must maintain temporal and spatial synchrony as they move across the dance floor."(Hoch et al., 2021). The child's overall development is the outcome of ongoing dynamic interactions with the caregivers (Ceulemans et al., 2019). While children need a good partner to learn it, for adults it seems easier to synchronize their behaviors in an interaction. No matter if it is intentional or incidental, in any case, behavioral synchrony necessitates the synchronization of perception and action. Dance associates are needed to perceive the behaviors and actions of each other (Demos et al., 2012)

Behavioral dance or behavioral coregulation forms a basis for social interaction in infants and young children and they get so upset if this concordance is interrupted for any reason (Provenzi et al., 2018). In other words, the behavioral dance of the mother-infant dyad refers to the contingent macro and micro behaviors from facial expression and vocalization to gestures, movements, and playing together in a spatiotemporal concordance happening between mother and newborn while interacting (Ceulemans et al., 2019; Hoch et al., 2021).

Above them, a synchronous behavioral system can lead to better cooperation, an increase in pain threshold, prosocial behaviors, altruism, compassion, trust, and self-regulation (Bartkowski et al., 2023; Bell, 2020; Cirelli et al., 2014; Lang et al., 2017; Valdesolo & DeSteno, 2011). And finally, this behavioral synchrony occurring during dyadic interaction, as noted, can lead to better social interaction and emotional dance (Ayache et al., 2024; Ceulemans et al., 2019; Crone et al., 2021). In the research field, the social interaction between mother-infant dyads is studied through the still-face paradigm which was introduced by Ed Tronick. He verifies the synchronization of the dyads during the social exchange.

To explore the components of the early interaction, we need an analysis approach toward behaviors and physiology (Feldman, 2012a, 2012b). These days, with the development of technology, social media has been added to everyday life and consequently, infants are exposed to new stressors that affect their interaction with their caregivers, particularly mothers (Porter et al., 2024). In this chapter, we dive into social interaction through the lenses of different theories.

While studying the mother-infant interactive signals, researchers should specify what they are measuring; macro signals and micro signals (Mesman, 2010), or autonomic and physiological changes which can be measured through cortisol tests (Provenzi et al., 2016), cardiac signals (Kolacz et al., 2022), or face temperature (Ioannou et al., 2021).

Macro expressions indicate observable behaviors and are mostly under control and micro expressions are small movements of the muscles and body movements that are difficult to inhibit (Ekman, 2003). So, it is not unlike to consider the macro signals as last-longer expressions while the micro signals are happening in very short temporal sections during the interaction (Mesman, 2010). Ekamn (2003) describes micro behaviors as muscular movements associated with real emotions of the person during a stressful situation or under pressure. In this way, it is considered that micro expressions contain emotional meanings for clinical experiments. As the external environment causes some changes through our senses (hearing, vision, taste, etc), the micro-expressions including facial expressions change (Saffaryazdi et al., 2022); which is accompanied by a change in autonomic responses including facial temperature (Abbas et al., 2012). It is noteworthy to mention that micro-level behaviors are not only related to a brief time frame but also intensity to the extent that some micro behaviors are difficult to see by the naked eye and are unfolded by facial action coding system (FACS) which breaks the facial signals into the components named action units (AU) (Yan et al., 2015).

The majority of studies measure just one of the macro or micro-expressions (Mesman, 2010). Studies focusing on the overall characteristics of the interaction are categorized under the label of macro-level studies, the ones that concentrate on certain modalities through interactive face-to-face communication such as eye tracks and expressions on the face are labeled as micro-level studies (Kahya et al., 2023). given this viewpoint, the mother and infant mutuality theories present a model to analyze the dyadic interaction more functionally (Beebe et al., 2010; Beebe et al., 2016).

There are few numbers of studies that employed both macro and micro analysis and surprisingly they revealed that there is no correlation between macro and micro maternal expressions (Mesman, 2010); so it is true that when the mother is asked to ignore the child, while the obvious expression is being indifferent, she may show some micro signals such as pressing or sucking the lips, wrinkling the nose, raising the cheeks, and eyebrow movements (Yan et al., 2015; Zurloni et al., 2015) whereas the macro behaviors are more under control, usually, micro level signals such as facial expressions are involuntary and less, but of course not totally, under control; however, for more reassurance, we can also assess anatomical and physiological body (Saffaryazdi et al., 2022) such as facial temperature (Nazzari et al., 2024). Through the parent's continuous synchronization with the infant's micro-level displays, infants are more sensitive to the temporal components of emotional communication as soon as they join the social environment, at roughly 2-3 months of age (Tronick & Cohn, 1989).

Signals at the macro level, as well as the micro level, can affect the mother-infant dyadic interaction (Yan et al., 2015) and consequently result in autonomic changes in a regulative approach (Porges, 2021). At a primary vision, we set out to explain the theoretical bases of mother-infant interaction in general and then delve into coregulation and its behavioral, emotional, and autonomic aspects.

1.2 Main contributions to the study of mother-infant early interaction

The study of mother-infant early interaction has been a cornerstone of developmental psychology and related fields for decades. Comprehending the interaction between caregivers, typically mothers, and their infants during the pivotal early stages of life is crucial for explaining various aspects of child development including social, emotional, and cognitive growth (Rose, 2024).

Indeed, initial interactions between parents and newborns can serve as a predictor of future socio-emotional development (Adamson & Frick, 2003; Russell & Gleason, 2018), emotion regulation (Harrington et al., 2020), self-regulation (Lengua et al., 2021), anxiety (Butterfield et al., 2021), and various neurodevelopmental concerns (Carozza & Leong, 2021). Numerous seminal contributions have significantly advanced our understanding of mother-infant early interaction which will be explained further.

1.2.1 Edward Tronick’s contribution

Edward Tronick emerged as a pioneering figure within the realm of parent-infant interaction in the 1970s. He introduced the concept of consciousness and developed the “mutual regulation” model, which relies predominantly on behavioral measures observed in dyadic interactions (Tronick et al., 1978; Tronick & Cohn, 1989).

His studies have extended our knowledge of the dynamics, complexities, and importance of parent-infant communication (Rose, 2024). The substructure of Tronick's studies is beyond the mother-infant synchrony to the biobehavioral aspect of this synchrony (Tronick, 2007). One of his important contributions is the still-face paradigm through which he has illustrated the significant role of responsiveness and attunement in the socio-emotional development of infants (Beebe & Lachmann, 2015). (Beebe & Lachmann, 2015)

1.2.1.1 The Face-to-Face Still-Face Paradigm

The Face-to-Face Still-Face (FFSF) paradigm is a good assessment to discover the different aspects of mother-infant interaction. This paradigm looked at how a newborn reacted when its mother chose to keep a frozen, unresponsive, and emotionless expression instead of interacting socially with her child; the classical version of the FFSF paradigm is characterized by three episodes. (Abney, daSilva, et al., 2021; Abney, Lewis, et al., 2021; Procyk, 2020; Provenzi et al., 2016).

In the first episode, free play (FP), the mother communicates with her child in the routine style that she uses in her normal life. This is the baseline for the mode of interaction (Provenzi et al., 2015; Provenzi et al., 2016). The FP episode has been found to inform about an infant's attention, social responsiveness, and emotional expressiveness (Giusti et al., 2018). This episode is indicative of typical interactive behaviors such as gaze, vocalization, facial expressions, affect, and touch (Aureli et al., 2015; Ebisch et al., 2012; Manini et al., 2013; Stockdale et al., 2020).

The second episode, still face (SF), refers to the mother having a neutral face with no expressions through which she is unresponsive to the child's needs. During the still-face episode, the infant's attempts to re-engage with the mother —such as cooing, crying, and squealing as well as physical actions like reaching, pointing, and smiling— demonstrates the physiological impact of the mother's still face on the infant (Adamson & Frick, 2003; Aureli et al., 2015; Chiodelli et al., 2020; Provenzi et al., 2016; Toda & Fogel, 1993; Tronick et al., 2005).

The infant exhibits signs of discomfort in response to the caregiver's lack of response. These behavioral responses are collectively referred to as the "still-face effect" (Giusti et al., 2018). Research confirms that the classical still-face effect encompasses a decrease in positive affect and gaze, alongside an increase in negative affect or negative emotionality (Montirosso et al., 2010). It also provides insight into an infant's self-regulation and sensitivity to maternal unresponsiveness (Mesman, 2010).

Following the still-face exposure, the third episode ensues; the reunion during which mother and infant resume their normal face-to-face interaction as it went through the FP phase; phase which is called reunion (Barbosa et al., 2021; Fuertes et al., 2021; Provenzi et al., 2015; Provenzi et al., 2016; Tronick et al., 1978).

Noteworthy, a full recovery from a still face does not occur during the reunion and there remain observable variations in the infant's behaviors compared to the baseline (Mesman, 2010); a phenomenon referred to as the carry-over effect is usually observed. The carry-over effect is characterized by the persistence of certain elements of the infant's negative emotionality into the reunion phase, which initially manifested during the still-face episode (Giusti et al., 2018).

The reunion phase and carry-over effect offer specific information about the infant's capacity to seek parental support for recovery from the experienced stressful condition as well as remembering prior interactive disruption. Additionally, it could serve as a means to delve into caregiver's emotional expressiveness both verbal and none verbal, as well as their physical interaction and emotional bonding with the infant (Mesman, 2010).

Various facets of parents' and infants' interactive behaviors can be assessed during the different episodes of the FFSF paradigm. These include the still-face effect as well as the carry-over effect through which we can investigate different elements of development. For instance, if an infant's exhibited behaviors are mature enough due to their age (Ostfeld-Etzion et al., 2015).

Furthermore, we can examine the synchrony of behaviors with autonomic responses, study behavioral and autonomic co-regulation between mother and infant, and analyze the diverse self-soothing strategies and re-engagement behaviors exhibited by infants. This Paradigm is often used in the context of developmental experiments to find out how the infant reacts to the social stress imposed by the mother which can be used for both healthy and disordered infants (Giusti et al., 2018; Pinna & Edwards, 2020).

There are different systems for Behavioral Coding of mother-infant behaviors during the FFSF. Regarding maternal behaviors, gaze, smiling, motherese vocalization, and affectionate touch are featured, and these behaviors are predictive of the newborn neurobehavioral development, attachment security, and mental maturation (Feldman & Eidelman, 2007). These factors including gaze direction, vocalization, and affect can be considered also for the child (Feldman, 2007a). It is important to note that gaze synchrony and co-vocalization are the interactive signals that indicate truly the synchronization of mother and infant (Feldman and Eidelman, 2007).

Most of the data coding systems follow the Infant and Caregiver Engagement Phases or ICEP (Weinberg & Tronick, 1998) which includes the interactive behaviors taking place during the social exchange (facial expressions, direction of gaze, and vocalizations); the behavioral expressions related particularly to the infant (passive–withdrawn, protest, object–environment, social monitor, and social positive engagement); and the behavioral expressions related particularly to the social partner (hostile–intrusive, withdrawn, social monitor with no vocalizing, social monitor with positive vocalizing, and social positive engagement). Oral self-comforting– mouthing, self-clasping, distancing–turning away, and autonomic stress indicators (e.g., hiccups, spitting up) refer to the further infant's codes. Rough touches and violations of the still-face instructions (i.e., touching or talking to the baby) are the further codes for the social partner (Tronick et al., 2005)

Ebisch and colleagues (2012) for children of 38-42 months applied a system including gaze direction, facial expression, bodily tension, actions, and verbalizations (Ebisch et al., 2012). Manini and colleagues (2013) similarly used gaze and eye, bodily tension, arms, repair, and verbalizations for children of 39-45 months (Manini et al., 2013). Aureli and colleagues (2015) considered a similar coding system with some variations. They applied a comprehensive collection of infant and social partner behaviors which were tied to facial expressions, gaze direction, and vocalization. For the infant, they applied the engagement codes: Protest, Withdrawn, Object/Environment Engagement, Social Monitor, Social Positive Engagement, Sleep, and unscorable (Aureli et al., 2015). Chiodelli and colleagues (2020) assigned three categories of positive social orientation, negative social orientation, and self-regulation to the coding system (Chiodelli et al., 2020). But in general, most of them are inspired by ICEP.

Aureli and colleagues (2015) found that during the still-face episode, there was a significant difference in social positive engagement (decrease) and looking around (increase) while there was no significant difference in protest, object engagement, oral self-comforting, and self-clasp. Noteworthy, autonomic stress indicators were absent. So, they confirmed that the infant's usual reactions to the SF such as a decrease in smiling, gazing, and vocalizing but not the aversive states such as an increase in negative facial expressions or self-regulatory behaviors. Consistently, there was no negative effect from the FT phase transferred to the reunion phase. All in all, this study was not consistent with the other SF studies which denote negative emotion increase in SF and cry-over it to the reunion phase (Aureli et al., 2015)

With a different approach, Kolacz and colleagues (2024) have studied different aspects of the mother-infant relationship during the still-face; instead of behaviors, they tended to discover autonomic synchronization (Kolacz & Porges, 2024).

1.2.2 Ruth Feldman's contribution

Ruth Feldman is another pioneering figure in the field of development; particularly known for parent-infant synchrony (Feldman, 2007b), social bonding (Feldman, 2012b), and early socio-emotional development (Feldman, 2007a). She has contributed significantly to our comprehension of the complex interplay between biological, psychological, and environmental elements influencing human development with a main focus on earlier stages of life (Feldman & Eidelman, 2007; Feldman et al., 2010). Through her work, she defines the term synchrony as the dynamic process and interactive exchange of hormonal, physiological, and behavioral signals between parent and young infant during social contact (Feldman, 2012a, 2012b)

Leclère and colleagues (2014) in a review paper affirmed that the term "synchrony" is the most commonly used term for referring to mother-infant social exchange. *Synchrony* explains the relation between the phenomena that happen which are linked temporally in a way that makes a united experience; the time relations can be concurrent, sequential, organized in a time series. When we talk about synchrony, it includes diversity from neurons and genes to behavior and population (Feldman, 2007b).

As it comes to the mother-infant dyad, describes a biological process (McFarland et.al, 2020) that makes the newborns more sensitive to the timing of their actions concerning others. It allows them to understand how their behaviors and those of others fit together to create meaningful experiences (Feldman,2007a). This ability to synchronize with others is essential for infants as they learn about themselves and the world around them through interactions with caregivers and the environment (Toda & Fogel, 1993). During the interaction of the mother-infant dyad, there is a following of second-by-second shifts in the level of micro behaviors—such as tone of voice, gaze direction, facial expressions, level of arousal, muscle tone, or body orientation— that is crucial for engaging in emotional exchange during the interaction (Feldman, 2007a).

It is noteworthy to differentiate between synchrony and imitation as they are related but different concepts. Synchrony emphasizes the temporal corresponding while imitation brings out the spatial corresponding (Ayache et al., 2024). However, imitation behavior can be synchronous or asynchronous. In other words, while they are two different concepts, they are related to each other. So, it is true to claim that while both synchronous and asynchronous imitation is helpful for motor skill development, synchronous ones perform a more important role (Crone et al., 2021). Synchrony is different from imitating and mirroring, instead, it refers to dyadic dance during the mother-infant relationship (Leclère et.al, 2014)

Feldman and colleagues (2011) categorized the aspects of synchrony into three main sections. Gaze synchrony (G) which identifies the long-lasting looking of the child and parent in a matched way. Affect synchrony (A), which is characterized by the synched indications of affects, is important to have an extended self-regulatory capacity. Finally, vocal synchrony (V) refers to the pre-verbal interaction and includes the simple and primary way of using spoken language for communication.

Feldman (2007a, 2007b) explained that the synchrony shaping during mother-infant communication, including physiological rhythms, vocal congruence, and cognitive functions is the base of many neurodevelopmental behaviors in newborns. When we talk about synchrony, we also should differentiate between different types of behaviors including verbal, non-verbal, and emotional parts (e.g., gestures, postures, vocalization, etc.) (Delaherche et al., 2012). Concerning the latter, we can differentiate three categories of emotion (Damasio, 2003): primary emotions, social emotions, and background emotions. Primary emotions refer to basic emotions such as happiness, sadness, etc. Social emotions are the ones that come up in the relationship with others including empathy, shame, pride, etc. Background emotions are related to the rhythms of the feelings. In other words, background emotion is not related to the obvious emotions but more related to changes of emotion in time, appearing, fading, accelerating, and so on. Background emotions characterize the continuous aspect of emotions, and the social environment serves as the primary medium for their manifestation (Feldman, 2007a).

Synchrony does not occur only at a behavioral level, indeed both mother and infant can influence the other's physiological reactivations during the social exchange while sending moment-to-moment visual-affective cues. During the episodes of affective or vocal synchrony, more physiological and autonomous synchrony are observable. It asserts humans in contrast to other mammalians can access the autonomic nervous system of each other not only by physical touch but also through visual-affective expressions (Feldman, 2007a, 2007b, 2012a, 2012b)

Behavioral and physiological dyadic synchrony is defined as the temporal coordination of social interaction and corresponding physiological reactivities (Feldman, 2012a; Feldman et al., 2011). Feldman (2012b) mentions three physiological systems that activate through biobehavioral synchrony: autonomic, hormones, and neurological activity.

Infants can achieve self-regulation by passing a fine co-regulation with the caregiver. The regulation explains the process of disparate elements to unify a cohesive system which alters between excitation and inhibition regularly and applies the bio-behavioral, and mental procedures to build a meaningful action and its mental representation. The newborn human needs the caregiver to take care of them after birth because they have a very immature self-regulatory system. For this reason, the parents should help them to improve self-regulation through social interaction and co-regulation. Vocalizations, face expressions, touch, and other macro and micro-expressions of the mother are the external regulatory factors to interact with the infant. In addition, as time passes, the autonomic nervous system of the mother and infant becomes finely attuned to achieve an attachment. On the other hand, infants can regulate the mother through rhythmic behaviors such as crying, gazing, and so on; and these displays influence the mother to downregulate or upregulate the baby. We can observe these kinds of synchronizations also through the release of hormones in mothers. Changes in the hormone system of the mother help her to attune to the infant precisely. During and after pregnancy there is an increase in oxytocin and prolactin for forming a better attachment. These dyadic interactions build a neural network that can be regulated by the social partner.

A growing body of research is investigating the link between dyadic synchrony and coregulation of autonomic nervous systems or/and brain reactivity of parent and child (Feldman et.al, 2011). The physiological synchrony during social interaction enhances the physiological regulation in infants which is related to environmental cues, as well (Feldman, 2006).

In a research, Feldman and colleagues (2011) tried to find out if there is an autonomic synchrony in a mother-infant face-to-face social interaction and if the three aspects of synchrony (vocal, gaze, and affect) enhance this synchrony. They discovered that there is an autonomic coregulation during mother-infant interaction specifically during the synchronous episodes; in other words, the autonomic coregulation significantly increases during the synchronous interaction compared to non-synchronous one.

While Feldman used the term “synchrony” and it is a more commonly used term, we use the term co-regulation to refer to the adjustment of biological and behavioral changes between the social partners (here is mother-infant dyad) regarding the partner conditions (Bornstein and et.al, 2023). Co-regulation will be discussed more in the next chapter.

As was discussed in this chapter, the still-face paradigm is a good assessment to discover the different aspects of mother-infant interaction including behavioral responses of the children during the still-face phase, synchrony of behaviors with autonomic responses, behavioral and autonomic co-regulation between mother and infant, and the different self-soothing strategies and re-engagement behaviors applying by infants.

For this aim, it is necessary to define a proper coding system through which the behavioral, autonomic, neural, and other preferable aspects to be measured can be coded scientifically. Related to the behavioral coding system, ICEP is the most well-known system on which the other coding systems are mainly based.

Chapter 2. Bio-behavioral mother-infant co-regulation through Poly-Vagal lenses

2.1 The autonomic nervous system

The autonomic nervous system (ANS), which is distinct from central nervous system (CNS), is the part responsible for regulating visceral activities; in fact, it innervates almost all parts of the body including smooth and cardiac muscles and glands (Gibbons, 2019; Porges, 2011); through which can control visceral functions such as cardiovascular activities, digestion, metabolism, and thermoregulation (Bonaz et al., 2017; Porges, 2003a) by up-regulating or down-regulating mechanism which makes the body remain in a homeostasis state (Bornstein & Esposito, 2023). The term “autonomic” refers to autonomous and its automatic activation (Dana, 2021).

However, the autonomic nervous system (ANS), working mainly in the subconscious domain, is in sync with the neural functions (Porges, 2003). The ANS is divided into a sympathetic nervous system (SNS) and a parasympathetic nervous system (PNS) (Bonaz et al., 2017); regarding the origin of autonomic nerves: brain or spinal cord (Porges, 2011). Fibers which come from thoracic and lumbar segments of the spinal cord characterize the SNS while the PNS comprises the cranial nerves of the brainstem and sacral parts of the spinal cord (Porges, 2003) Recently one more system named the enteric nervous system is also been taken into consideration in the ANS (Gibbeson, 2019)

At first, the main focus was just on the motor fibers of the ANS, and this unfair viewpoint ignored the important role of sensory fibers which accompany the majority of efferent. With this consideration, we can focus on both efferent and afferent pathways of the ANS. Furthermore, it was supposed that the SNS activates in fight/flight behaviors and the PNS was involved in restorative states but after presenting the poly-vagal theory a hierarchy took the place of two portions of ANS (Porges, 2003). First, it is important to note that the vagus nerve is the most important element of the ANS which can play a role in different psychiatric disorders.

The vagus nerve (VN), among 12 pairs of cranial nerves in the body, is the tenth cranial nerve and the longest making a bidirectional link between the brain and the visceral organs such as the heart, the lungs, and the gastrointestinal (GI) tract (Bonaz et al., 2017; Geller & Porges, 2014; Porges, 2003a). It connects the heart to the face, as well (Yap et al., 2020). Cranial nerves are the ones that originate directly from the brain and brainstem (Porges, 2011). Because of the VN's innervation to the visceral organs, the nerves of the stomach and lungs are also known as the pneumogastric nerves. Its name comes from the Latin word "vagary" which means ''wandering''; So the vagus nerve can be called "the wandering nerve" (da Silva & Dorsher, 2014).

From a neuroanatomical point of view, the vagus nerve fibers in the brainstem have four brain projection areas: the nucleus ambiguus (NA-ventral) dorsal motor nucleus of the vagus (DMNXdorsal), which branches in vagal efferent fibers, and the nucleus tractus solitarius or nucleus of the solitary tract (NTS) and spinal trigeminal nucleus, which contain vagal afferent fibers. The dorsal nucleus projects to the stomach and viscera. As such it is involved in digestion. The ventral nucleus (or nucleus ambiguous) projects to the larynx, pharynx, esophagus, and heart. It is more involved in parasympathetic regulation during stress (Porges, 1995).

As mentioned before, the VN is also a major component of the parasympathetic nervous system (Porges, 2003; Bonaz et.al, 2017). As estimated, the VN is composed of 80% afferents that send the state of internal organs to the brain (eg. heart, lungs, stomach) and 20% efferent fibers or motor fibers (Porges, 2011; Bonaz et. al,2017). Afferent fibers are important for relaying visceral, somatic, and taste sensations (C.-H. Liu et al., 2020). However, most interest has been directed to the motor fibers that regulate the visceral organs, including the heart and the gut (Geller & Porges, 2014). VN links the heart and brain differently from the spinal cord and sympathetic system. In addition, by linking the face and heart, participates in regulating emotions (Porges, 2003).

Research has manifested that stimulation of vagus afferents can be influential in restructuring brain functions and consequently behavioral and affective disorders. Situations such as epilepsy (González et al., 2019), depression (C.-H. Liu et al., 2020), anxiety (Austelle et al., 2022), and some other disorders. The core of vagal afferent fibers is the solitary tract which is important for controlling the behavioral state, respiration, and blood pressure and in conveying information to higher brain structures

(Porges, 2003). As the VN is stimulated, it affects the neurotransmitter "acetylcholine" which is important for learning and memory as well as resulting in sooth and calmness.

2.2 The Polyvagal Theory by Stephen Porges

The Poly-vagal theory (PVT) was proposed by Stephen Porges in the 1990s due to considering two branches of the vagus nerve each of which facilitates a specific response system ordering through social communication (e.g., facial expression, vocalization, and listening), mobilization (e.g., fight-flight behaviors) and immobilization (e.g., feigning death, vasovagal syncope and behavioral shutdown) (Porges, 2003). Based on PVT, the ANS is hierarchically shaped due to the hierarchical emergence of the pathways (Kolacz & Porges, 2024).

The Vagus nerve links the heart and face. That's why one person's autonomic responses can be indicated through the face; in fact, Porges rediscovered the two vagal pathways existing in ANS which makes a heart-face link to facilitate social interactions (Dana, 2021). For a better understanding of the PVT, we should consider its main three principles:

Principle1. Autonomic Hierarchy: The PVT indicates that ANS, through the evolutionary changes, has been formed hierarchically among which there are two different vagal pathways (Kolacz & Porges, 2024). The hierarchy is respectively ventral vagal system (connection), responsible for the social engagement system and therefore frontal cortex, sympathetic nervous system (activation), not vagal but it works more efficiently while there is vagal suppression and is responsible for fight/flight responses and therefore limbic brain, and dorsal vagal system (shutdown), part of parasympathetic nervous system and responsible for freezing and immobility and therefore brain stem (Provenzani, 2020; Stephen & Eichhorn, 2017). These three systems reveal how our autonomic system reacts during social interaction and challenges (Dana, 2020).

The ventral vagus nerve (vVN) which is the most recent pathway through the evolution and development is the part of social engagement system (which can be indicated by respiratory sinus arrhythmia) and activates through a safe and secure interaction; in fact, it provides ease and calm and guarantees the health and wellbeing (Dana, 2021).

The ventral pathway originates from an area of the brain stem called the ventral vagal complex (VVC). This area of the brain stem encompasses the source nuclei of motor fibers which oversee striated muscles of the face and head. From a poly-vagal point of view, the ventral pathway is When the VVC system deactivates (through experiencing the challenge, stress, threat, etc.), and the ANS switches to the older systems which are in charge of defensive responses (Kolacz & Porges, 2024).

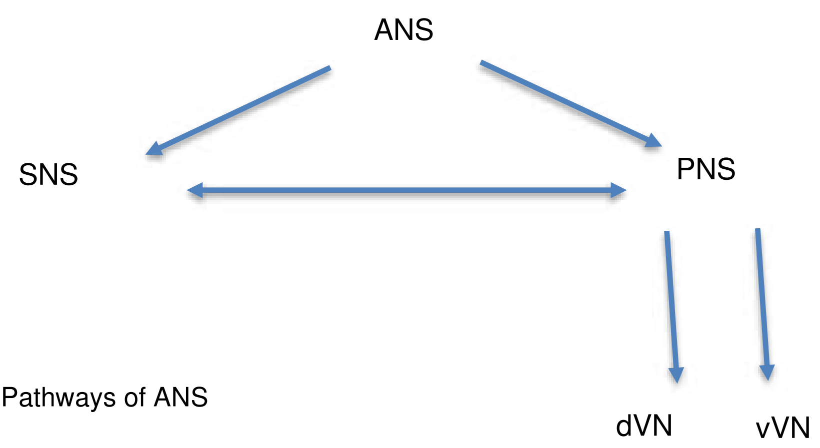
The sympathetic pathway is the system that activates when we face a threat or stressful situation and we decide to fight or flight (Dana, 2020). When the VVC is inhibited, the fight or flight mechanism can be experienced as hypervigilance or anxiety, or – in the case of the oldest system – shut down. Deactivation of the social engagement system leads to an increase in cardiac responses, which is an important factor for behavioral activation such as fight-or-flight responses, and is supported by the sympathetic nervous system (Kolacz & Porges, 2024). It seems when the situation gets harder and overwhelming, we move one step down through the hierarchy from the ventral vagal system to the sympathetic pathway; where there are more metabolic activities to serve the mobilization (Dana, 2021)

The dorsal vagal pathway which is a set of pathways originating from the dorsal motor nucleus of the VN (Kolacz & Porges, 2024) activates when the threat or stressful condition continues and there is no possible way of management (Dana, 2021) In this condition, the ANS declines one step to reach the dorsal vagus nerve (dVN) which comes along with a feeling of collapse, shutdown, and disconnection. In this state, the stressful situations do not matter anymore because the ANS began to shut down and immobilization mechanism (Dana, 2021; Porges, 2021, 2022).

Table 1. The three phylogenetic stages of the neural control of the heart proposed by the Polyvagal Theory (Porges, 2003)

Poly-genic stage	ANS components	behavioral functions	Lower motor neurons
III	Myelinated vagus	Social communication, self-soothing and calming, inhibit sympathetic-adrenal influences.	Nucleus ambiguus
II	Sympathetic Adrenal	Mobilization (active avoidance)	Spinal cord
I	Unmyelinated vagus	Immobilization (death feigning and passive avoidance)	Dorsal motor nucleus of the vagus

ANS as a whole system: The dorsal vagal system innervates the organs below the diaphragm including the digesting system. The sympathetic mechanisms circulate blood, monitor normal heart rhythms, regulate body temperature, respond to changes in posture, and supply energy for the body to get activated and get through the challenge. The ventral vagal system which innervates the organs above the diaphragm including the heart, head, and face initiates interaction and social engagement. The ventral vagus monitors the function of the autonomic nervous system, integrating the sympathetic and the dorsal pathways. Activation of the ventral pathway reassures a healthy homeostasis (Dana, 2020).



The Three Pathways of ANS

Principle 2. Neuroception: based on PVT, there is no need for conscious awareness but requires the neural evaluation of cues of danger and safety distinguished in the environment; We typically recognize the physiological change—interoception—even though we are typically unaware of the stimuli that cause neuroception (Porges, 2021, 2022). Neuroception illustrates how the nervous system (neuro) is aware (caption) of cues of danger and safety in the environment (Dana, 2020). Both defensive and prosocial behaviors can be influenced by how safe one feels. When individuals feel safe and secure in their environment, they are more likely to engage in prosocial behaviors, such as helping others, cooperating, and forming positive social connections. This is because feeling safe reduces the perceived threat in the environment, allowing individuals to focus on building and maintaining social relationships. On the other hand, when individuals feel threatened or unsafe, they are more likely to exhibit defensive behaviors, such as avoidance, aggression, or withdrawal. Feeling unsafe triggers the body's fight-or-flight response, leading individuals to prioritize self-protection over social engagement. Feeling safe fosters prosocial behaviors, while feeling threatened promotes defensive behaviors (Porges, 2003b).

Principle 3. Co-regulation: It refers to the physiological regulation of other people to find safety and survival (Dana, 2020). During social engagement, through neuroception, it is possible to co-regulate the vagal mode (Friedland-Kays & Dana, 2017). The facial and head muscles can effectively shorten or lengthen social distance by influencing both the expression and responsiveness of social cues. This is evident in actions such as head positioning, eye contact, vocal tones, and facial expressions. Through actions like sustaining eye contact, using intonation in speech, displaying responsive facial expressions, and adjusting middle ear muscles to better discern human voices in noisy environments, the neural control of these muscles can minimize social distance (Porges, 2003b). Conversely, a decrease in muscle tone in these regions causes drooping eyelids, a reduction in prosodic variation, a decrease in the expression of positive and responsive facial expressions, a compromise in the ability to distinguish background noise from human speech, and a possible impairment in the ability to perceive cues associated with social engagement from other people. As a result, the cerebral regulation of the striated muscles in the face and head performs two functions: it reduces psychological distance, which actively promotes social engagement, and it filters information that may affect how one interprets the engagement cues displayed by others (Porges, 1995, 2003a, 2003b, 2011, 2022). During social engagement, through neuroception, it is possible to co-regulate the vagal mode (Friedland-Kays & Dana, 2017).

2.2.1 Vagus Nerve Functions

The communication of the body's internal state is termed interoception and underlies what we later experience as feelings (Porges,2011). The VN, because of its role in interoceptive awareness, is able to sense the microbiota metabolites through its afferents, to transfer this gut information to the central nervous system where it is integrated into the central autonomic network, and then generate an adapted or inappropriate response (Bonaz et.al, 2018).

Neuro-Immune Axis: Neural mediation of myelinated vagus may affect Thymus and together with inhibition of the sympathetic nervous system results in a neuro-physiological balance that could enhance the immune procedures. Furthermore, mobilization strategies resulting in a withdrawal of vagal tone to the heart, the increased sympathetic tone, and the release of cortisol have been associated with suppressed immune function (Porges, 2003)

HPA Axis: The VN plays a role in the HPA axis, as well. Vagal afferents have an inhibitory effect on the HPA axis and decrease the release of cortisol. Research attests that a decrease in cardiac vagal tone is accompanied by an increase in cortisol levels. So, it should be a structure that takes place to enhance the metabolic procedures and encourage the mobilization response system. This entails raising sympathetic activity and activating the HPA axis while concurrently decreasing vagal tone via the myelinated vagus (Porgs, 2003).

Vasovagal Syncope: Sudden activation of the vagus nerve can cause a "vasovagal reflex," which is characterized by a sharp drop in blood pressure that affects heart rate. This reflex may be brought on by a stomach ailment, as well as by pain, fear, or abrupt stress. The vasovagal reflex is particularly prone to many people. Their heart rate and blood pressure fluctuate, which can lead to "vasovagal syncope," a condition in which they lose consciousness (Komisaruk & Frangos, 2022).

ANS: The sympathetic and parasympathetic nerve systems have mainly anatomical meanings. The parasympathetic nervous system primarily receives input from the vagus nerve. The nervus facialis, nervus glossopharyngeal, and nervus oculomotorius are the other three parasympathetic cranial nerves (Komisaruk & Frangos, 2022).

Brain-Gut Axis: There is a connection between the CNS and ENS via the VN which is called the brain-gut axis. It oversees regulating physiological homeostasis and establishes connections between peripheral intestinal processes such as immune activation, intestinal permeability, enteric reflex, and enteroendocrine signaling and the cognitive and affective regions of the brain. The brain, spinal cord, autonomic nervous system (ENS, SNS, PNS), and the hypothalamic-pituitary-adrenal (HPA) axis make up the brain-gut axis (Frankiensztajn et al., 2020)

2.2.2 Studying bio-behavioral Co-regulation through a polyvagal perspective

As extensively detailed in chapter 1, co-regulation is defined as a synchrony in behavioral, physiological, neural, and hormonal systems within and/or between individuals; it means the co-regulation can happen between those systems in one person or between both social partners (Abney, daSilva, et al., 2021). Arielle Schwartz refers to co-regulation as “how one person’s autonomic nervous system sensitively interacts with another person’s autonomic nervous system in a way that facilitates greater emotional balance and physical health” (Procyk, 2020). Co-regulation can take place trough voice, touch, and listening and can be measured by autonomic responses such as cardiac and hormonal reactions (Kolacz & Porges, 2024; Schwartz, 2018).

When it comes to the mother-infant dyad, it is worthwhile to note that there is a co-regulation not just in behaviors and affects but also in biological rhythms and physiological responses (Abney, daSilva, et al., 2021; Feldman, 2007a, 2007b).

Co-regulation Through the Voice: Infants typically express their needs and states through simple vocal cues such as cries and coos, which serve as signals to caregivers. Meanwhile, caregivers employ a variety of vocalizations, including speech and song, which not only reflect their states but also act as regulators of the infant's autonomic states. This reciprocal interaction forms a crucial part of early social development, fostering attachment and facilitating emotional regulation in infants. The caregiver's responsive vocalizations can help soothe and regulate the infant's physiological responses, contributing to the establishment of a secure attachment bond between caregiver and child (Cirelli et al., 2020). In general, Vocalizations, which convey internal states and influence the physiological states of listeners, enhance infant and caregiver co-regulation. Early in life, these emotional facets of vocalizations become a part of a person's social repertory, opening a route for interaction coordination (Kolacz & Porges, 2024).

Co-regulation Through the Touch: Different studies support the function of touch in affective co-regulation during early life development. Touch is one of the components that co-regulates the communication between infant and caregiver (Procyk, 2020). There is evidence indicating that touching during a stressful situation can reduce perceptive pressure (Carozza & Leong, 2021; Feldman, 2012a, 2012b). Also during the still-face procedure, infants smiled more, vocalized more, made greater eye contact, grimaced less, and objected less when it was accompanied by touch (Moreno et al., 2006).

Hormonal Co-regulation: Hormones have a major role in how the body develops and how it adapts to changes in its surroundings (Wang et al., 2022). Hormonal co-regulation refers to the synchronized hormonal activations between social partners during the interaction (Daneshnia et al., 2024; Timmons et al., 2015). Some hormones can be considered in parent-child co-regulation, including cortisol, oxytocin, and alpha-amylase (Bornstein and Esposito, 2023).

Oxytocin (OXT) is a peptide hormone (Carter et al., 2020) that helps the body integrate social and non-social sensory signals essential for survival (Quintana & Guastella, 2020) in addition to protecting against stress (Vittner et al., 2018) and autonomic regulation (Tsai & Kuo, 2024) which brings about more synchronization during social exchanges including mother-infant interaction (Moberg et al., 2020). It has been affirmed that the level of oxytocin during infancy can be regulated by parental touch; at the same time, this affectionate touch increases the mothers’ oxytocin level which shows a coregulation in hormones between mother and infant (Scatliffe et al., 2019).

Cortisol is a glucocorticoid produced from cholesterol and discharged into the bloodstream by the adrenal glands (Bozovic et al., 2013). Cortisol is known as a biomarker of stress or a stress hormone (Pulopulos et al., 2020; Sheibani et al., 2021) and is increased in infants as a response to stressful situations including still-face procedures (Puhakka & Peltola, 2020). During a stressful situation, the HPA axis's activity increases. There is support for the HPA axis (hypothalamic–pituitary–adrenal axis) activation during the still-face procedure (Provenzi et.al, 2016). The disrupted interaction of mother and infant impacts this axis and consequently the salivary cortisol reactivity during the SFP (Ginnell et. al, 2022). The parents must adopt a sensitive and responsive approach toward their infant's needs to guarantee a normal development of stress regulation in the infant (Broeks et al., 2021; Suchecki, 2018).

Autonomic Co-regulation: in human beings, mothers help their infants not only regarding survival issues but also by regulating the physiological responses (Abney, daSilva, et al., 2021; Feldman, 2012a, 2012b; Feldman & Eidelman, 2007; Feldman et al., 2011). Due to PVT (Porges, 2003a, 2003b, 2011, 2021) vagus nerve is responsible for cardiac responses during the social stress situation through eye contact, smiling, and vocalizing. The ventral fibers which are involved in the social engagement system improve the visceral responses and an independent behavioral system (Porges, 2022).

While there is no stressful or demanding situation, a vagal tone establishes homeostasis. The VN acts as a brake (vagal brake) to reduce the cardiac responses. In contrast, during a demanding situation, the vagal brake is released which brings about vagal suppression and an increase in cardiac responses (Porges, 1995, 2003a, 2003b, 2011, 2021). The indicator of vagal tone is respiratory sinus arrhythmia (RSA) which refers to the heart rate variability (HRV) within a whole breathing cycle (Abney, daSilva, et al., 2021). Higher RSA is accompanied by a greater tendency to suppress vagal tone to regulate the stressful situation in a better way (Porter et al., 2024).

Positive or Negative RSA Synchrony: It is noteworthy to consider that the RSA synchrony can be positive or negative. Positive synchrony relates to the conditions in which the RSA in both mother and infant change in the same way while negative synchrony points to the conditions in which the RSA in mother and infant shifts in the opposite way (Abney, Lewis, et al., 2021).

Vagal Responses to Stress: there are two different responses that vagal tone can show; adaptive and maladaptive. The adaptive response refers to vagal suppression during stressful conditions while the maladaptive response defines the vagal activation in the stressful situation (Abney, daSilva, et al., 2021). It can be measured through RSA suppression or reactivity (Porter et al., 2024) and cortisol (Haley, 2011; Provenzi et al., 2016). The infants with dropped RSA during social stress (SF) are called suppressors and the ones with RSA reactivity are called non-suppressors (Montirosso et al., 2014; Provenzi et al., 2015) one reason for vagal activation or suppression among infants can be parental conflict (Busuito & Moore, 2017).

2.3 Within and Between Individual Co-regulation During the Still-Face Paradigm

Affects and behaviors of the caregiver can influence the affect and behavior of the infant (Tronick & Cohn, 1989). The positive affect and behavior of the mother are not just mirrored by the infant but also facilitate the infant's positive affect and behavior (Beebe et al., 2010) in other words they form a co-regulation which signifies that the mother's affect affects the child's and vice versa (Somers et al., 2022).

In a study it was exhibited that the infants experience more negative affects during the SF phase, indicating that an unresponsive face is a potential stress for the infants compared to the free-play and reunion phase. They also showed that infants' affect was more negative during the reunion phase compared to the base line (free play), proposing that infants are still tending to recover from the stress of the SF phase during the reunion. During the SF phase, infants use self-regulatory behaviors to reduce stress reduction and self-soothing. One more factor affecting the co-regulation is mutual gaze which makes the infant feel more positive affects (MacLean et al., 2014).

In addition, there is proof that the mother and infant are in physiological co-regulation because of their dyadic synchronicity. It is shown that mother-infant behavioral mutuality was related to higher levels of oxytocin in both mothers and infants as well as hormonal concordance in the dyad (Gordon et al., 2010). Consistent with this result, Morre and Calkins (2011) indicate that when there is a stronger synchrony between the mother and infant during the SFP, infants show better emotion regulation by a higher vagal suppression in the SF phase (Moore & Calkins, 2004).

In their study, Abney and colleagues (2021) examined the possibility that, in the presence of social stressors, physiological synchrony between mothers and infants helps in the regulation of infants' emotions. Consistent with previous studies, they perceived that during the SF phase, there is an increase in infant distress and a decrease during the reunion phase. Furthermore, they indicated that if they consider the physiological synchrony, they discovered that when there was a positive co-regulation in the dyad, the infant's emotion regulation improved but no improvement during negative co-regulation (Abney, daSilva, et al., 2021).

Provenzi and colleagues (2015) in a study with 4-month-old infants explored vagal suppression during the SFP. They indicated that suppressors show a better reparation during the free-play and reunion phase compared to the non-suppressors indicating the role of individual differences in RSA activation on stress regulation among young infants (Provenzi et al., 2015).

Busuito and Moore (2017) in an FFSF study with 6-month-old infants discovered that children who experienced more parental conflicts showed less vagal activity and less flexibility during the reunion phase indicating that parental conflict can result in less adaptive response during social stress and less effective recovery after a social stress (Busuito & Moore, 2017). As the development of the physiological system of the infant is co-regulated through the parent-infant interaction; so, seems predictable that parent conflict can affect negatively on adaptive physiological regulation of the infant.

Montirosso and colleagues (2014) in an SF study with four-month-old infants have shown that infants have a capacity for biological memory. They repeated an SF experiment after two weeks with the same SF groups. They observed that while non-suppressors showed no changes in RSA, suppressors showed no suppression any more. It is interesting to note that there was no change in behavioral responses. Suggesting that infants have a biological memory of social stress due to their RSA reactivity (Montirosso et al., 2014).

Haley (2011) in an SF experiment tended to investigate the cortisol changes among infants during the SF procedure. For this aim, the salivary cortisol was measured at the beginning, after 20 and 30 minutes; proposing an increase in the HPA axis and cortisol during the time (Haley, 2011).

Provenzi and colleagues (2016) in a meta-analysis investigated the HPA reactivity during the SF procedure. They discovered that a 3-episode (single exposure) SF can be a different stressful situation compared to a 5-episode (double exposure) procedure for young infants. To find a significant HPA reactivity, a 5-episode SF procedure is needed while for investigating the behavioral response, a 3-episode procedure can be a reliable measure (Provenzi et al., 2016). The 5-episode SF procedure (A-B-A-B-A) was applied for the first time by Haley and Stansbury (2003) to discover the infant's HPA reactivity during maternal unresponsiveness (Haley & Stansbury, 2003).

2.4 Infrared Thermal Imaging as a potential tool to study co-regulation processes.

2.4.1 The thermal response

As previously mentioned, the autonomic nervous system (ANS) is in charge of involuntary, mostly subconscious processes such as heart rate, digestion, respiratory rate, perspiration, and cutaneous temperature (Cardone & Merla, 2017) that regulate physiology by both up-regulation (arousing) and down-regulation (soothing) processes. Blood pressure and cardiac activity are the important elements through which it is possible to explore the ANS functions (Bornstein & Esposito, 2023). Blood flow, which is regulated by vascular processes transfers the heat of visceral parts to the skin. While a local drop-in skin heat is linked to Vasoconstriction, an increase in skin temperature is associated with vasodilation (Nazzari et al., 2024). Vasoconstriction is the condition in which the vessels narrow dawn while vasodilation is the opposite (IJzerman et al., 2012).

Different measurements are available and accessible to study the autonomic and physiological coregulation processes such as respiratory sinus arrhythmia (Skoranski et al., 2017) and heart rate variability (Porter et al., 2022) which are electrocardiographic measures, as well as skin conductance (Ioannou et al., 2021), and peripheral vascular tone (Iani et al., 2004). While these methods require the use of sensors (Cardone & Merla, 2017), Infrared thermal imaging (ITI) is a non-invasive, contactless, and ecological technique to reach temperature variations (Abbas et al., 2012; Cardone & Merla, 2017; Ioannou et al., 2013; Nazzari et al., 2024). ITI methods make it possible to investigate changes in the ANS activity and responses through changes in skin temperature. Cutaneous temperature is a good measurement to explore the ANS (Cardone & Merla, 2017).

Noteworthy, skin temperature serves as a significant factor in interpersonal connections. Essentially, individuals who experience exclusion from social interactions may indeed exhibit colder fingers, illustrating a physical manifestation of social exclusion while secure interactions are linked to improved cardiac output and healthier ANS activity, loneliness can cause physiological changes like increased total peripheral resistance, which may worsen cardiovascular health. Perceptions of a threat or fear can lead to vasoconstriction (IJzerman et al., 2012). Ijzerman and colleagues (2012) discovered that people who are excluded from social groups have a decrease in fingertip temperature.

Warming up the fingertips artificially by holding a cup of tea can down-regulate the negative affect happening after social suffering. What we refer to as social thermoregulation emerged in 2008 (IJzerman et al., 2018) as Williams and Bargh (2008) indicated that when people hold something warm in their hand, the evaluate others more sociable and behave in a more friendly way (Williams & Bargh, 2008). In another study, IJzerman and colleagues (2018) showed that while people hold something warm in their hands, they think about loved ones more probably if they had a positive experience in their relationships (compared to a negative experience). While temperature affects cognition accessibility and social interaction (IJzerman et al., 2018) the opposite way is also true. It means that social interaction can affect the cutaneous thermal states.

Infrared thermography seems to be a proper and secure technique to investigate behavioral and autonomic reactions, particularly among infants (Nakanishi & Imai-Matsumura, 2008; Nazzari et al., 2024). Clarck and Stothers (1980) employed thermal imaging to observe the skin temperature of newborns and it was the initiation of thermal imaging utilization in infancy but with medical intention (Abbas et al., 2012; Clark & Stothers, 1980). While it is highly employed in biomedical fields, the application in developmental science is still low and it has a high capacity to be used particularly during the communication between caregivers and infants (Nazzari et al., 2024).

Furthermore, the evidence has shown that emotions are linked to temperature changes; for instance, anger is related to higher temperatures while sadness shows a lower temperature (Ekman et al., 1983). Pleasant emotions are related to an increase in facial skin blood flow of eyelids while unpleasant emotions can indicate a decrease in nasal tip. One possible mechanism that accounts for it can be the sympathetic vasoconstriction and parasympathetic vasodilation in the face. However, as both sympathetic and parasympathetic nerves innervate the facial vessels, explaining the vasomotion of facial skin is challenging and needs more investigation (Izumi, 1995; Miyaji et al., 2019). The evidence only shows that the facial blood flows, in particular the nose and eyelid, are regulated through autonomic vasomotion (Kashima & Hayashi, 2011).

2.4.2 Facial thermal affective response during social interaction

The human face holds particular significance as it serves as a primary interface for social communication and interaction. This makes it an ideal area for studying using thermal infrared (IR) imaging. Through facial thermal analysis, different autonomic responses can potentially be estimated (Cardone & Merla, 2017); such as heart rate and breathing rate (Hu et al., 2018), breathing rate (Pereira et al., 2018), respiratory sinus arrhythmia (Lewis et al., 2011), and cutaneous blood perfusion rate (Cardone & Merla, 2017).

Thermal imaging is considered a proper technique in the neuroscience and psychophysiology field particularly to explore ANS as it is possible to measure different participants simultaneously without contact with the device (Cardone & Merla, 2017). For these reasons, as well as keeping and ecological context of interaction, thermal imaging is suitable for studying co-regulation during interaction, particularly in mother-infant dyads. As applying sensors is a barrier to discovering the autonomic responses of young children, a contact-free technique such as thermal imaging is very helpful.

In response to stressful or threatening situations, the facial skin temperature drops in some particular regions such as the maxillary, nasal tip, and cheeks areas, whereas it increases in periorbital and supraorbital areas (Aureli et al., 2015); among which the nasal tip is the most reliable region (Ioannou et al., 2013). How ever, it seems that periorbital and forehead are stress-insensitive in adults (Engert et al., 2014).

While evidence shows that variation in temperature of the nasal tip and maxillary areas may reflect the sympathetic activation during the stress experience (Ebisch et al., 2012) there is no consensus about how it affects the facial cutaneous temperature.

Complex interactions between skin tissue, internal tissue, the local vasculature, and metabolic activity are involved in variations in cutaneous heat. Both the sympathetic and parasympathetic nervous systems play key roles in regulating these variations throughout the body. Essentially, these systems help the body respond to changes in temperature by either conserving or dissipating heat through processes like vasodilation and vasoconstriction. Given the polyvagal theory, this balance is an important element of the social engagement system (Aureli et al., 2015; Porges, 2003b).

2.4.3 Facial thermal affective response during parent-infant interaction

Thermal infrared imaging is an effective tool for examining the autonomic responses of infants and caregivers during live interaction. As previously noted, various techniques are available to explore parent-infant co-regulation. However, most devices necessitate attaching sensors and electrodes to the infant's body. In contrast, thermal imaging is a safe and efficient alternative that overcomes this challenge. In addition, unlike other methods, thermal imaging excels in its ability to capture a range of physiological changes by monitoring the heat patterns on the face (Ebisch et al., 2012).

As an illustration, Ebisch and colleagues (2012) explore dyadic coregulation using thermal imaging. Based on thermal outputs, they asserted that thermal coregulation occurs between the mother and her offspring. Specifically, a child's distress can evoke the mother's arousal system. Notably, the variations in the mother's facial cutaneous temperature mirrored those of their children during the experiment. This is a sign of emotional synchrony between mother and child.

In line with this, several other studies have investigated dyadic autonomic coregulation through thermal imaging. These studies consistently exhibited a clear synchrony between the facial temperature of the mother and the child (Aureli et al., 2015; Aureli et al., 2022; Manini et al., 2013).

The majority of research confirms a decrease in particular facial temperatures such as the maxillary, nasal tip, and cheeks areas, alongside an increase in temperature of periorbital and supraorbital areas during stressful conditions (Ebisch et al., 2012; Ioannou et al., 2013; Manini et al., 2013). However, there is some evidence that exhibits varied results (Aureli et al., 2015).

There is limited knowledge about measuring skin temperature as a physiological response to explore the infant's ANS and emotions. But the results are noteworthy. For instance, considering the drop in forehead temperature of the infant, we can understand their reaction is different to the absence and presence of their mother compared to a stranger. In other words, when the infant experiences a stressful moment, the facial skin temperature decreases (Mizukami et al., 1990).

In a similar study, Ioannou and colleagues (2021) achieved the opposite results. They observed that the skin temperature of the maxillary area, the nose, and the forehead in 2-month-old infants is higher when they interact with strangers compared to their mothers. But in general, thermal investigation shows that the infant's thermal response is different from the mother and stranger.

Nakanishi and Matsumura (2008) indicated a decrease in facial skin temperature occurred when the infants were laughing; The decrease was in the nose, cheeks, and forehead with the nose having the most profound temperature drop of as much as 2.0 °C in 2 min and this result was related to the infants 2 to 10 months of age. This indicates that joyful emotion could be associated with a drop in facial skin temperature which has been considered just as an indicator of unpleasant emotions such as fear or threat. So, the thermal decrease is related to more than one affective state for the infants.

The infants of 3 to 4 months old were observed during the interaction through the SFP. They explored the thermal variation of facial cutaneous using the ITI technique based on nasal tips. They intended to understand the autonomic responses to social stress at a thermal level and found a decrease in facial skin temperature which indicates the sympathetic activation of ANS over the parasympathetic. It reflects the infant's autonomic reaction to the still-face presentation (Aureli et al., 2015). As there was no significant increase in negative affects during the SF phase, in line with the behavioral pattern, no significant decrease in facial skin temperature was observed during the SF.

It is expected that while facing a stressful situation (like the SF), the sympathetic system activates while the parasympathetic deactivates, but Aureli and colleagues (2015) showed the opposite. They have exhibited that the nasal tip temperature had an increase from free play to SF episode which can be a signal to parasympathetic activation. This contrary is an important signal to express the necessity for more research.

Chapter 3. Technoference: an emerging challenge to parent-infant co-regulation processes

3.1 Technoference: definitions of the phenomenon

Today, lifestyles have changed with the penetration of technology in almost all aspects of our lives (Lederer et al., 2022; Tharner et al., 2022). With the integration of technology into our lives, we can discern between the beneficial aspects of technology which enhance productivity and life facilitation, and the dark side which is detrimental and intrusive negatively impacting human well-being (Golds et al., 2024; Sundqvist et al., 2020).

The productive side can be observed through the significant advantages of increasing leisure time (McDaniel et al., 2021), academic learning (Wang et al., 2023), education (Ghazala & Elshall, 2021), health issues (Lell & Kachelrieß, 2020), medical achievement (Zhou et al., 2021), cancer treatment (Shiwlani et al., 2023) and so on. Moreover, during the COVID-19 pandemic gadgets were consumed a lot to access informative content and new data about the virus as well as communication (Tejedor et al., 2020).

On the other hand, the dark side comes up. Smartphones and gadgets cause the students' academic achievement to decrease and academic procrastination to increase (Türel & Dokumacı, 2022), affect relationships adversely (Türel & Dokumacı, 2022), lessen the quality of parenting (McDaniel & Coyne, 2016), learning deficit (Morris et al., 2022) and other harmful effects that will be discussed in the following sections. Many people act as if their smartphone is part of the self; in fact, they make a strong connection to their device. The phenomenon which mostly refers to as self-extended (Belk, 2016; Belk, 2013).

Following the prevalence of technology consumption, a new phenomenon known as "technoference" emerged (McDaniel & Bruess, 2013); the combination of interference and technology (McDaniel & Coyne, 2016). Technoference refers to the interference of technology in modern life (Q. Liu et al., 2020; Tharner et al., 2022), in particular within close relationships such as family members and romantic partners (Amaliyah & Agustina, 2023). Technoference manifestations vary from checking the smartphone during face-to-face interaction to choosing virtual communication over the face-to-face form.

3.2 The impacts of technoference on social interaction

The technoference which is specifically related to phone usage is called “phubbing” (Lapierre & Zhao, 2022); a combination of phone and snubbing (McDaniel & Drouin, 2019). The origin of the term “phubbing” is Australia and self-phubbing refers to the act of being absorbed in one’s smartphone and ignoring the partner. The person who is actively phubbing others is called a “phubber”. Conversely, partner-phubbing refers to the state of feeling ignored and neglected by a partner who is obsessed with the smartphone during the conversation. The daily use of technological devices makes phubbing behaviors increase which can lead to more conflict and less satisfaction (Mahmud et al., 2024). Phubbing behavior makes the phubbed person feel ignored. It seems that looking at the smartphone to check the messages or the social media is more important and more enjoyable than interacting with them. This perception makes the phubbed person more dissatisfied (Mahmud et al., 2024). On the other hand, evidence shows that fear of missing out and loneliness as well as boredom are two strong predictors of problematic smartphone usage and phubbing behaviors (Al-Saggaf & O'Donnell, 2019; Q. Liu et al., 2020). While shared technology use can increase the amount of leisure time and shared-time satisfaction (McDaniel et al., 2021) it is still lowering the quality of shared time as a result of a reduction in eye contact and active conversations (McDaniel & Wesselmann, 2021).

Technoference in close relationships such as family members or romantic partners demonstrates poor quality and dissatisfaction (Amaliyah & Agustina, 2023). However, we need to take into consideration that only using the device does not lead to intruding interaction and other negative results. Technoference has the potential to form conflict, poor quality of relationship, less satisfaction, and other negative outcomes when it is associated with distraction or phubbing (McDaniel & Coyne, 2016). As a clarification, mobile phone usage during communication brings about repeated disconnections between the people who interact as well as less engagement after the rematching again (Reed et al., 2017).

When loneliness is observed through the lenses of “expectation violation theory” demonstrates the social expectations which are not fulfilled by the social partner. According to this theory, expectations are formed due to past experiences as well as personal desires which if not met, lead to feeling disconnected and loneliness (van Essen, 2024). For instance, when the phubber ignores the partner, it results in a gap between the expectation (of the partner being emotionally available) and the experience (Roberts & David, 2023).

It is common to ignore people while using smartphones. This made them feel dissatisfied and excluded. It is interesting to note that in a study, individuals who were phubbed felt more excluded and dissatisfaction regardless of the reason; but when participants knew that the phone distraction was because of an emergency reason, they felt less excluded. It shows that people consider the attributional information while being ignored. So if there is a proper explanation for using the smartphone, maybe the negative feelings can be alleviated (McDaniel & Wesselmann, 2021).

It seems that being snubbed by the smartphone can lead to an experience of social exclusion. Based on survival functioning, social exclusion is considered a social threat. The same as physical threat and physical pain, being rejected causes “social pain” (broken heart, broken bones). The neurological pain system detects both physical and social pain as a threat (Eisenberger & Lieberman, 2004). Technoference or phubbing due to the disruption in conversation and eye contact indicates the signals of exclusionary. So we can trace the pain system activation (McDaniel & Wesselmann, 2021). Evidence demonstrates that when people report more technoference, they report an increase in negative mood. They also evaluated their interactions less positive and more negative (McDaniel & Drouin, 2019).

3.3 The impact of technoference on infant development

Childhood is a sensitive period to enhances or damage the child’s development and health (Konrad, Berger-Hanke, et al., 2021). Child development refers to different aspects including gross and fine motor, language, social, and cognitive domains. Furthermore, child health is characterized by biological health and psychological health. Parental technoference can influence both realms of child health and child development (Mackay et al., 2022) by impacting child-parent interaction (McDaniel &

Drouin, 2019). Besides, parent media usage is strongly associated with a child's screen usage from infancy to 8 years of age (Konrad, Berger-Hanke, et al., 2021). It seems parents are considered models to replicate the technology use behaviors (Anderson & Hanson, 2017; Sundqvist et al., 2020)

Recent research indicates that technoference is growing in families (Anderson & Hanson, 2017). Due to the interruption in the mother-infant interpersonal relationship, technoference carries significant implications for infant development (McDaniel & Coyne, 2016; Nguyen, 2024). Not just smartphones but any type of screen usage can affect parent-child interaction; Anderson and colleagues (2017) Indicated that even coviewing television can indirectly influence on reduction of child-parent communication (Anderson & Hanson, 2017).

Parents use their mobile devices while playing with their children, going to the restaurant, feeding the infant, and other situations (Gutierrez & Ventura, 2021). Mothers report smartphone usage while caring for their infants in different conditions (Corkin et al., 2021).

Parent distraction has a negative effect also on parenting quality (McDaniel & Coyne, 2016) including less verbal and non-verbal communication as well as responding more harshly (Porter et al., 2024). By technoference affecting the parenting style, parents who are absorbed in smartphones skip the critical moments for attachment and bonding with their children which can adversely impact the child's socio-emotional development (Zayia et al., 2021).

Evidence indicates that technoference is associated with infants' language development as well as socio-emotional development (Beamish et al., 2019). Nguyen (2024) demonstrated no association between parental phone text and child learning in the lab whereas he revealed an effect of parental screen time in real life on the language vocabulary of 16-month-old children (Nguyen, 2024). This contradiction may arise from the important indirect effects of technoference on dyadic interaction rather than those direct ones (Anderson & Hanson, 2017).

Corkin and colleagues (2021) conducted research illustrating that higher parental technoference is associated with lower infant vocabulary (Corkin et al., 2021).

Furthermore, this distraction can lead to child externalized and internalized behaviors such as hyperactivity, aggression, anxiety, and depression.

Additionally, phone calls on mobile devices seem to influence children's learning. In an investigation, mothers were asked to teach two new words to their infants. The results suggest that infants learn more when there is no interruption from mobile devices compared to the existence of technoference. There was no difference in children's performance even when mothers provided an explanation regarding their phone calls (Reed et al., 2017).

In another study, scholars sought to demonstrate the effect of text interruption during a teaching episode on subsequent infant learning. Through the study, parents performed three specific actions for their infants four times. Text interruptions took place either before or between demonstrations. There were also two baseline control groups, one of which infants were exposed to no demonstration and the other no interruption. The parent's still face was affirmed during the text interruptions. However, the infants' performance was higher than the base line group with no demonstration indication learning can occur despite interruption. Higher reported maternal reliance on mobile devices was linked to poorer infants' imitation performance. Conversely, parents who found multitasking easier had infants with higher performance. These outcomes reveal that newborns can learn with limited exposure to technoference, and that learning in impacted by individual differences in media usage patterns (Konrad, Berger-Hanke, et al., 2021).

The impact of technoference is not confined solely to infancy but also extends into childhood and adolescence. In this regard, Sundqvist and colleagues (2020) have found how parental self-report of technoference is linked to the behaviors of 4- to 5-year-old children. In this study, parents reported an association between technoference and heightened externalized and internalized behaviors of children. Parents also reported experience of technoference not just due to their own DM use but also due to their child's use (Sundqvist et al., 2020).

Another research has examined how adolescents' perception of their own and their parents' conference is linked to various adolescent positive and negative behaviors including anxiety, depression, cyberbullying, prosocial behaviors, and civic engagement. The results revealed that adolescent perceptions of parental technoference correlated with heightened levels of anxiety, depression, cyberbullying, and prosocial behaviors with parental warmth acting as a mediator in these associations. Noteworthy, adolescent technoference was linked to higher levels of cyberbullying, anxiety, and depression, as well as lower rates of prosocial behavior and civic participation. However, it was not related to perceived parental warmth (Stockdale et al., 2020).

3.4 Technoference: implications for parent-infant relationship and co-regulation processes

Numerous studies emphasize the importance of fine coregulation between parent and child as the newborn achieves self-regulation through passing coregulation with parents (Lobo & Lunkenheimer, 2020). Considering the importance of the bidirectional relationship between mother and infant states including behaviors, affective states, and biological rhythms (Feldman, 2007b), any intrusive factor can have the potential to harm the coregulation (Gutierrez & Ventura, 2021). For instance, using more technology devices is reported to be associated with more behavioral and emotional problems (Q. Liu et al., 2020); in other words, mothers exposing their children to technoference describe their child as more difficult and problematic (McDaniel & Drouin, 2019; McDaniel & Radesky, 2018).

It aligns with other research showing that maternal technoference during feeding and caring for the infant significantly predicts the infant's negative affectivity and lower attachment quality (Gutierrez & Ventura, 2021). As an illustration, mothers confirm the difficulty of keeping the attention in balance between the child and mobile device and they should divide their attention between them. This divided attention can interfere with the coregulation process through dyadic interaction (Kushlev & Dunn, 2019).

The literature suggests that while studying technoference and its impacts on mother-infant interaction, additional risk factors should be taken into consideration. In a study, Gold and colleagues (2024) used cluster analysis to find out if there are specific risk and protective factors associated with problematic smartphone usage and mother-infant responsiveness. They studied 450 participants and ultimately, the analysis ended up with three distinct clusters: infants at risk (38%), mothers at risk (15.1%), and low risk (46.9%) group.

“Infants at risk” describes a high level of maternal technoference and low responsiveness. Mothers of infants at risk indicated a medium level of depression, stress, and anxiety symptoms alongside with medium level of wellbeing and perceived social support. They also defined their infants with higher levels of socio-emotional development concern. In the second cluster, “mothers at risk” mothers revealed lower levels of infant development concerns but high depression, anxiety, and stress as well as lower wellbeing. Lower concerns in this cluster may be attributed to maternal inattentiveness resulting from being absorbed in smartphone use. In the last cluster, “low risk”, a lower level of smartphone use was reported by mothers. They also announced lower levels of depression and anxiety alongside higher levels of well-being (Golds et al., 2024). Persistently, it has been found that a longer duration of maternal smartphone use is associated with being less sensitive and less responsive to infants. This issue disrupts mother-infant interactions (Tharner et al., 2022).

Align with it, Liu and colleagues (2020), proposing a “risky family model”, identified parental technoference as a predictor of adolescent smartphone addiction. They highlighted the mediating role of loneliness signifying that parental technoference induces feelings of loneliness in adolescents within the family context. This makes them more vulnerable to smartphone addiction (Q. Liu et al., 2020).

There is evidence indicating that the maternal technoference impacts behavioral and physiological responses. In a study, mother-infant dyads were assigned in three different conditions to interact with their infant. The first condition was disrupted by technoference, the second condition was disrupted by another adult, and the third condition was interrupted undisrupted. The technoference condition indicated the highest heart rate and negative effect in infants compared to other conditions. This physiological and behavioral reactivity posits that technoference is a stressful condition for infants (Gutierrez & Ventura, 2021).

Furthermore, studies suggest that maternal technoference results in a lower maternal sensitivity. This disruption is related to the negative affect and regulatory capacity of the infant, but the magnitude of this association is related to the infant’s age. It signifies the smaller infants need more responsiveness and better coregulation (Davis et al., 2022).

3.5 Adapting the Still Face paradigm to study technoference: available studies

Studies indicate parents frequently display a neutral face when silently reading content on their cellphone; The lack of social expression when engaging with digital screens can be perceived by young children as a still face (Konrad, Berger-Hanke, et al., 2021).

With the expansion of smartphone usage, a modified version of the still-face experiment was created which has been applied in many studies. The difference is related just to the still-face episode. Thus, instead of looking at the child with a masked face, the mother is engaged in working with the smartphone; mostly, filling out a survey (Konrad, Hillmann, et al., 2021; Stockdale et al., 2020).

In a study, scholars used a technoference-based version of the still face. They indicated a decrease in positive affect and an increase in negative affect from free play to technoference with no total recovery during the reunion episode. Infants showed more engagement during the free play compared to the reunion. In addition, infants displayed social bids and room exploration during technoference more than a reunion. The results were also indicative of the association between frequent maternal smartphone usage with less room exploration and positive affect during the technoference as well as less recovery. It suggests that phubbing infants may influence their ability to emotional recovery (Myruski et al., 2018).

In line with Myruski and colleagues (2018), Stockdale and colleagues (2020) conducted a study through which parent-infant dyads were engaging in technoference-based SF in a home-planned visit. They discovered a still-face effect across the three episodes of the experiment. In this research, infant behavior was investigated through the presence or absence of positive or negative vocalization.

Results of this research showed a drop in positive affect from free play to technoference and less positive vocalization in reunion compared to free play. Conversely, negative affect increased significantly during the technoference compared to free play and did not return to the base line during the reunion.

Noteworthy, older infants (older than 9 months) demonstrated more negative affect across all three phases compared to younger infants. They explained this variation regarding the age of children through the higher motor ability of the older children. So, the conditions of the SF are more restrictive for them compared to the younger infants who are used to the sitting conditions (Stockdale et al., 2020). Besides, some other studies are confirming this explanation regarding the importance of age (Yato et al., 2008).

In another study, scholars demonstrated the variations of mother-infant interaction through different phases of technoference-based SF as well as an analog medium in children aged 20 to 22 months. Through technoference, mothers had to fill in a form with a smartphone whereas in the analog group, mothers were supposed to fill in the same form but through pen and paper. The result showed that maternal responsiveness decreased during the interruption episode for both groups. In addition, children’s positive affect decreased in both groups and texting was not more interruptive than writing on paper. It posits the fact that the decrease in the quality of interrupting is not related to digital media but is related to any kind of interruption (Konrad, Hillmann, et al., 2021).

In another smartphone-adapted SF study, researchers explored interactive behavior and brain-to-behavior association. They measured frontal alpha asymmetry (FAA) through EEG hyperscanning. The outputs indicated an obvious still-face effect through the technoference episode. In this exploration, they clarified that higher negative affect in infants is associated with more leftward FAA during technoference (Swider-Cios et al., 2024). It seems that during the technoference, the mother-child neural synchrony decreases (Zivan et al., 2022).

In addition to brain-to-behavior association, developmental neuroscientists are interested in physiological responses due to behavioral expressions, as well. Porter and colleagues (2024) conducted an investigation to illustrate toddlers’ physiological responses to the parental technoference-adapted version of still-face. They indicated that toddlers, during technoference, showed a decrease in positive affect while they did not show any increase in negative affect, compared to the initial phase as well as recovery. The behavioral expressions were also reflected in cardiac responses by an increase in heart rate (HR) and a decrease in RSA (vagal withdrawal). However, some toddlers were indicating vagal tone increase to the technoference. They also posited that greater vagal suppression was linked to decreased and heightened negative affect during parental phone distraction (Porter et al., 2024).

A review of the available literature reveals varied results regarding infants' behavioral and autonomic responses to still-face and technoference during the mother-infant interaction. Consequently, further research is necessary to explore this field in fine detail and address the gaps in existing knowledge.

Chapter 4. The ARIEL Study

4.1 Introduction

The Autonomic Regulatory Interaction in Early Life (ARIEL) study, led by Dr. Sarah Nazzari, is an ongoing project conducted at the Developmental Psychobiology (dpb) laboratory within the Department of Brain and Behavioral Sciences of the University of Pavia and of the IRCCS Mondino Foundation.

The research began by exploring how infants and their caregiver co-regulate their autonomic nervous system, particularly through thermal cutaneous mechanism during face-to-face interactive exchanges, and how this physiological coregulation is influenced by technoference, distraction occurs by smartphone absorption (Provenzi, 2023).

In this project, we assessed both behavioral and thermal responses within the mother-infant dyads through an adapted version of the FFSF paradigm. In ARIEL, we tended to extend beyond the three typical episodes and add two more, including the initial episode describing free play (FP) which serves as a baseline for dyadic interactive signals. The initial phase was always followed by a varied still face/distraction episode, which could be either technoference (TF) or paper-ference (PF) after each of which a reunion (R) occurred. Dyads were randomly assigned to two groups in one of which the initial distraction was technoference, and in the other the initial distraction was paper-ference.

4.2 Aims and Hypothesis

In this project, we aim to investigate the mechanism of face thermal coregulation in mother-infant dyads during an adapted version of still face, and how this mechanism impacts on behavioral responses of mother-infant dyads. In this way, we can divide our aims into three categories, exploring thermal responses, behavioral expressions, and co-regulation processes.

Our first objective is to quantify infant and maternal thermal variations during the two stressful conditions and two recovery episodes, comparing them to baseline temperatures. Our second objective is to examine behavioral responses in correlation with facial temperature in both infants and mothers across the five episodes. Finally, we investigate the behavioral and thermal coregulation patterns within mother-infant dyads during these different episodes.

Hypothesis 1. Infants show significant thermal changes during technoference and paper-ference.

Hypothesis 2. Infants show significant behavioral changes during technoference and paper-ference.

Hypothesis 3. Mothers show significant thermal changes during technoference and paper-ference.

Hypothesis 4. Mothers show significant behavioral changes during technoference and paper-ference.

Hypothesis 5. There is a dyadic thermal coregulation in the initial phase and recovery episodes.

Hypothesis 6. The thermal coregulation is disrupted during technoference and paper-ference episodes.

4.3 Methods

4.3.1 Participants

Mothers and their infants were recruited through the collaboration with IRCCS San Matteo, a leading research hospital located in Pavia, Italy. Eligibility criteria included parental age of at least 18 years old with proficiency in the Italian language and infant gestational age at birth of at least 37 weeks with no major pre-or-post natal complications. In the present thesis, 37 mother-infant dyads were included. Details of the study samples are provided below. To estimate the required sample size for the ARIEL study within a single participant group, an a priori power analysis was performed. The objective of the analysis was to provide sufficient statistical power to detect significant changes over time. For this aim, G*Power 3.1.9.7 software was used. A two-tailed test was chosen to assess the differences within the group, with an effect size of 0.5, which corresponds to a moderate effect. A significance level (α) of 0.05

and a desired statistical power (1 - β) of 0.80 were selected. This power level means an 80% probability of detecting true effects, if they exist, and thus minimizes the risk of type II errors. The analysis revealed that a sample size of 34 participants was necessary to achieve the desired statistical power.

4.3.2 Procedure

4.3.2.1 Pre-session coordination

Participant preparation and scheduling:

Consent participants received guidelines and consent forms to review and sign. In this way, they could understand the objective of the study and the potential benefits and side effects, as well as particular instructions that were supposed to be taken into consideration to ensure the validity of the experimental session. After the participants' confirmations, the experimental session was scheduled on a convenient date and time for the participants. Detailed guidelines were emailed to the participants including specifying that on the day of the experiment, mothers should refrain from using facial makeup, lotion, sunscreen, and oil. Additionally, participants were also asked to avoid smoking, consuming vasoactive substances, engaging in physical exercise, and drinking caffeine or sparkling water, in accordance with ITI guidelines (Monitoring & Join, 2015).

Experimental room preparation

To ensure high-quality thermal and behavioral assessment the setting was carefully designed. Blackout curtains were applied to prevent outside infrared radiation from entering the room. Additionally, the air conditioner was turned on about 45 minutes before participants arrived to set the temperature to 23°C (Monitoring & Join, 2015).

A convenient ergonomic infant seat and a flexible swivel chair for the mother were utilized. They ensured an optimal distance interaction for the dyads, allowing minor adjustments without interfering with the thermal imaging. Three tripods were also strategically positioned, two of which were equipped with Samsung smartphones and FLIR One thermal cameras placed at proper angles for effective monitoring.

4.3.2.2 Experimental session

A single data-collection session was conducted when infants were 3-4 months old. Upon arrival, participants were instructed to wait for 10-15 minutes to allow their body temperatures to acclimate to the ambient conditions and to reach a stable autonomic baseline. During this acclimation period, the procedure was thoroughly re-explained to the mothers to ensure they were fully informed about their responsibilities during the session.

The experimental procedure consists of an adapted version of the FFSF paradigm with 5 episodes incorporating modifications including the use of a smartphone and a paper survey as modifications of the still-face episode. The 5 episodes are as follows:

1) Free play episode: lasting for 2 minutes, this episode involves the mother engaging with her infant as usual, providing a baseline for interaction.

2) Technoference: this episode lasts for 1 minute and is characterized by smartphone interference. Here the mother is asked to fill out a survey on her smartphone and does not respond to the infant's signals or bids.

3) Reunion episode: this 2-minute episode is characterized by a natural interaction resume, where the mother and infant engage in interaction following the previous distraction phase.

4) Paper-ference: this paper-based counterpart of technoference lasts for 1 minute and involves the mother being engaged with a paper survey, leading to a temporary interruption in interaction with the infant.

5) Reunion episode: this episode, the same as the other reunion episode, lasts for 2 minutes and marks the return to natural interaction between the mother and infant after the paper interference episode.

It is important to note that the order of the two conditions, technoference and paper-ference episodes, was counter-balanced in the sample.

4.3.2.3 After session coordination

After completion of the experiment, the participants were asked to complete the questionnaires and were given a symbolic certificate as a token of appreciation.

4.3.3 Behavioral assessment

A Samsung 360 camera was utilized to record dyadic behaviors throughout the five episodes of the experiment. A behavioral coding system was implemented to measure mother and infant behavioral expressions, based on previous studies (Aureli et al., 2015; Ebisch et al., 2012; Manini et al., 2013) and previous coding systems such as the Infant and Caregiver Engagement Phases or ICEP (Weinberg & Tronick, 1998). Noldus observer XT software was employed for the behavioral assessment.

Behavioral analyses for both the mother and the infant were conducted continuously using the scales categorized by measurement type: time duration (state events) and frequency (point events).

Infant Affect (State Event):

Infant affect was measured based on the duration of negative, neutral, and positive affect.

- Negative Affect: Includes negative vocalizations, and facial or body expressions such as screeching, screaming, crying, fussiness, protesting, withdrawal, arching, twisting back, and yawning.
- Neutral Affect: Defined as the absence of clear positive or negative emotionality in facial expression or other modalities.
- Positive Affect: Includes positive vocalizations or facial expressions such as laughing, cooing, smiling, and vocalizations with a positive tone.

Infant Self-Comforting (State Event):

Infant self-comforting describes self-comforting behaviors such as thumb-sucking, rubbing the face or head, holding the ear, and rubbing feet or hands together repetitively (excluding spastic movements).

Infant Gaze (State Event):

Infant gaze was assessed depending on the object of interest. The following were coded

- Gaze to mother's face: When the infant's gaze is directed toward the mother's face.
- Gaze to mother's hands: The infant's attentional focus is on maternal hands or held objects (i.e., smartphone or questionnaire).
- Gaze to objects in the room: The infant's attentional focus is on an object (different from maternal hands, smartphone, or questionnaire), the infant might be exploring or scanning visually the object (e.g. 360 camera).
- Gaze aversion: When the infant's attention is not on objects or the mother, the gaze appears lost with no eye movements indicating active visual scanning or exploration of the environment. Also used when the infants are distressed and close their eyes.

Infant Social Bid (Point Event):

Infant social bid refers to attempts by the infant to gain the parent's attention either physically or vocally, in negative, positive, or neutral ways. This includes gestures to be picked up, leaning forward, and attention-seeking vocalizations.

Maternal Touch (State Event):

Maternal touch was assessed concerning the following categories:

- No Touch: When the parent does not touch the infant.
- Negative Touch: Non-contingent, intrusive touch that provokes negative responses and stress in the infant, such as being intrusive, awkward, overwhelming, or rough.
- Scaffolding: Touch that has instrumental, pragmatic (e.g., supporting the infant's posture), cognitive (e.g., attention-getting), or "static" functions.
- Nurturing Touch: Touch that can be playful or affectionate.

Maternal Voice (State Event):

Maternal voice during the procedure was assessed for the following:

- No Voice: When the parent is silent.
- Negative Voice: Verbalizations that communicate rejection or negative comments on the infant's behavior.
- Scaffolding Voice: Verbalizations that include requests, explanations, attempts to gain the infant's attention, and directiveness.
- Nurturing Voice: Verbalizations that include playful vocal productions such as singing and laughing, mirroring previous vocal or gestural outputs of the infant, affectionate comments, soothing speech, and mind-related comments.

Control Codes

Maternal control and infant control codes were used for any duration of the video where vocal, facial, or physical components were not codable due to technical reasons.

4.3.4 Thermal assessment

The autonomic responses of the mother and infant were inferred from regional facial thermal imprints as captured by two FLIR cameras. Following recommendations from previous ITI studies in early childhood, we selected the nose and forehead as regions of interest (ROI) for the facial thermal analysis (Aureli et al., 2015; Filippini et al., 2020; Ioannou et al., 2021; Manini et al., 2013).

Image sequences were obtained at a rate of 1 frame every five seconds for each thermal video using Virtual Dub software. Thermal data analysis was performed with a customized Python script. The ROIs were manually selected for each ITI frame to adjust for head movements, capturing the temperature of the nasal tip and forehead. The Python code converted the thermal image frames to greyscale, averaged the pixel values to reflect the regional temperature, and exported these thermal values to an Excel file. The Mean temperature change in the nasal tip and forehead across the 4 episodes was used as a proximal measurement of autonomic activation.

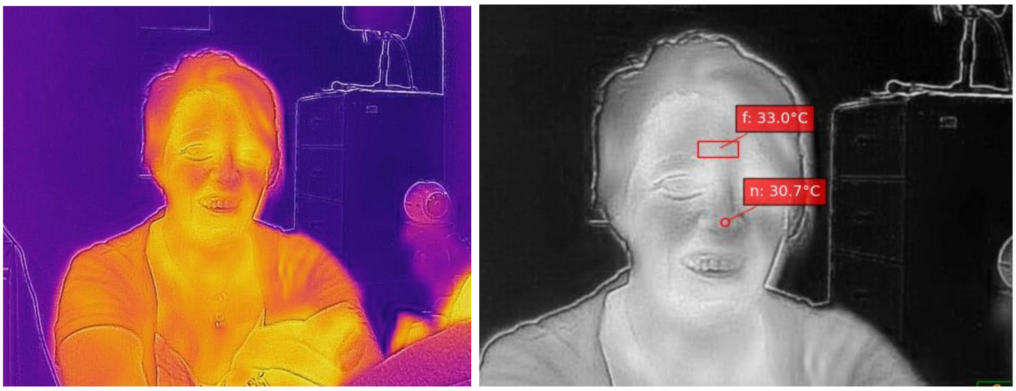


Figure 1. A visual example of the mother's raw ITI data and temperature extraction at the nasal tip and forehead regions of interest

Figure 2. A visual example of the infant's raw ITI data and temperature extraction at the nasal tip and forehead regions of interest

4.3.5 Statistical Analyses

The data for this thesis was processed using Jamovi, an open-source statistical analysis software that fulfilled all our analytic requirements. The analyses were conducted with data on 37 dyads to investigate infants' thermal and behavioral responses to maternal smartphone use and possible associations with maternal thermal and behavioral responses. This analytic work possibly reveals trends that lead to investigating autonomic coregulation in mothers and their infants.

Within-individual changes in behavior and temperature across the 5 episodes of the procedure were examined using repeated measured analysis of variance (ANOVA). Post-hoc tests were employed to explore significant ANOVA tests.

4.4 Results

4.4.1 Demographics

All participants including infants and parents were Italians. Among 37 infants, 16 (43.2 %) were females and 21 (56.8 %) were males. Maternal education ranged from high school and master's degree, with 10.8 % having completed high school, 54.1 % holding a bachelor's and 35.1 a master's degree or post-graduation specialization. On the paternal side, education level ranged from medium high school to master's degree, with 40.5 % and 5. % having completed medium high school and high school, respectively. Additionally, 2.7 % had attended some university courses, while 29.7% held bachelor's degrees and 21.6 % held master's degrees. 23 parents were married and 12 of them were cohabitant partners.

The mean age of infants was 3.89 months (SD=0.94). Additionally, the mean ages of mothers and fathers were 34.6 (SD=3.97) and 36.8 (SD=5.53), respectively. Among the infants, 51.4 % were the first child, 43.2 % were the second child, and 5.4 % were the third child in their family.

4.4.3 Thermal Analyses

Objective 1: Quantifying infant and maternal thermal variations across the procedure

The first objective was to quantify the thermal variations in both infants and mothers during two stressful conditions and two recovery episodes, comparing them to baseline responses. To achieve this, we analyzed the temperature variations in the infant's forehead, infant's nose, mother's forehead, and mother's nose across five episodes using separate repeated measures ANOVA.

Repeated Measures ANOVA Results

The repeated measures ANOVA indicated significant temperature variations across the five episodes for both infants and mothers.

Infant Forehead Temperature

To investigate the difference in infant forehead temperature across episodes, we applied repeated measures ANOVA. A significant difference among the episodes was found ($F(4,120) = 4.42$, $P = 0.002$). To specify the precise variations, we conducted post-hoc pairwise comparisons. The results are summarized in table 2 and figure3.

Table 2. Post Hoc Pairwise Comparisons for Infant Forehead Temperature

Infant Forehead		Infant Forehead	Mean Difference	SE	df	t	p
Play	-	Smart	0.2581	0.0747	30.0	3.456	0.002
	-	RU Smart	0.0396	0.0973	30.0	0.408	0.687
	-	Paper	0.1588	0.0830	30.0	1.913	0.065
	-	RU Paper	-0.0166	0.0772	30.0	-0.215	0.831
Smart	-	RU Smart	-0.2185	0.0790	30.0	-2.766	0.010
	-	Paper	-0.0993	0.0649	30.0	-1.531	0.136
	-	RU Paper	-0.2747	0.0747	30.0	-3.677	< .001
RU Smart	-	Paper	0.1191	0.0877	30.0	1.359	0.184
	-	RU Paper	-0.0562	0.0639	30.0	-0.879	0.386
Paper	-	RU Paper	-0.1754	0.0802	30.0	-2.187	0.037

The post-hoc comparisons indicated that the infant forehead temperature during the Play (free play) episode was significantly higher compared to the Smart (technoference) episode with a mean difference of 0.2581 ($t(30) = 3.456$, $p = 0.002$) and marginally higher compared to Paper (paper-ference) episode with a mean difference of 0.1588 ($t(30) = 1.913$, $p = 0.065$). Also, forehead temperature during the Smart episode was significantly lower than reunion following technoference (reunion of technoference) episode with a mean difference of -0.2185 ($t(30) = -2.766$, $p = 0.010$) as well as Reunion following paper-ference (reunion of paper-ference) episode with a mean difference of -0.2747 ($t(30) = -3.677$, $p < 0.001$). Furthermore, forehead temperature during Paper was significantly lower than the temperature at the subsequent reunion with a mean difference of 0.0802 (t (30) = -2.187, p = 0.037)

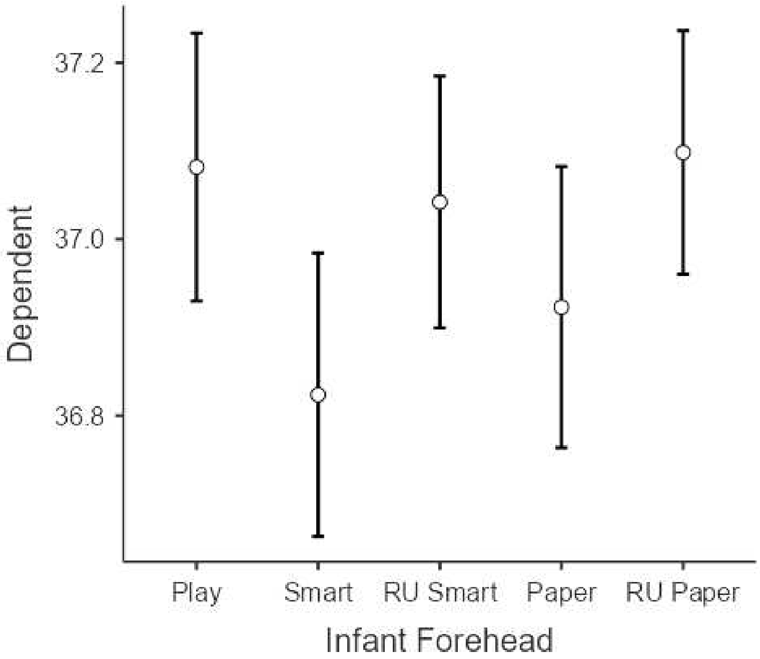


Figure 3. Estimated Marginal Means in Infant Forehead Temperature Across Episodes

Infant Nose Temperature

For infant nose temperature, no significant differences were found among the episodes (F (4, 120) = 0.690, p = 0.600).

Mother Forehead Temperature

Similarly, we applied repeated measures ANOVA across episodes to examine maternal forehead temperature, indicating significant differences (F (4, 104) = 7.45, P < 0.001). Post-hoc comparisons further exhibited the differences between episodes. Table 3 and figure 2 summarize these comparisons.

. Table 3. Post Hoc Comparisons for Mother Forehead Temperature

Comparison							
Mother Forehead		Mother Forehead	Mean Difference	SE	df	t	p
Play	-	Smart	0.1442	0.1319	26.0	1.093	0.284
	-	RU Smart	-0.1299	0.0877	26.0	-1.480	0.151
	-	Paper	0.3665	0.1197	26.0	3.062	0.005

	-	RU Paper	-0.1102	0.1102	26.0	-1.000	0.327
Smart	-	RU Smart	-0.2741	0.1090	26.0	-2.515	0.018
	-	Paper	0.2223	0.0930	26.0	2.390	0.024
	-	RU Paper	-0.2543	0.1023	26.0	-2.486	0.020
RU Smart	-	Paper	0.4964	0.0953	26.0	5.211	< .001
	-	RU Paper	0.0197	0.0975	26.0	0.202	0.841
Paper	-	RU Paper	-0.4766	0.1121	26.0	-4.252	< .001

Maternal forehead temperature was significantly lower during the Play episode compared to the Paper-ference episode with a mean difference of 0.3665 (t (26) = 3.062, p = 0.037). Conversely, comparisons between Play vs. other episodes such as Technoference, Reunion following technoference, and Reunion following paper-ference did not show any significant differences. However, a significant decrease was observed in maternal forehead temperature from Technoference to reunion following technoference episode with mean differences of -0.2741 (t (26) = -2.515, p = 0.018).

It has been also exhibited that the maternal forehead temperature during the Technoference episode is significantly higher than the paper-ference episode with a mean difference of 0.2223 (t (26) = 2.390, p = 0.024) and lower than the reunion following the paper-ference episode with a mean difference of -0.2543 (t (26) = -2.486, p = 0.020). Additionally, the Paper is significantly lower than Reunion following paper-ference and Reunion following technoference with mean differences of -0.4766 (p <0.001) and -0.0197 respectively (p < 0.001).

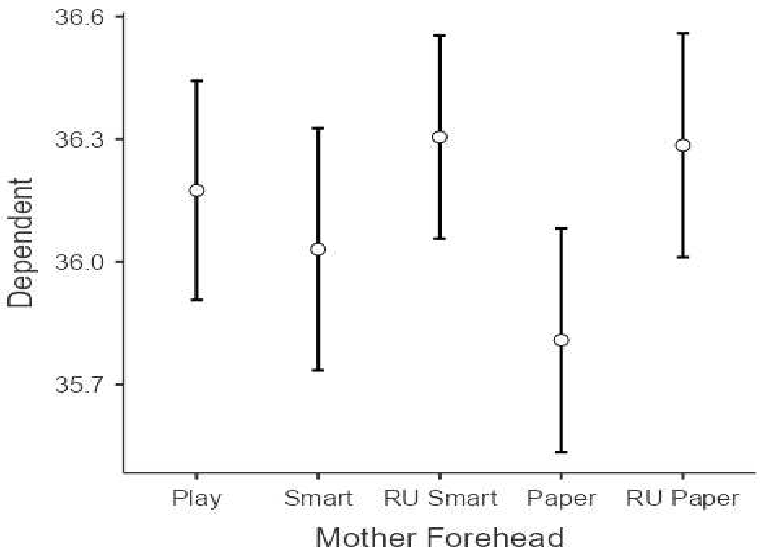


Figure 4. Estimated Marginal Means for Mother Forehead Temperature

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Figure 4 illustrates the variations from one episode to the next as well as the differences between episodes regarding the maternal forehead temperature.

Mother Nose Temperature

Repeated measures ANOVA for maternal nasal tip temperature exhibits thermal variations across the episodes (F (4, 112) = 10.7, P < 0.01).

As illustrated in table 10, post hoc tests posit the significant variation in temperature of the nose between free play episode as the base line and 4 other episodes as follows.

Table 4

Mother Nose		Mother Nose	Mean Difference	SE	df	t	p
Play	-	Smart	-1.3468	0.326	28.0	-4.135	< .001
	-	RU Smart	-1.6596	0.408	28.0	-4.063	< .001
	-	Paper	-1.0560	0.240	28.0	-4.395	< .001
	-	RU Paper	-1.2666	0.242	28.0	-5.229	< .001
Smart	-	RU Smart	-0.3127	0.156	28.0	-2.003	0.055
	-	Paper	0.2909	0.276	28.0	1.055	0.300
	-	RU Paper	0.0802	0.211	28.0	0.380	0.707

RU Smart	-	Paper	0.6036	0.335	28.0	1.801	0.083
	-	RU Paper	0.3929	0.258	28.0	1.525	0.138
Paper	-	RU Paper	-0.2107	0.192	28.0	-1.096	0.283

Maternal nose temperature during the Play episode was significantly lower compared to the Technoference episode (mean difference = -1.3468, t(28) = -4.135, p < 0.001), Reunion following technoference episode (mean difference = -1.6596, t(28) = -4.063, p < 0.001), Paper-ference episode (mean difference = -1.0560, t(28) = -4.395, p < 0.001), and Reunion following paper-ference episode (mean difference = -12666, t(28) = -5.229, p<0.001). The findings also reveal that thee is a marginally significant increase from the Technoference episode to the Reunion following technoference episode with a mean difference of -0.3127 (t (28) = -2.003, p = 0.055).

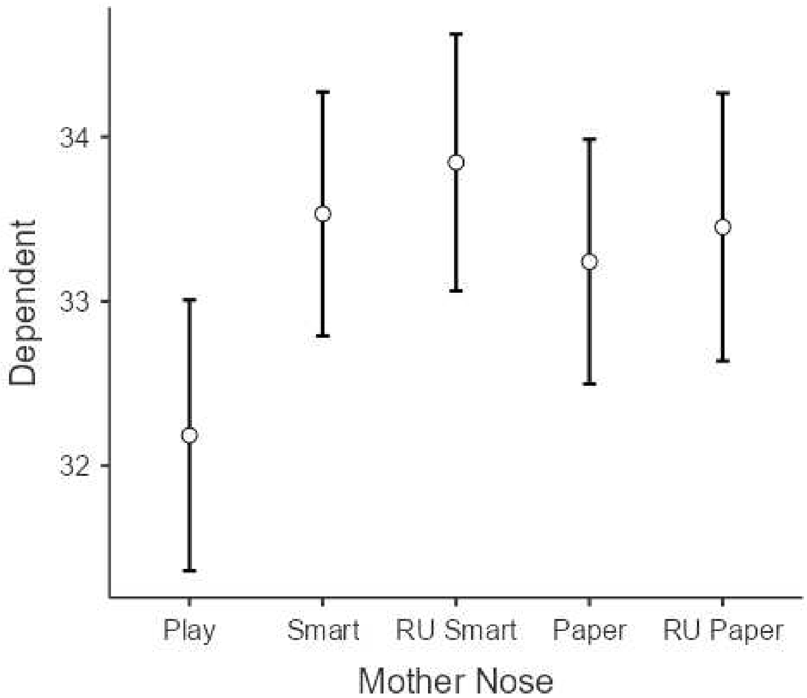

Figure 5. Estimated Marginal Means for Mother Nose

Figure 3 illustrates the variations in maternal temperature of the nose through episodes. As shown, all episodes had an increase from base line. Furthermore, we observe an obvious increase in thermal responses from technoference to reunion of technoference.

4.4.4 Behavioral Analysis

Objective 2. Examining behavioral responses in both infants and mothers across the five episodes.

The second objective focused on understanding the differences in infant and mother behavioral responses across episodes. The behavioral variables analyzed included infant negative and positive affect, infant self-comforting behaviors, infant social bids, infant gaze, and maternal touch. To achieve this, we analyzed infant and mother behavioral variations across the five episodes using repeated measures ANOVA.

Repeated Measures ANOVA Results

The repeated measures ANOVA indicated significant infant's and mother's behavioral variations across the five episodes.

Negative Affect

The repeated measures ANOVA for infant negative affect revealed a significant effect among the episodes (F (4, 100) = 4.55, P = 0.002). This analysis underscores the differences observed in infant negative effects across the evaluated episodes. To examine differences in infant negative affect across episodes, pairwise comparisons were conducted. Table 12 summarizes the mean differences, standard errors (SE), t-values, and p-values for each comparison.

Table 5. Infant ***Negative Affect***

Negative Affect			Mean Difference	SE	df	t	p
Play	-	Smart	-0.23105	0.0553	25.0	-4.1794	< .001
	-	RU Smart	-0.18111	0.0599	25.0	-3.0220	0.006
	-	Paper	-0.18349	0.0398	25.0	-4.6111	< .001
	-	RU Paper	-0.15663	0.0499	25.0	-3.1367	0.004
Smart	-	RU Smart	0.04994	0.0529	25.0	0.9436	0.354
	-	Paper	0.04756	0.0545	25.0	0.8732	0.391
	-	RU Paper	0.07442	0.0710	25.0	1.0477	0.305
RU Smart	-	Paper	-0.00238	0.0722	25.0	-0.0329	0.974
	-	RU Paper	0.02448	0.0660	25.0	0.3710	0.714
Paper	-	RU Paper	0.02686	0.0564	25.0	0.4765	0.638

As shown in table 12, significant differences in infant negative affect were found between several conditions. Specifically, the comparisons between Play and Technoference episode with the mean difference of -0.23105 (t (25) = -4.1794, p < 0.001), Play and Reunion following technoference episode with the mean difference of -0.18111 (t (25) = -3.0220, p = 0.006), Play and Paper-ference episode with the mean difference of -0.18349 (t (25) = -4.6111, p < 0.001), and Play and Reunion following paper-ference episode with the mean difference of -0.15663 (t (25) = -3.1367, p = 0.004). The results are indicative of a significant increase in infants' negative affect from free play episode to the other four episodes.

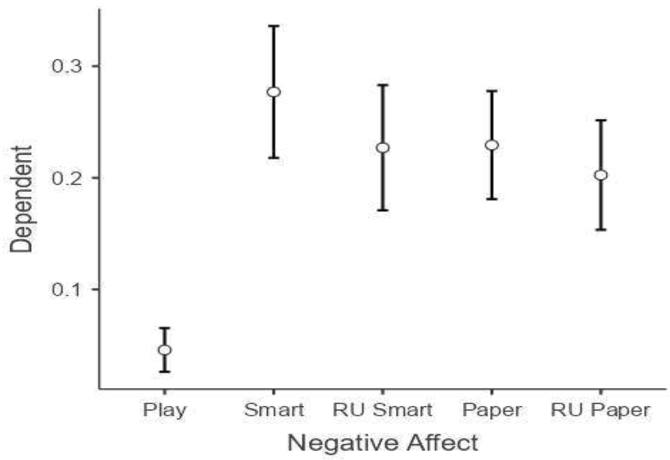

Figure 6. Infant Negative Affect

Positive Affect

The repeated measures ANOVA examining the effect of different episodes on infant positive affect indicates a significant difference in positive affect among the episodes (F (4, 100) = 12.9, p < 0.001).

Post-hoc pairwise comparisons showed a significant decrease in infant positive affect from the Play episode to the technoference episode, with a mean difference of 0.17192 (t (25) = 0.2502), and the Paper-ference episode, with a mean difference of 0.17072 (t (25) = 4.4438, p < 0.001).

Conversely, we observed a significant increase in infants' positive affect from

Technoference episode to Reunion following technoference episode with a mean difference of -0.16028 (t (25) = -4.9970, p < 0.001) and to the Reunion following paper-ference episode, with a mean difference of -0.17009 (t (25) = -5.1846, p < 0.001). Similarly, positive affect during the Paper-ference episode was significantly lower than during the Reunion following technoference episode, with a mean difference of -0.15908and (t (25) = -5.0818, p < 0.001), and the Reunion following paper-ference episode, with a mean difference of -0.16889 (t (25) = -4.8951, p < 0.001). These differences are also illustrated in Figure 7.

Table 6. Post Hoc Comparisons – Positive Affect

Positive Affect		**Positive Affect**	**Mean Difference**	**SE**	**df**	**t**	**p**
Play	-	Smart	0.17192	0.03968	25.0	4.3327	< .001
	-	RU Smart	0.01164	0.04653	25.0	0.2502	0.804
	-	Paper	0.17072	0.03842	25.0	4.4438	< .001
	-	RU Paper	0.00183	0.04373	25.0	0.0418	0.967
Smart	-	RU Smart	-0.16028	0.03208	25.0	-4.9970	< .001
	-	Paper	-0.00120	0.00893	25.0	-0.1345	0.894
	-	RU Paper	-0.17009	0.03281	25.0	-5.1846	< .001
RU Smart	-	Paper	0.15908	0.03130	25.0	5.0818	< .001
	-	RU Paper	-0.00981	0.03860	25.0	-0.2542	0.801
Paper	-	RU Paper	-0.16889	0.03450	25.0	-4.8951	< .001

Self-Comforting Behaviors

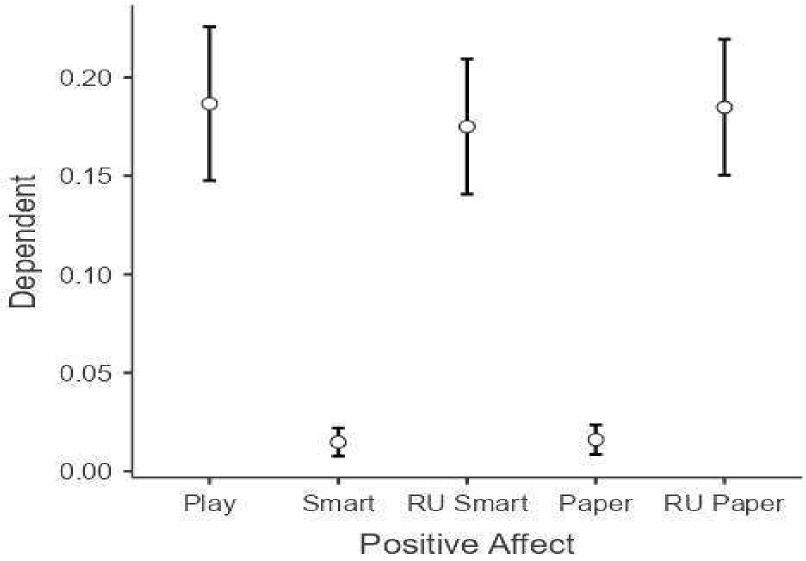

*Figure 7. Estimated Marginal Means- **Positive Affect***

The repeated measures ANOVA indicates a significant difference in infant self-comforting behaviors among the episodes ($F(4, 100) = 5.41$, $p < 0.001$).

To further understand these differences, post-hoc pairwise comparisons were conducted (table 7). The results revealed the following significant variations:

Table 7. Post Hoc Comparisons for Infant Self-Comforting Behaviors

Comparison

Self-Comforting Behaviors		**Self-Comforting Behaviors**	**Mean Difference**	**SE**	**df**	**t**	**p**
Play	-	Smart	-0.11374	0.0640	25.0	-1.776	0.088
	-	RU Smart	-0.15229	0.0599	25.0	-2.544	0.018
	-	Paper	0.01495	0.0424	25.0	0.353	0.727
	-	RU Paper	0.01004	0.0354	25.0	0.284	0.779
Smart	-	RU Smart	-0.03855	0.0547	25.0	-0.705	0.488
	-	Paper	0.12869	0.0425	25.0	3.025	0.006
	-	RU Paper	0.12378	0.0512	25.0	2.418	0.023
RU Smart	-	Paper	0.16724	0.0483	25.0	3.461	0.002

	-	RU Paper	0.16233	0.0431	25.0	3.764	< .001
Paper	-	RU Paper	-0.00491	0.0249	25.0	-0.197	0.845

The play episode and Reunion following technoference episode showed a significant difference in self-comforting behaviors with a mean difference of -0.15229 (t (25) = -2.544, p = 0.018). In addition, the Technoference episode and Paper-ference episode

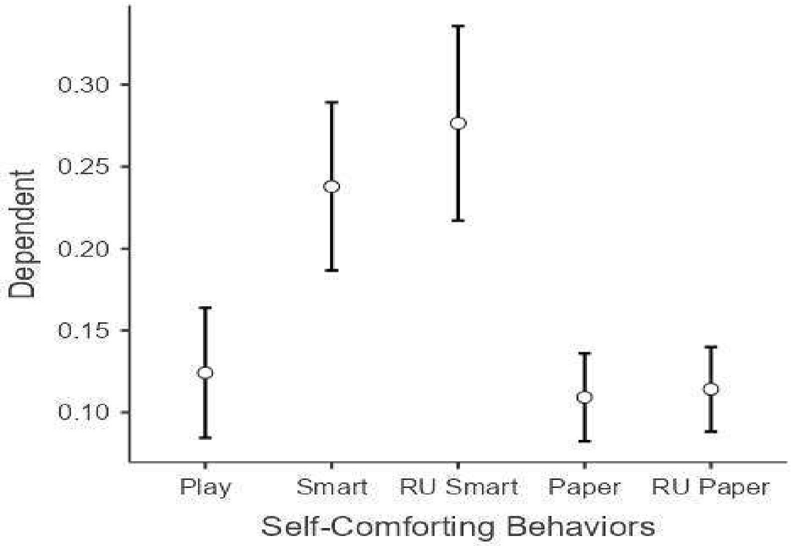

Figure 8. Estimated Marginal Means for Infant Self-Comforting Behaviors

comparison showed a significant difference with a mean difference of 0.12869 (t (25) = 3.025, p = 0.006). The other comparisons showed a significant decrease from the Technoference episode to Reunion following paper-ference episode with a mean difference of 0.12378 (t (25) = 2.418, p = 0.023). Infant self-comforting behaviors during the Reunion following technoference episode was significantly higher than self-comforting behaviors during the Paper-ference episode with a mean difference of 0.16724 (t (25) = 3.461, p = 0.002) and the Reunion following paper-ference episode with a mean difference of 0.16233 (t (25) = 3.764, p < 0.001). As illustrated in the graph in figure 8, the estimated marginal means for infant self-comforting behaviors across different episodes shows that self-comforting behaviors are in the lowest amount during the Play, Paper-ference, and Reunion following paper-ference episodes. We observe a significant increase during Technoference and Reunion following technoference episodes.

Social Bid

The repeated measures ANOVA for infant social bid revealed no significant differences across episodes ($F (4, 112) = 2.29$, $p = 0.064$).

Infant Gaze to Parent

The repeated measures ANOVA for infant gaze toward parent revealed a significant difference across the episodes ($F (4, 96) = 30.1$, $P < 0.001$).

To further understand the differences, post-hoc pairwise comparisons were conducted (Table 19). As shown in Figure 9, the results revealed a significant decrease in gaze toward the parent from the Play episode to the Technoference episode with a mean difference of 0.3272 ($t (24) = 5.782$, $p < 0.001$), and from the Play episode to the Paper-ference episode with a mean difference of 0.4063 ($t (24) = 7.307$, $p < 0.001$).

Additionally, we observe that gaze to parent during the Technoference episode is significantly lower than the Reunion following technoference episode (Mean Difference = -0.3796, $t (24) = -7.565$, $p < 0.001$) and Reunion following paper-ference episode (Mean Difference = -0.3414, $t (24) = -5.991$, $p < 0.001$). Furthermore, we found out that gaze to parent during the Paper-ference episode was significantly lower than the Reunion following paper-ference episode (Mean Difference = -0.4204, $t (24) = -6.552$, $p < 0.001$) and the Reunion following technoference episode (Mean Difference = 0.4586, $t (24) = -7.932$, $p < 0.001$).

Table 8. Post Hoc Comparisons for Infant Gaze to Parent

Gaze parent		Gaze parent	Mean Difference	SE	df	t	p
Play	-	Smart	0.3272	0.0566	24.0	5.782	< .001
	-	RU Smart	-0.0523	0.0489	24.0	-1.070	0.295
	-	Paper	0.4063	0.0556	24.0	7.307	< .001
	-	RU Paper	-0.0141	0.0594	24.0	-0.237	0.814
Smart	-	RU Smart	-0.3796	0.0502	24.0	-7.565	< .001
	-	Paper	0.0791	0.0495	24.0	1.597	0.123
	-	RU Paper	-0.3414	0.0570	24.0	-5.991	< .001
RU Smart	-	Paper	0.4586	0.0578	24.0	7.932	< .001
	-	RU Paper	0.0382	0.0549	24.0	0.697	0.493

Paper	-	RU Paper	-0.4204	0.0642	24.0	-6.552	< .001

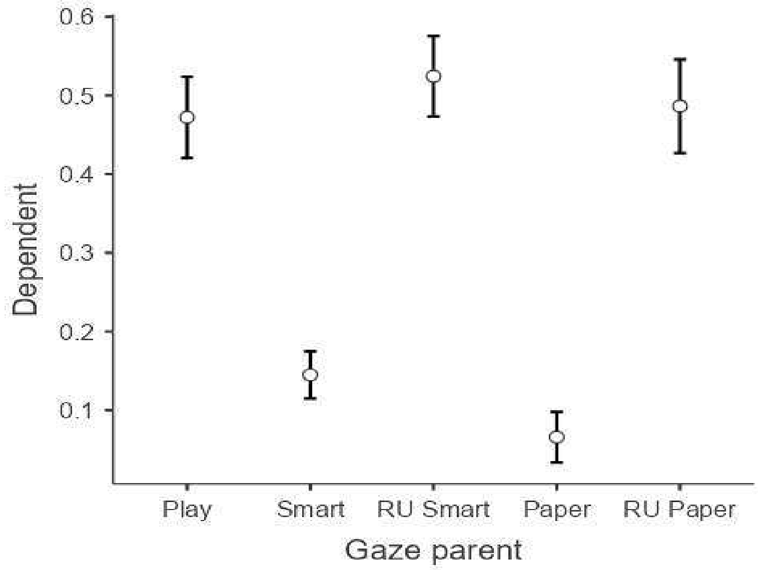

Figure 9. Estimated Marginal Means for Infant Gaze to Parent

Infant's Gaze to Parent's Hands

The repeated measures ANOVA for infant gaze to parent's hand suggested no significant differences across episodes ($F(4, 96) = 0.468$, $p = 0.759$).

Infant Gaze Aversion

The repeated measures ANOVA posited a significant difference in infant gaze aversion across the episodes ($F(4, 96) = 5.76$, $p < 0.001$).

As shown in Table 9 and illustrated in Figure 10, there is a significant decrease in gaze aversion from the Play episode to the Technoference episode (Mean difference = -0.2572 ($t(24) = -4.678$, $p < 0.001$), the Reunion following technoference episode (Mean difference = -0.1390 ($t(24) = -2.468$, $p = 0.021$), the Paper-ference episode (Mean difference = -0.2463 ($t(24) = -4.564$, $p < 0.001$), and the Reunion following paper-ference episode (Mean difference = -0.1160 ($t(24) = -2.940$, $p = 0.007$). Other comparisons did not reach statistical significance or showed a less notable effect.

Table 9. Post Hoc Comparisons for Infant Gaze Aversion

Gaze avert		Gaze avert	Mean Difference	SE	df	t	p
Play	-	Smart	-0.2572	0.0550	24.0	-4.678	< .001

	-	RU Smart	-0.1390	0.0563	24.0	-2.468	0.021
	-	Paper	-0.2463	0.0540	24.0	-4.564	< .001
	-	RU Paper	-0.1160	0.0394	24.0	-2.940	0.007
Smart	-	RU Smart	0.1183	0.0646	24.0	1.832	0.079
	-	Paper	0.0109	0.0668	24.0	0.164	0.871
	-	RU Paper	0.1413	0.0647	24.0	2.185	0.039
RU Smart	-	Paper	-0.1073	0.0872	24.0	-1.230	0.231
	-	RU Paper	0.0230	0.0517	24.0	0.445	0.660
Paper	-	RU Paper	0.1303	0.0701	24.0	1.860	0.075

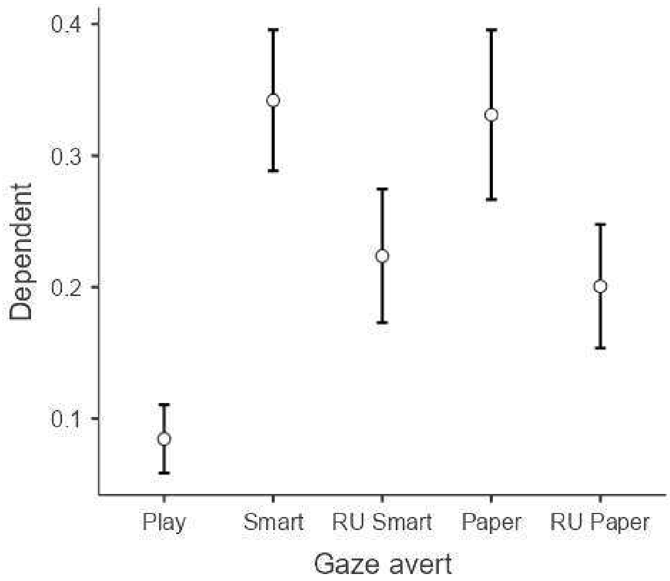

Figure 10. Estimated Marginal Means for Infant Gaze Aversion

4.4.5 Mother-Infant Behavioral and Thermal Coregulation

Objective 3. investigating the thermal coregulation patterns within mother-infant dyads during these different episodes.

To explore behavioral coregulation and thermal coregulation patterns within mother-infant dyads across five episodes, correlations between behavioral expressions as well as thermal responses in both mothers and infants were examined.

Thermal Coregulation

Pearson correlation analysis was indicative of no significant correlations between the mother and the infant's forehead temperature during the procedure.

We applied the same method to explore the thermal coregulation between the mother and infant nose during the five episodes. Results from Pearson correlation analysis revealed a significant positive correlation between mother and infant nose temperature during the reunion episode following technoference (Pearson's r = 0.349*, p = 0.047).

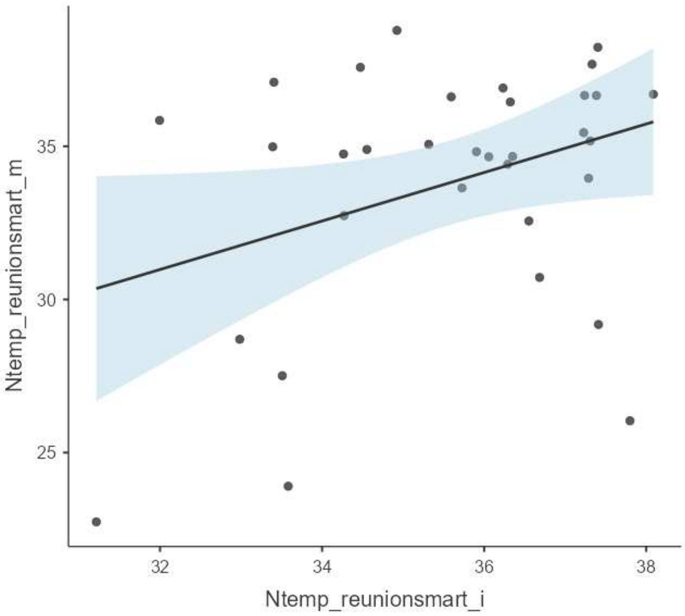

Figure 11. Scatterplot. The Correlation between mother-infant nose temperature during the RU Smart Episode

Figure 11 presents a scatterplot depicting the correlation between mother-infant nose temperature during reunion following the technoference episode. As shown, there is a direct positive relationship between maternal and infant temperatures, suggesting coordinated thermal responses between mothers and infants at this time.

Behavioral Coregulation: Maternal Touch with Infant Affect

To explore the dyadic behavioral coregulation, we evaluated the correlation between Maternal Touch and, respectively, Infant Negative Affect, Infant Positive Affect, and Infant Gaze Aversion.

The results from Pearson's r analysis indicated a negative correlation between maternal nurturing touch and infant negative affect (r = -.494**, p = 0.009) during the reunion following paper-ference episode, indicating greater negative affect during the reunion in infants of mothers showing less nurturing touch A positive correlation also has been found between maternal nurturing touch and infant positive affect during reunion of paper-ference (r = 0.477*, p = 0.012), suggesting maternal nurturing touch, positively, accompanied by infant positive affect.

No significant associations between maternal touch and infant gaze aversion were found.

Chapter 5. Discussion

Our study aimed to explore the variations in thermal and behavioral responses of infants aged 3 to 4 months and their mothers during interactions using an adapted version of the still-face paradigm, including technoference and paper-ference. In these scenarios, the dyadic interaction was interrupted as the mother was involved in filling out a questionnaire either on paper (paper-ference) or digitally (technoference). This disruption created a stressful situation for the infant.

Evidence from former research highlights the importance of safe and secure mother-infant interaction during infancy and early childhood (Swider-Cios et al., 2024). Through such interaction, the infant is more likely to achieve more efficient self-regulation skills as well as less serious psychological and social developmental issues (Montirosso et al., 2010). As infants express their emotions and inner states through behavioral physiological responses, we can track the signs of infants' stress and insecurity through their behavioral expressions and facial temperature reactivities. Porter and colleagues (2024) indicated that toddlers' autonomic responses are consistent with their experiencing affects.

Interestingly, emotional situations can influence not only infant affects and behaviors but also their skin temperature. Ekman and colleagues (1983) expressed that higher temperature is related to anger while lower temperature is related to sadness. Miyaji and colleagues (2019) further indicated that pleasant and unpleasant emotions are linked to different thermal responses. A possible mechanism underlying this variation can be sympathetic vasoconstriction and parasympathetic vasodilation in the face (Kashima & Hayashi, 2011). Both the sympathetic and parasympathetic systems innervate the facial muscles and skin (Dana, 2020; Gibbons, 2019), assisting the body to respond to thermal changes by either up-regulating or down-regulating through vasomotion. According to the polyvagal theory, this regulation is a critical component of the social engagement system (Aureli et al., 2015; Porges, 2003b). Yet, explaining the emotions given the vasomotion and facial temperature variations would be challenging, and further exploration is warranted.

Thermal variations can be observed in the nasal tip, nose, forehead, cheeks, perioral, maxillary areas, periorbital, and supraorbital areas (Cardone & Merla, 2017). Previous studies have displayed that stress is associated with a temperature decrease in facial regions, particularly in the maxillary region, nasal tip, and cheeks. In contrast, an increase in temperature in the periorbital and supraorbital areas corresponds to the experience of pleasant emotions (Aureli et al., 2015). However, the periorbital and forehead regions seem to be stress-insensitive in adults (Engert et al., 2014), and the nasal tip shows more reliability among the regions (Ioannou et al., 2013). Evidence exhibits that thermal variation in the nasal tip and maxillary area exposes sympathetic activation while experiencing stressful moments (Ebisch et al., 2012) Yet, there is not a solid consensus among the outcomes. In the current study, the behavioral and thermal responses of infants and their mothers were recorded during the episodes of still-face (through technoference and paper-ference) and reunions compared to a baseline.

Chapter 5. Discussion

5.1 Thermal Findings

Previous studies have indicated that infant stress is accompanied by cardiac and hormonal responses. For example, Haley (2011) found infant's cortisol increases during the still-face procedure, showing the HPA axis activation. Similarly, various studies have concluded that cortisol, a biomarker of stress, increase in infants in response to stressful situations, including still-face (Ginnell et al., 2022; Haley, 2011; Provenzi et al., 2016). Furthermore, other investigations have revealed the association of cardiac responses with the still-face procedure to discover how infants' ANS responds to the still-face procedure (Kolacz et al., 2022). Consistent with the findings of autonomic responses to stress experience, we tried to discover autonomic reactivation at the thermal level, as well.

Given objective 1, we measured the forehead and nasal tip temperatures of young infants and their mothers during the experimental procedure. The results from repeated measure ANOVA for infant forehead temperature demonstrated a significant decrease during technoference and a marginally significant paper-ference compared to free play (baseline) which might be indicative of sympathetic activation (Cardone & Merla, 2017). Mizukami and colleagues (1990) confirm that infant facial skin temperature decreases during stressful conditions. In line with this, Aureli and colleagues (2015) found that infants' forehead temperatures were higher during the toy play episode compared to the still-face episode; suggesting that variations in thermal levels may reflect the infants' arousal and soothing mechanisms. Similarly, Güney and colleagues reported an increase in skin temperature after shifting from the baseline to relaxation (Okur Güney et al., 2015).

Although the forehead temperature drops suggested a still-face effect during the technoference and paper-ference, no significant variation was detected in nasal temperature. In varied studies, infant nasal temperature was reported as a region of interest in studying temperature changes during social interactions (Cardone & Merla, 2017; Ioannou et al., 2014; Nazzari et al., 2024). Although the nasal tip has been identified as a reliable region for detecting stress signatures in adulthood, similar data are lacking in early infancy. In a study, Aureli and colleagues (2015) observed an increase in infant nose and forehead temperature during the still-face procedure, suggesting a parasympathetic activation during the experiment.

Some methodological explanations might underline this null finding. During the procedure (except for technoference and paper-ference episodes), mothers were allowed to touch their infants. Touching and physical closeness can cause variations in skin temperature (IJzerman et al., 2012; IJzerman et al., 2018). In addition, as presented in Figure 2 in Chapter 3, a rectangular box was used to record the forehead temperature and a circle for the nose temperature (10x10 pixels). Due to the small size of the infants' noses, the circle measurement may not have been accurately taken for the nose temperature. We also found that the infants' forehead temperature during technoference and paper-reference conditions was significantly lower than in both reunion episodes.

We discovered a significant increase from the technoference condition to the reunion following the technoference and the reunion following the paper-ference. Besides, we observed an increase from the paper-ference condition to the reunion of the paper-ference condition showing the full recovery during the reunion episode. As a clarification, facial temperature, involving vasomotion, is a coordinated function of both the sympathetic and parasympathetic nervous systems (Kashima & Hayashi, 2011). An increase in cutaneous temperature is indicative of parasympathetic reactivation while facing a soothing condition (Cardone & Merla, 2017). Scientific evidence has shown that pleasant experiences are related to an increase in facial temperature as a result of the parasympathetic vasodilation mechanism which brings about a heightened facial skin blood flow (Izumi, 1995; Miyaji et al., 2019). In a mishap paradigm project, Ioannou and colleagues (2013) found that the mishap of the toy caused sympathetic arousal reflected in nasal temperature drop compared to the baseline. Conversely, during the soothing episode following the mishap, there was an increase in children's nose temperature, reflecting the parasympathetic activation.

Regarding the maternal thermal responses, we found a significant decrease in maternal forehead temperature from the free-play episode to paper-ference; suggesting that the paper-ference episode was distressing for mothers. However, such a decrease was not observed in the technoference episode. In addition, maternal forehead temperature during the technoference episode was significantly higher than the paper-ference episode, whereas this variation was not observed for infant thermal analysis. Moreover, we discovered a thermal increase from technoference to the reunions following the technoference and paper-ference episodes as well as an increase from paper-ference to the reunion of paper-ference. The findings suggest that the emotional dynamics and thermal cutaneous responses of mothers may vary between episodes of distraction and re-engagement with the infant.

The observed variations in maternal thermal responses between technoference and paper-ference episodes underscore how technological distractions influence maternal stress levels, contrasting with smartphones' consistent impact on personal engagement and attention. Smartphones have become integral to personal life and many people are strongly connected to their devices, treating them as part of themselves. This phenomenon, known as self-extended, makes people nervous while putting their gadgets away and relaxed when connecting with them again (Belk, 2016; Belk, 2013; Clayton et al., 2015; Okur Güney et al., 2015; Turkle). Additionally, the distracting effect of smartphones can reduce individuals' attentiveness to important matters and commitments (Oraison et al., 2020). However, our results indicated that the distracting effect does not impact engagement in paper tasks. So, technoference is not more stressful than free play for mothers while paper-ference is. Ewin and colleagues (2021) indicated that both digital and non-digital devices interfere with dyadic interaction; however, parents tend to interact more with their children while using non-digital tools compared to digital ones (Ewin et al., 2021). It may occur because parents are less distracted by non-digital tools and more attuned to their inner states.

Our findings also reveal a significant increase in maternal nasal temperature from the free play episode to all other four episodes, suggesting a pattern of thermal response to different levels of engagement and disengagement. Interestingly, we also observed a marginal yet noteworthy increase in nasal temperature from the technoference episode to the reunion following technoference. This shows that although technological distractions (phubbing) generally lead to a decrease in maternal nasal temperature, there may be a subsequent increase when the mother reengages with the infant after a phubbing experience.

5.2 Behavioral Findings

In pursuit of objective two, repeated measures ANOVA for infant affect revealed a significant increase in negative affect from the free play episode to all subsequent episodes, including technoference, reunion of technoference, paper-ference, and reunion of paper-ference. Additionally, Infant positive affect significantly decreased during technoference and paper-ference compared to free play and both reunions. These results suggest that infants exhibited higher levels of distress during technoference and paper-ference. So, the experimental procedure overall may have caused stress in the infants.

The infant comforting behaviors indicated an increase from free play to technoference and reunion of technoference; the increase in the technoference phase was not statistically significant while the reunion of technoference was. Additionally, infant self-comforting behaviors in technoference and reunion of technoference were significantly lower than paper-ference and reunion of paper-ference. Furthermore, the analysis for the infant social bid indicated no differences across the episodes. Additionally, the findings suggest that infants had a significant decrease in gaze at parents during technoference and paper-ference. However, infants showed an increase in gaze aversion from free play to the other four episodes, which suggests the whole stressful procedure of the experiment.

The free-play episode serves as a baseline to measure infant attention and socio-emotional expressions (Giusti et al., 2018). Through this episode, typical interactive behaviors including gaze, vocalization, facial expressions, affective displays, and tactile interactions are taken into consideration (Aureli et al., 2015; Ebisch et al., 2012; Manini et al., 2013; Stockdale et al., 2020). Traditional studies of still-face have shown that after the free-play episode, we observe a still-face effect which is characterized by infant attempts, including cooing, crying, etc. to re-engagement which is accompanied by loss of positive affect and increase in negative affect (Adamson & Frick, 2003; Aureli et al., 2015; Chiodelli et al., 2020; Provenzi et al., 2016; Toda & Fogel, 1993; Tronick et al., 2005). Our findings indicated that this still-face effect occurs not only in the traditional version of still-face but also in the technoference and paper-ference versions. Aligning with our findings, Porter and colleagues (2024) demonstrated that toddlers experience less positive affect during a technoference episode, reflected in an increase in heart rate and a decrease in respiratory sinus arrhythmia. However, no variation in negative affect was reported across the episodes.

We did not see any recovery from technoference and paper-ference to the reunions for the negative affect. Infants in both reunion episodes showed a significant increase from baseline to reunions following technoference and paper-ference. Previous studies have illustrated that a full recovery does not occur during the reunion and the infant responses do not return to the baseline (Mesman, 2010). Yet, our findings did not show any recovery in negative affect during the reunions following technoference and paper-ference. Interestingly, regarding the positive affect, we observed a full recovery in reunions following technoference and paper-ference. In other words, the positive affect during reunion episodes returned to the baseline (free-play episode).

Myruski and colleagues (2018) utilized a technoference-modified version of the still-face paradigm. They observed a decrease in infants' positive affect and an increase in negative affect from free play to technoference, with no full recovery during subsequent reunion episodes. Infants exhibited higher engagement levels during free play compared to the reunion phases. Additionally, during technoference, infants showed more social bids and explored their environment more actively than during the reunion phases. In another study, scholars demonstrated that both maternal smartphone usage and reading a magazine negatively affect the dyadic interaction with the children compared to uninterrupted conditions (Lederer et al., 2022).

Gutierrez & Ventura (2021) indicated that maternal technoference during caring the newborns predicts the infant's negative affectivity and lower attachment quality. Tharner and colleagues (2022) found that maternal smartphone use is linked to being less sensitive and less responsive to infants. This issue disrupts mother-infant interactions, increasing the infant's social distress.

5-3 Coregulation Findings

According to the poly-vagal theory, the parasympathetic system, specifically the ventral vagal system, is responsible for social engagement (Porges, 2003b, 2021). Myelinated vagal pathways facilitate parasympathetic regulation of the heart by lowering heart rate and promoting calmness. These pathways contribute to social engagement. The development of these systems occurs in early childhood which improves the capacity for inter-personal coregulation and supports the soothing system for social interaction. In the current study, while the Pearson correlation analysis showed no significant dyadic thermal coregulation in the forehead, it was found a nasal temperature coregulation during the reunion of technoference as indicated by a positive correlation between maternal and infant nasal temperature. In previous research projects, scholars have found some instances of thermal coregulation between mother and child.

Ebisch and colleagues (2012) reported mother-child thermal coregulation through a mishap paradigm involving children aged 38-42 months. Children were asked to play with a toy that the experimenter introduced as her favorite. The toy was pre-manipulated to break on the child's hands, causing the impression that the child had accidentally broken it. This experiment included 5 episodes: presenting the toy, the child playing with it, the mishap of the toy breaking, the experimenter re-entering and silently observing the top, and finally, soothing the child. Children's mothers were observing the entire procedure through a one-way mirror. They suggested empathy as a core element impacting the autonomic coregulation in particular in thermal levels. Compared to our study, since the children were more than 3 years old, they were capable enough to show their distress, which their observing mother could more easily perceive. If mothers closely observed their children while undergoing a stressful paradigm, a higher degree of coregulation was found which was hypothesized to be due to empathetic responses. So, it can be speculated that when mothers engage in smartphone and paper tasks, this coregulation is interrupted.

Coregulation during the interaction is indicative of a heightened parasympathetic activation, particularly in the ventral vagal system (Kolacz & Porges, 2024). Infants achieve self-regulation through passing coregulation with parents (Lobo & Lunkenheimer, 2020). Mothers admitted the fact that it is difficult to keep their attention balanced between their children and smartphones. This attention division can interfere with the coregulation process through dyadic interaction (Kushlev & Dunn, 2019).

Our findings from dyadic thermo-behavioral coregulation indicated a negative correlation between maternal nurturing touch and infant negative affect during the reunion of paper-ference. This means that infants and mothers show biobehavioral coregulation. A positive correlation also has been found between maternal nurturing touch and infant positive affect during reunion following paper-ference. Specifically, greater maternal nurturing touch is associated with greater infant positive affect.

Moreno and colleagues (2006) showed that maternal touch is associated with infant smile, vocalization, and eye contact during still-face (Moreno et al., 2006). The positive maternal behaviors are mirrored by the infant's affect (Beebe et al., 2010); they form a co-regulation; signifying that the mother's affect affects the child's and vice versa (Somers et al., 2022).

Kolacz and colleagues (2021) posited that infant physiological responses are coregulated with the mother during the interaction. In their study, they showed that higher maternal prosody is associated with lower infant heart rates and reduced behavioral distress. Tharner and colleagues (2022) found that maternal distraction from the child is linked to being less sensitive and less responsive to infants. This issue disrupts mother-infant interactions.

Physiological and biobehavioral coregulation during early childhood is the foundation of later well-being and social interaction (Feldman, 2012b). Having an immature self-regulatory system, newborns need to achieve self-regulation by passing a fine co-regulation with the caregiver (Feldman, 2007b). As time passes, the autonomic nervous system of the mother and infant becomes finely attuned to achieve an attachment (Feldman et al., 2011). Infants can also regulate the mother through rhythmic displays including crying, gazing, and so on; and these displays influence the mother to downregulate or upregulate the baby (Adamson & Frick, 2003). We can observe these kinds of synchronizations also through the release of hormones in mothers. Changes in the hormone system of the mother help her to attune to the infant precisely (Feldman, 2012a, 2012b)

Abney and colleagues (2021) discovered dyadic physiological synchrony in RSA between mother and infant, indicating the role of the vagus nerve in autonomic coregulation. Also, Feldman and colleagues (2011) found that autonomic coregulation is enhanced during the presence of elements of synchrony including vocalization, gaze, and affect are present. Therefore, it can be expected that during maternal distractions, less coregulation happens, particularly regarding technoference and paper-ference,

Limitations

As infrared thermal imaging is a novel measuring tool for recording autonomic responses in dyadic interactions, its application in studies of mother-infant interaction remains limited. This restricted application makes it challenging to interpret and generalize the results confidently.

Furthermore, we lost some of our participants due to the challenges related to their age. As the infants were less than 5 months old. This led to complications such as infants arriving asleep or starting to cry, which interrupted and sometimes stopped the session. It is also noteworthy that maternal distraction due to smartphone usage in experimental settings is different from real-life experiences.

Moreover, our study was conducted with a relatively small sample size which can limit the strength of conclusions. We were eager to classify participants into thermal suppressors (infants showing a decrease in thermal response during interferences) and non-suppressors (infants not showing a decrease in thermal response during interferences) and conduct separate analyses for each group. However, due to the small number of participants, we were unable to do so.

Additionally, our study employed a cross-sectional design, where the order of the two conditions (technoference and paper-ference episodes) was counterbalanced within the sample. Roughly half of the participants experienced technoference before paper-ference, while the other half experienced them in the reverse order. The counterbalancing of conditions might affect the generalizability of findings. The order effect implements a potential challenge, as any observed differences may be attributed to the sequence rather than the actual conditions of technoference and paper-ference.

Future directions

In this thesis, we measured autonomic responses at the thermal level. It would be beneficial and informative to examine other autonomic responses, such as cardiac reactivity, to see if they align or not. Previous studies (e.g., Porter and colleagues,

2024) have demonstrated differentiation between vagal suppressors and non-suppressors. With a larger sample size, it would be possible to investigate this aspect in thermal responses, as well.

Touch, gaze, and vocalization are important elements for enhancing autonomic coregulation. Future research could explore whether these synchronized interactions lead to enhanced thermal coregulation. Ebisch and colleagues (2012) identified empathy as an important factor in autonomic coregulation. It remains to be investigated whether there are differences in autonomic coregulation between the traditional face-to-face still-face paradigm and a technoference-modified version. It is also noteworthy to explore the effect of maternal touch on facial temperature variations during technoference.

Thermal regulation of facial skin is regulated through vasomotion mechanism which is a function of ANS. Considering the role of the vagus nerve, it is suggested to study the role of the vagus nerve in thermal regulation, in addition to exploring the differences between vagal suppressors and non-suppressors.

Conclusions

The current study has pursued three objectives: examining thermal and behavioral responses of infants and mothers to free play, still-face including technoference and paper-ference, and reunions following the still-face conditions; exploring dyadic thermal and behavioral coregulation.

Stressful conditions can impact infants' autonomic responses. Interestingly, we found a decrease in infant forehead temperature during maternal involvement in technoference and paper-ference. However, during the reunions following the technoference and paper-ference, we noted a recovery from these autonomic variations. But no carry-over effect has appeared, signifying that the forehead temperature returned to the baseline during the reunions following technoference and paper-ference. It confirms the facial temperature decreases during stressful conditions, but it returns to the baseline level after a brief recovery. It appears that thermal changes are not steady and long-lasting, making them a suitable tool for measuring short-term autonomic changes during the interactions. Yet, we found no nasal temperature variation across episodes, highlighting the need for future studies to address limitations and overcome current methodological and technical challenges.

We also found that maternal forehead temperature decreased in the paper-ference condition compared to the baseline, while no similar change occurred during technoference. It suggests that the extent to which paper-ference and technoference are stressful for mothers varies. It seems that technoference is less stressful than paper-ference. Reasons for these differential findings are still unknown but might include, the level of distractibility involved compared to the baseline. Paper-ference keeps mothers more aware of the situation and less absorbed than technoference. Variations in maternal forehead temperature also indicated the recovery from both technoference and paper-ference was complete, with temperatures returning to baseline levels, similar to the pattern observed in infants' forehead temperature. This finding further confirms the short-lasting nature of the facial temperature. Nasal temperature analysis for mothers suggested an increase in nasal temperature across the remaining episodes. Notably, we observed an increase in maternal nasal temperature from the baseline episode to the rest. Thus, it seems the overall procedure is not as stressful for the mothers as it is for the infants. However, we still observe the subtle soothing effects of reunions following technoference and paper-ference in thermal level, evidenced by the increase in mothers' nasal temperature.

Furthermore, we investigated thermal coregulation between mother and infant. As expected, no thermal coregulation happened during technoference and paper-ference. Autonomic coregulation strongly relies on cognitive and emotional engagement, including empathy towards the other person. However, during technoference and paper-ference there is no vocal, observational, or tactile synchronization and thus no sensory connection. Noteworthy, we found a nasal temperature coregulation during reunion following technoference. Further research is needed to better understand the additional factors influencing thermal coregulation.

In conjunction with thermal changes, we also observed an increase in infant negative affect throughout the procedure compared to baseline, with no changes found across other episodes. Additionally, there was a decrease in infant positive affect during technoference and paperference while no differences were found among the reunions following technoference and paper-ference compared to baseline. Generally, we observed increased infant negative affect and decreased infant negative affect during technoference and paper-ference compared to the baseline. While there was no recovery for the negative affect and a full recovery for the positive affect. It signifies that during reunions of technoference and paper-ference, both negative affect and positive affect were observed. In other words, we observed a still-face effect for technoference and paper-ference and a carry-over effect only for infant negative affect, as the infant positive affect showed full recovery.

Infants displayed heightened self-comforting behaviors across episodes compared to baseline. It suggests that infants may use these behaviors to manage their stress during interactions. Interestingly, they expressed more self-comforting behaviors during the technoference section compared to paper-ference, as well as during the reunion of technoference compared to the reunion of paper-ference, indicating that infants perceive technoference as more disruptive or stressful, causing a stronger need for self-comforting behaviors.

While maternal involvement in technoference and paper-ference, infants gaze less at their mothers compared to baseline. Additionally, no carry-over effect was observed in infants' gaze toward mothers during subsequent interactions. Similarly, gaze aversion increases from baseline across other episodes. Alongside behavioral responses, behavioral coregulation was also explored. A negative association was found between maternal nurturing touch and infant negative affect during the reunion following paper-ference. It appears that when infants experience more negative affect, mothers tend to increase nurturing touch to comfort them.

In conclusion, the ARIEL study explored how maternal distraction through smartphone usage can influence an infant's affect and distress, reflected in thermal cutaneous responses. Given the pervasive role of smartphones in personal life, it is essential to understand how they affect mother-infant interactions. Individual self-regulation stems from dyadic coregulation during early childhood, making it vital to identify challenges and address them securely. While the majority of studies have focused on behavioral responses, autonomic reactivities also play a crucial role in the formation of self-regulation. Infrared thermal imaging is a suitable technique in the neurodevelopmental field to record and measure the autonomic responses at a thermal level during the dyadic interaction. Due to the limited findings available with this method, further investigations and research directions in this area are needed.

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Appendix

INFANT BEHAVIORAL RESPONSE TO TECHNOFERENCE CODING SYSTEM

This system has been adapted from Stockdale et al., 2020 and is a tool to assess infants' micro-analytical response to episodes of technoference during mother-infant interaction using the Noldus Observer XT.

Scales	Description	Variable Type	Noldus coding	Noldus key
Infant Affect	1) **Negative:** Negative vocalizations, facial or body expressions: screeching, screaming, crying, fussiness, protesting, withdrawn, arching, twisting back, yawn. 2) **Neutral:** The infant does not display clear positive or negative emotionality through facial expression or other modalities 3) **Positive:** Positive vocalizations or facial expressions: laughing, cooing, smiling, vocalizations with a positive tone etc.	State event (duration)	A. Negative aff A. Neutral aff A. Positive aff	a1 = start a2 = start a3 = start **initial-state: Neutral*
Infant self-comforting	Any kind of self-comforting behaviors such as sucking thumb, rubbing face or head, holding ear, rubbing feet or hands together repetitively(not spastic movements) etc. (not including chewing or sucking lip behaviors)	State event (duration)	B. Self-comforting	s1= start s2= stop
Infant gaze	1) **Gaze to mother face**: infant's gaze is directed toward mother's face 2) **Gaze to parent's hands**: the infant's attentional focus is on maternal hands or held objects (i.e., smartphone or questionnaire) * use only when very confident 3) **Gaze to other objects in the room**: The infant's attentional focus is on an object (different from maternal	State event (duration)	C. Parent orientation C. Hands orientation C. Object orientation C. Averting	g1= start g2= start g3 = start g4 = start **initial-state: parent orientation (default)*

	hands, smartphone or questionnaire), the infant might be exploring or scanning visually the object (e.g. 360 camera). 4) **Avoiding/averting gaze**: The infant attentional focus is not on objects or mother. The gaze appears lost. There is no eye movements suggesting that the infant is engaged in active visual scanning or exploration of the environment. Use also when an infant is distressed and closing eyes.			
Infant social bid	Making attempt to get the attention of the parent either physically or vocally, either in a negative, positive or neutral way. It includes gesturing to be picked up, leaning forward,attention-seeking vocalizations etc. (may be useful to have a second coder confirm)	Point event	D. Social Bid	b = yes
Infant control	The infant face is totally or partially covered and/or is not possible to code the infant behavior for technical issues.	State event (duration)	E. Infant face is not visible and/or cannot be coded for technical reasons.	n1 = start (non-codable part) y1 = stop
Maternal touch	1) **No touch:** The parent does not touch the infant. Use this code also for "cannot see", "accidental" and "unspecified" touch occurrences. 2) **Negative:** Parent touch is somehow non-contingent, intrusive and provokes negative responses and stress in the infant. The touch may be intrusive, awkward, overwhelming, rough, etc. For instance, code was used when mother disrupts infant self-regulating behavior (ie. removing hand from mouth) resulting in infant distress.	State event (duration)	F. No touch F. Negative F. Scaffolding F. Nurturing	t1 = start t2 = start t3 = start t4 = start **initial-state: No touch*

	3) **Scaffolding:** Touch that has an instrumental/utilitarian, pragmatical (such as supporting the posture or moving the body of the infant), cognitive function (such as attention getting). Use this code also for the "static" touch. 4) **Nurturing**: touch that can be playful or affectionate			
Maternal voice	1) **No voice:** The parent is silent. Use this code also for "cannot hear" or unspecified" vocal occurrences by the parent. 2) **Negative:** Verbalizations that communicate rejection or negative comments on infants' behavior 3) **Scaffolding:** Verbalizations that includes requests, explanations, attempts to get the attention to the infant, directiveness. 4) **Nurturing:** Verbalizations that includes playful vocal productions (singing, laughing, nursery rhymes), mirroring previous vocal or gesture outputs of the infant, affectionate comments, soothing speech, mind-related comments.	State event (duration)	G. No voice G. Negative G. Scaffolding G. Nurturing	v1 = start v2 = start v3 = start v4 = start **initial-state: No voice*
Maternal control	Maternal hands are totally or partially covered and/or it is not possible to code maternal behavior for technical reasons	State event (duration)	H. maternal hands are not visible and/or touch or voice cannot be coded for technical reasons.	n2 = start (non-codable part) y2 = stop
Episode	1) Trash (before/after the SF procedure) 2) Free play 3) Technopherence 4) Paperpherence 5) Reunion techno 6) Reunion paper	State event (duration)	I. trash I. free play I. techno I. paper I. reunion techno I. reunion paper	e0 = start e1 = start e2 = start e3 = start e4 = start e5 = start

				*initial-state: Trash

ARIEL certificate given to mother-infant experimental subjects