A study on how interactions with the father influence the infant's physiological regulation of emotions within the family

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THESE

Présentée à la
Faculté de psychologie et des sciences de l'éducation
de l'Université de Genève
pour obtenir le grade de Docteur en Psychologie

par

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Thèse No 875

GENEVE

Juillet 2024
No d'étudiant : 19-339-720

Remerciements

Ce travail de thèse marque la conclusion d'une longue période de formation que je considère mémorable, notamment grâce au soutien de nombreuses personnes.

Tout d'abord, je tiens à exprimer ma profonde gratitude au Professeur Nicolas Favez, mon directeur de thèse, pour sa supervision attentive, disponible, empathique et bienveillante tout au long de mon doctorat. Un remerciement particulier va au Dr Hervé Tissot, qui a su s'adresser à cette partie de moi qui nécessitait d'être encouragée pour améliorer mes capacités de chercheur. Sur un plan personnel, je les remercie tous les deux d'avoir cru en moi et de m'avoir donné l'opportunité de concrétiser mon souhait de m'investir dans la recherche.

Un grand merci aux Professeurs Didier Maurice Grandjean et Antoine Guedeney d'avoir accepté de faire partie du jury de thèse et d'évaluer ce travail.

Je remercie mes collègues de l'UPCRI, la Dre Amylie Paquin-Boudreau, la Dre Francesca Suardi, Hana Bida, Sadegh Nashat, la Dre Sarah Cairo Notari et Thierry Matthieu, pour leur disponibilité, leur sympathie et leur énergie positive. Merci à la Dre Valentine Rattaz, avec qui j'ai étroitement collaboré durant mon doctorat. Son professionnalisme, son intelligence, y compris son intelligence émotionnelle, ainsi que son esprit positif, ont été d'un appui immense pendant mon doctorat, tant sur le plan professionnel que personnel.

Je tiens à exprimer ma gratitude envers les personnes qui ont participé à cette recherche : les Professeures Chantal Razurel et Manuella Epiney, qui ont contribué à la réalisation du projet de recherche; Caroline Eicher et Dominique Delecraz, qui ont recruté les familles participantes avec

un enthousiasme et une efficacité remarquables ; et le Dr Sylvain Delplanque, qui a beaucoup contribué à mes connaissances dans la collecte et l'analyse des données psychophysiologiques.

Un merci plein de reconnaissance à toutes les familles qui ont participé à la recherche. Leur confiance en notre travail a été essentielle à sa réalisation.

Je remercie la Fondation As’trame pour son soutien, notamment durant les mois de rédaction de cette thèse. De nombreuses réflexions dans ce travail sont liées à mon expérience clinique avec les familles que j'ai rencontrées à As’trame, ainsi qu'aux discussions stimulantes avec mes collègues de clinique.

Merci à toute ma famille. Je suis particulièrement reconnaissant envers mes parents de m'avoir transmis l'idée que le courage et la persévérance sont des atouts précieux lorsqu'on cherche à atteindre un objectif. Un affectueux merci à ma grande sœur, qui m'accompagne et m'encourage dans toutes mes initiatives. Je tiens également à remercier ma "famille de cœur", Bartolo, Catherine, Franco, Marzia et Baptiste, pour avoir facilité mon doctorat grâce à leur support et leur solidarité. Un immense merci à mes ami·e·s pour les moments partagés en Suisse et ailleurs, qui ont été précieux pour la réalisation de cette thèse.

Enfin, un merci à mon mari Dario. Ses mots d'encouragement, ses réflexions et son aide ont été indispensables pour l'élaboration de cette thèse. Aus tiefstem Herzen: Danke.

Resumé

Contexte théorique et objectifs généraux : La régulation des émotions est cruciale pour comprendre comment la relation parent-enfant façonne le développement psychologique de l'enfant. Cette étude se concentre sur la manière dont les interactions précoces avec les parents influencent la capacité des enfants à réguler leurs émotions, observables au niveau physiologique. Alors que la recherche passée s'est principalement concentrée sur la relation mère-enfant, l'impact spécifique de la relation père-enfant sur la régulation physiologique de l'enfant doit être davantage investigué. Les comportements parentaux jouent un rôle crucial dans le façonnement des interactions précoces. Des études antérieures ont montré que les symptômes dépressifs prénataux des parents et le temps partagé entre parent et enfant influencent les comportements parentaux et les relations parent-enfant, et ont finalement une incidence sur les interactions parent-enfant. Cependant, ces résultats sont principalement basés sur des études impliquant des mères, négligeant ainsi l'influence des pères au sein de la famille. Les objectifs généraux de cette thèse visent à combler ces lacunes dans la recherche passée.

Méthodes : 119 familles ont été recrutées pendant la grossesse. Trois mois après l'accouchement, les familles ont été invitées à une rencontre dans un laboratoire de l'Université de Genève. Chaque parent a été invité à interagir avec l'enfant pendant que l'autre attendait à l'extérieur de la pièce. Ces interactions ont été enregistrées, et des évaluations de la synchronie interactive ont été menées pour mesurer la qualité des interactions. Pendant les interactions, un électrocardiogramme (ECG) a également été enregistré chez l'enfant pour mesurer le tonus vagal, un indicateur des capacités de régulation. De plus, les parents ont rempli des questionnaires avant la naissance et dans les quatre semaines suivant la rencontre au laboratoire.

Résultats : Globalement, les résultats de cette étude confirment l'influence des interactions mère-enfant sur la régulation physiologique de l'enfant. Les pères n'influencent pas directement les processus de régulation physiologique de l'enfant, mais passer plus de temps avec lui en présence de la mère augmente la probabilité d'influences directes. Les pères pourraient suivre un chemin d'influence indirect en raison de leur impact sur les interactions mère-enfant et les processus de régulation de l'enfant pendant ces interactions. Les résultats ont montré que les influences mutuelles entre les membres de la famille jouent un rôle dans les processus de régulation des enfants, car elles contribuent à l'impact négatif des symptômes dépressifs prénataux des parents sur les interactions parent-enfant.

Conclusions : En conclusion, l'étude souligne l'importance de considérer les interactions familiales au-delà de la dyade mère-enfant pour une compréhension plus approfondie du développement des capacités de régulation émotionnelle de l'enfant. L'étude contribue également à une meilleure compréhension du rôle des pères dans le développement de la régulation émotionnelle des enfants et des interactions au sein de la famille, ce qui aide à clarifier l'impact des interactions familiales sur le développement socio-émotionnel précoce.

Abstract

Theoretical background and general objectives: Emotion regulation (ER) is crucial in understanding how the parent-child relationship shapes the child's psychological development. This study focuses on how early interactions with parents shape infants' ability to regulate emotions, which are observable at a physiological level. While research has mainly focused on the mother-infant relationship, the specific impact of the father-infant relationship on neonatal physiological regulation needs to be more noticed. Parenting behaviors have a crucial role in shaping early interactions. Previous studies indicate that parental prenatal depressive symptoms and parent-infant shared time are influencing factors of parenting behaviors and parent-infant relationships in early infancy, ultimately influencing parent-infant interactions. However, these findings are mainly based on studies involving mothers overlooking the influence of fathers within the family. The general objectives of this thesis are based on these gaps.

Methods: 119 families were recruited during pregnancy. At three months postpartum, the families were invited to a meeting in a laboratory at the University of Geneva. Each parent was requested to interact with the infant while the other waited outside the room. These interactions were recorded, and interactive synchrony assessments were conducted to measure the quality of interactions. During interactions, an electrocardiogram (ECG) was also recorded in the infant to measure vagal tone, an indicator of ER abilities. Furthermore, parents completed questionnaires before birth and in the four weeks following the meeting in the laboratory.

Results: Overall, the results of this study confirm the impact of mother-infant interactions on the infant's physiological regulation. Fathers do not directly influence infants' regulatory processes, but an increased time spent with the infant in the mother's presence heightens the likelihood of

direct influences. Fathers may follow an indirect pathway of influence, as they indirectly impact mother-infant interactions and infants' regulatory processes during interactions with the mother. The results showed that mutual influences between family members play a role in infants' regulatory processes as they might exacerbate the negative impact of parental depressive symptoms during the prenatal period on parent-infant interactions.

Conclusions: In conclusion, the study highlights the importance of considering family interactions beyond the mother-infant dyad in understanding the development of an infant's ER abilities. It provides valuable insights into the nuanced role of fathers in shaping infant ER and family dynamics, contributing to a better understanding of how family influences early socioemotional development.

Preface

This thesis is part of a research project titled "A process-oriented study of infant's ER during mother-father-infant interactions" (Project No. 10531C_179442), funded by the Swiss National Science Foundation (SNSF). The data presented here is directly derived from this project. This manuscript was written to obtain a Ph.D. in Psychology from the Faculty of Psychology and Education Sciences at the University of Geneva. This manuscript follows the format of an "article-based" thesis: four articles have been drafted and subsequently submitted for peer-reviewed publication in scientific journals. These four articles, included in "The empirical section" chapter, constitute the core structure of the manuscript.

The present manuscript is organized into five chapters. The "Theoretical background" chapter introduces the research described in this manuscript; it notably outlines its theoretical framework, defines its objectives, and illustrates the past research contribution. The "Methods" chapter focuses on this research's methodological and practical aspects, including details on recruitment, procedures, tools used, and a presentation of the research sample. The "Empirical Section" chapter represents the empirical part of the manuscript, composed of the four articles mentioned above. The "Discussion" chapter offers a summary of the results obtained and a discussion of the various conclusions presented in each article. Finally, the "Conclusions" chapter briefly summarizes the key aspects found in the research.

Table of contents

THEORETICAL BACKGROUND

1. Emotion regulation

1.1. Definition

Emotion regulation (ER) refers to the process by which individuals initiate and inhibit actions and modulate responses triggered by emotions (Thompson, 1994). Thompson (1994) defined ER as a "process responsible for monitoring, evaluating, and modifying emotional reactions, especially their intensive and temporal features, to accomplish one's goal" (p. 27). This definition reflects a functionalist view of emotions, wherein ER is seen as an adaptive process that enables an individual to achieve goals in the surrounding environment (e.g., coping with situational demands; Campos et al., 1994; Cole et al., 1994). In this sense, the functionalist perspective assumes the existence of a constant and mutual influence between intrapersonal experiences of emotions (e.g., feelings) and their extrinsic regulation, which depends on the environment (Walle & Campos, 2012). It follows that emotions and ER are part of the same process. Within this process, emotions are regulated and regulatory. Precisely, individuals' emotions are regulated by their intentions and their internal/external environment, and they are regulatory when they serve as information that influences the individual's relationship to the environment. In light of these considerations, ER appears inherently relational because the person and the environment are inseparable (Dempsey, 2017; Lafreniere, 2009). Therefore, to understand ER processes, it is necessary to consider the individual as inseparable from their environment, especially their social environment. In this regard, ER has an essential interpersonal component.

1.2. ER as an interpersonal process

The interpersonal component of ER is crucial in early infancy when infants depend on others to regulate their emotions. The immature infant develops patterns of ER during interactions. Parents play a pivotal role in shaping these ER patterns because they are usually the infant's principal interactants during early infancy. When interacting with the parents, the infant may need to regulate a physical or emotional state. To this end, an emotional communication system is activated between the infant and parents (Weinberg et al., 1999). This communication system, according to theories of mutual regulation (e.g., Tronick & Reck, 2009) or bio-behavioral synchrony (e.g., Feldman, 2012), enables parents and the infant to co-construct their interactive behaviors moment by moment, with changes at a physiological level (e.g., the infant's arousal). The mutual ability of each interactant to adapt to the other enables them to co-regulate during interactions. This co-regulation significantly influences ER processes. For instance, the infant uses her behavior as a signal to indicate intrapersonal (e.g., signaling hunger) or interpersonal goals (e.g., signaling a desire to interact) to the parents (Cole et al., 2004; Tronick & Cohn, 1989). The parent's ability to recognize and respond to signals from the infant influences the infant's emotional experience and arousal. As time progresses, infants shift from co-regulating emotions during interactions to advanced self-regulation, reducing their reliance on external support. This is because, over time, the co-regulation processes between the parents and the child allow the child to recognize internal states and learn how to self-regulate emotions. These co-regulation processes typically enable the child to transition from reactive, co-regulated emotions during interactions with parents to more advanced forms of emotional, cognitive, and

behavioral self-regulation in different life contexts (e.g., family and school; Kim & Cicchetti, 2010; Rutherford et al., 2015).

Considering these regulatory processes, the quality of interactions between parents and children emerges as essential. It indeed shapes the patterns of ER, which, in turn, play a crucial role in determining both the child's health and well-being (Mennin & Farach, 2007; Spangler & Zimmermann, 1999; Uvnäs-Moberg et al., 2005). Therefore, studying how the quality of parent-child interactions influences early ER is essential. It enhances our comprehension of the factors contributing to a child's socio-emotional development (Cabrera et al., 2014; Cole et al., 2004; Low et al., 2019; Morris et al., 2017; Tronick & Cohn, 1989).

2. Parent-infant interactions

In the initial months of life, infants interact with several adults (e.g., parents, grandparents, aunts, uncles, and professional caregivers) to meet their needs (e.g., feeding) and enhance their health and well-being. However, the most frequent interactions occur with parents, who significantly contribute to the infant's healthy development. Additionally, early interactions with parents are crucial, as they tend to repeat in quantity and quality, molding the parent-child relationship. Moreover, these interactions serve as a model for the infant's future understanding of the external environment and the associations between her behaviors and those of others (Stern, 1985). During infancy, research on early interactions has mainly focused on mother-infant interactions because, traditionally, the mother has assumed the role of the primary caregiver, placing the father in a secondary role. However, research has increasingly focused on fathers in line with the evolving socio-cultural perceptions of fatherhood. Since the 1970s, there has been a more extensive investigation into father-infant interactions, comparing them with

mother-infant ones to discern similarities and differences. For example, previous studies have found that fathers often adopt a play-oriented interactive style, while mothers lean towards caregiving (Cabrera et al., 2014) and that children seem to respond more positively to physical contact with fathers than mothers, possibly because mothers hold them for caregiving purposes, while fathers do so for play (Flanders et al., 2013; StGeorge et al., 2018). This disparity may manifest in the child's physiological response during interactions, with higher arousal levels with the father and lower to moderate levels with the mother (Choi et al., 2021). These findings suggest that children develop distinct expectations and learn different behavior patterns from each parent during interactions. In this sense, evidence has shown that children seem to turn to mothers for comfort and emotional support while seeking social and exploratory support from fathers (Paquette et al., 2013). These sex-specific parenting differences have been found in animal and human research alike, suggesting that they may be at least partially supported by biology. Consistent with this, some hormones associated with parenting (e.g., oxytocin, prolactin, vasopressin) have been shown to be present at similar levels in both parents but to have different effects on parental behaviors. For example, oxytocin is associated with affectionate and nurturing behaviors in mothers, while it promotes touch behaviors in fathers (Paquette & StGeorge, 2023). These differences between mother and father can contribute differently to mother-infant and father-infant interactions, which can have consequences on children's ER development. These differences can also contribute to the creation of distinct bonds, depending on the specificities of each relationship. In this sense, Paquette (2004) has proposed considering the father-child relationship as an "activation relationship" and the mother-child relationship as an "attachment relationship," although children develop an attachment relationship and an activation relationship

with each parent. The activation relationship would address the child's need to be activated and take risks while protected from potential dangers. Within this activation relationship, the child would learn to understand her or his abilities in the face of the physical and social environment. Conversely, the attachment relationship would allow the child to respond to the need to be soothed and reassured. Differences in parental behavior between mother and father could be at the origin of each relationship and how each relationship influences the child's development.

Based on previous evidence suggesting that parent-child relationships have varying impacts on socio-emotional development, as well as that social interactions play a crucial role in shaping emotional regulation patterns, it's important to assess the quality of interactions with both parents to understand the infant's socio-emotional functioning.

2.1. The quality of parent-infant interactions

Previous studies on parent-infant interactions have identified the characteristics of positive social interactions for the infant, such as "dyadic reciprocity," "dyadic conflict," "maternal sensitivity," and "dyadic synchrony" (for a review, see Lotzin et al., 2015). This study focuses on interactive synchrony, one characteristic that has been shown to be crucial between the parent and infant during their interactions. Provenzi et al. (2018) defined interactive synchrony as the "degree of congruence between trans-modal behaviors of two partners, which is lagged in time and which promotes infants' learning of emotional regulation skills and the emergence of expectations on interactive repertoires." (p.12.). Interactive synchrony implies the parent's and infant's joint efforts in interaction to increase or decrease mutual involvement and positive arousal (Feldman, 2012). In previous research, interactive synchrony has been used as an index of the quality of interactions. It has also been shown to be linked with better cognitive

development, fewer externalizing and internalizing symptoms, and adaptive self-regulation, with effect sizes ranging from small to large (e.g., Feldman & Eidelman, 2009; Hinnant et al., 2013; Kochanska et al., 2008; Laible & Thompson, 2000; Pesonen et al., 2010; Suveg et al., 2016). Interactive synchrony has temporal characteristics of "correspondence" or "co-occurrence," that is, the temporal relation of correspondence and co-occurrence between the behaviors (e.g., smiles, vocalizations) and affective states (e.g., matching of arousal level) of parent and infant (Brazelton et al., 1975; Papousek, 1995). Interactions are considered synchronous when there is a correspondence or co-occurrence between behaviors and affective states. Interactions are considered non-synchronous when this correspondence or co-occurrence is lacking. Parent-infant interactions typically contain mistakes and interactive errors that can reduce interactive synchrony (Abney et al., 2021; Lindsey et al., 2009; Tunçgenç & Cohen, 2018). For example, mistakes and interactive errors could be present when a parent continues stimulating a highly aroused infant or when a parent provides little stimulation to an infant awake and willing to interact. When the parent fails to repair mistakes and interactive errors, the infant will likely have difficulties regulating, with negative consequences for the infant's activation state and the need to increase infant regulatory efforts. However, if the parent responds promptly, flexibly, and adaptively to interactive errors, they facilitate the repair of the interaction. This, in turn, leads to an increase in interactive synchrony, allowing the infant to reduce regulation efforts. As a result, the infant becomes calmer and more attentive to the parent, fostering positive consequences for the infant's activation state. Regarding the ability to synchronize in face-to-face interactions, previous studies have shown that fathers, like mothers, can synchronize with infant signals

(Feldman, 2003), influencing children's ER and socio-emotional development (Rodrigues et al., 2021).

However, synchrony during interaction is rarely permanent, as suggested by evidence on mother-infant interactions (McFarland et al., 2020). There are at least three challenges that the parent-infant dyad must face to maintain constant synchrony during interaction. First, it proves challenging to consistently identify and correct interactive errors (Tronick & Gianino, 1986). Second, it might be challenging for parental behaviors to always be contingent upon those of the infant. Contingency is defined as a correspondence between the infant's signals and the parent's response, both in type and timing (Ainsworth et al., 1974; Bell & Ainsworth, 1972). For instance, a contingency in an interaction between a mother and an infant occurs when the mother smiles at the infant, eliciting a smile in return from the infant, demonstrating mutual responsiveness and engagement. Third, it might happen that parents sometimes unintentionally propose stimuli that are less appropriate for the infant's age and state. For example, during interaction with a 3-month-old infant, the parent can offer simple stimuli such as eye contact, smiles, vocalizations, and a toy, but quickly and without a specific order of presentation. These stimuli should be presented slowly and sequentially at this age to allow the infant to maintain an optimal level of arousal, neither too high nor too low, in order to be engaged and participate in the interaction.

As moments of reduced interactive synchrony are common, it is crucial to underline that non-synchronous interactions can be adaptive depending on the situation. To better understand how non-synchronous interaction can be adaptive, we propose three examples based on evidence in the scientific literature. First, non-synchronous interactions may contribute to the diversification of communication strategies within parent-child dyads, fostering resilience and

adaptability in response to changing environmental demands (Abney et al., 2015). Second, non-synchronous interactions could decrease the risk of synchronizing with a stressed interacting partner, thereby reducing the likelihood of heightened tensions (Wass et al., 2019). Third, non-synchronous interactions between a caregiver and an infant can demonstrate the infant's sense of security in their relationship. When the caregiver briefly steps away, the infant continues playing independently, confident in the caregiver's return for synchronous interaction later. This reflects the infant's trust in the caregiver's availability and fosters a secure attachment bond between them (Feniger-Schaal et al., 2016).

2.2. Influencing factors of parent-infant interaction

During early infancy, the quality of interaction is mainly influenced by the parent's ability to adapt their behavior to the signals and behaviors of the infant. Given the crucial role of parental behaviors, past research on parenting has focused on factors that may influence them, such as parents' own (problematic) child-rearing histories, personality disorders, and inadequate social support (Belsky & Jaffee, 2006). In this study, we focus on two factors that have been shown to be crucial for parental behaviors and parent-infant relationships during early infancy: parental prenatal depressive symptoms and parent-infant shared time (Crouter & Crowley, 1990; Larson et al., 1996). However, these findings are mainly based on studies involving mothers, overlooking the influence of fathers. From fatherhood literature, we can highlight three key aspects that underline the importance of looking at paternal influences on infants (Barker et al., 2017; Cabrera, 2020). First, fathering behaviors influence early socio-emotional development; second, there is a trend of contemporary fathers increasingly participating in infant care; and third, fathers, like mothers, can experience depressive symptoms during the prenatal period. In

light of these aspects, we think that a better understanding of how paternal prenatal depressive symptoms and the time fathers spend with infants influence early interactions within the family will provide valuable insights into how these interactions relate to infants' ER. In the following paragraphs, we delve into insights from past research on the influence of parental prenatal depressive symptoms and parents' shared time with the infant on parenting behaviors, with an emphasis on fathers.

2.2.1. Parental prenatal depressive symptoms

Previous research on early interactions has highlighted that the presence of depressive symptoms, both in mothers and fathers, constitutes a risk factor for parenting and family dynamics, subsequently influencing the well-being of children. Indeed, findings from previous studies suggest that parental depressive symptoms are correlated with a reduced capacity to interact with the child, leading to consequences on the quality of parent-child interaction (Lindstedt et al., 2021; Medina et al., 2022; Parfitt & Ayers, 2014; Sethna et al., 2015). It has been suggested in past research to differentiate between prenatal and postnatal symptoms because, despite their similar manifestation, their effects may be independent (Evans et al., 2012; Pawlby et al., 2011). In light of this suggestion, the results of a recent meta-analysis by Golds et al. (2022) appear surprising. The authors revealed that only a few studies conducted on mothers have investigated prenatal symptoms as predictors of interactive synchrony. The conclusions of these studies were inconsistent, as associations between maternal prenatal depressive symptoms and interactive synchrony after birth were negative in some studies and positive in others. Another result of this meta-analysis was to highlight the absence of studies on fathers. These findings reveal a need to further explore the effects of prenatal depressive symptoms in both

parents, with a specific emphasis on fathers, for many reasons. First, a growing body of research supports the idea that the father-child relationship is at least as meaningful as the mother-child relationship in the early months of life (Cabrera et al., 2007; Lamb & Lewis, 2004). Second, over the last 20 years, studies have found that a significant portion of fathers experience depression during the prenatal period (Barker et al., 2017; Top et al., 2016), indicating the need to consider, similarly to mothers, the influence of prenatal symptoms in fathers on the father-child relationship. Lastly, maternal and paternal depressive symptoms correlate with each other in the perinatal period (Paulson & Bazemore, 2010), necessitating a dual focus on maternal and paternal prenatal symptoms. A dual focus can allow us to investigate how mothers' and fathers' influences can be cumulative, mutual, and reciprocal on the infant and the interactions of each parent with the infant (Cabrera, 2020). This dual focus on both parents' symptoms aligns with the family-system approach, which suggests studying the interdependencies among family members (Cox & Paley, 1997; Minuchin, 1974). Examples of interdependencies among family members are the spillover and the crossover effects. The spillover effect refers to the transfer or diffusion of emotions, feelings, behaviors, or experiences generated in one subsystem (e.g., the marital relationship) to another (e.g., the parent-child relationship; Engfer, 1988; Erel & Burman, 1995). For example, satisfaction in the marital relationship influences the quality of the parent-child relationship, such as when parents transfer negativity in the marital relationship to their interactions with their children (Golds et al., 2022; Medina et al., 2022). The crossover effect refers to the transfer of experiences or affects between individuals. For example, a crossover effect occurs when parents support their children to compensate for the depressive symptoms of their spouse (Kouros et al., 2014; Nelson et al., 2009) or when their interactions with the child

are negatively affected by their spouse's symptoms (Goodman et al., 2014; Ponnet, Mortelmans, et al., 2013). Based on these premises, this study focuses on maternal and paternal depressive symptoms before birth and how they may influence the quality of interactions with the infant while considering the influence of interdependencies among family members.

2.2.2. Father-infant shared time

The time parents spend with infants influences their relationship, with consequences on their interactions. However, the time fathers spend with infants is often reduced compared to that of mothers during the perinatal period. Usually, most mothers assume the role of the primary caregiver, aligning with the traditional idea that the maternal figure is central in providing direct care to the infant, such as breastfeeding. Consequently, fathers may assume a secondary role in direct care, prioritizing indirect support, such as managing financial aspects, in line with the "breadwinner" father model. This unequal distribution of time spent with the infant by parents poses challenges as it reduces the occurrence of father-infant interactions and overlooks the potential effect of shared time by the father. Indeed, extended periods the father spends with the infant strengthen the parent-child bond, influencing the perception of intimacy, closeness, and mutual support. These perceptions, in turn, impact interactions between father and child and the child's regulation of emotions during such moments.

In the early months of life, fathers and infants can share two main types of time: dyadic time, where father and infant are together without the presence of others, and social time, where father and infant are in the presence of others, usually the mother in the early months (Bryant & Zick, 1996; Lam et al., 2012). These two types of time can have different influences on the father-child relationship. In addition to developing additional social and regulatory skills

compared to those acquired with the mother, dyadic time provides opportunities to foster father-child relational intimacy, with potential effects on the quality of interactions and infant ER (Amodia-Bidakowska et al., 2020; Crouter & Crowley, 1990; Larson et al., 1996; Palkovitz, 2019). Father-child social time in the presence of the mother represents an opportunity for the infant to develop social and regulatory skills in the presence of multiple individuals (e.g., joint attention and request, shared laughter, shared enjoyment) and for fathers, an opportunity to contribute to family processes essential for the socio-emotional development of the infant (e.g., coordination and collaboration of parents to raise their infant and the amount and intensity of positive affection directed toward the spouse as facial expressions, verbalizations with a positive tone/content, or physical signs of affection in front of the infant). For the father, who typically spends less time with the infant than the mother, shared mother-father-infant moments can be an opportunity to observe and learn from the mother's experience, that is, to observe and learn the mother's behaviors, gestures, and general ways of doing things with the infant. The influence of social time refers to the existence of mutual influences among family members, resulting from the interdependencies among its members, as previously mentioned.

3. The physiological regulation of emotions

Most studies have assessed ER in infants through observing behaviors (e.g., qualified in terms of emotional reactivity, distress regulation, ER strategy, regulatory behaviors, and recovery from a stressful situation; Ham & Tronick, 2006; Thompson, 2011). However, observed behaviors are influenced by physiological or neural processes involved in ER (Calkins & Hill, 2007; Moore et al., 2009). Therefore, supplementing observational methods with physiological measures appears essential for achieving a more comprehensive understanding of the modulation

of ER behaviors. Physiological-biological indicators provide an objective measure of the physiological or neural processes involved in ER, thereby offering insights into the modulation of ER behaviors (Dennis et al., 2012; Zeegers et al., 2018). An appropriate way to measure the physiological processes involved in infants' ER is to measure the vagal activity.

3.1. Vagal tone as a physiological index of ER

Vagal tone is an index of physiological regulation, as it contributes to the physiological mechanisms of the autonomic nervous system related to ER. According to Porges' polyvagal theory (2007), there is an association between autonomic regulation and social, emotional, and communicative regulation during interactions. Porges (2007) suggested that the two branches constituting the autonomic nervous system (ANS) —the sympathetic nervous system (SNS) and the parasympathetic nervous system (PSNS)— support adaptive behavioral strategies. Both systems are antagonists and regulate homeostatic functions. The SNS enables the mobilization of resources to cope with environmental demands, while the PSNS allows the activation of growth and restoration systems. The activity of these two systems is measurable through changes in vagus nerve activity (i.e., the tenth cranial nerve).

The vagus nerve has afferent and efferent fibers originating in the brainstem and projecting onto various organs. These fibers permit the vagus nerve to modulate organ activity and physiological processes related to ER through dynamic regulatory feedback between the brain and the organs (Montirosso et al., 2014). The vagus nerve fibers come from a dorsal and a ventral branch. The dorsal branch regulates visceral functions (i.e., respiration and digestion). The ventral branch is associated with motion, emotion, and communication processes. The evolution of the nuclei from which the two branches of the vagus nerve originate is linked to

three neurophysiological subsystems. These subsystems are phylogenetically ordered and behaviorally linked to social communication (e.g., facial expression, vocalization, listening), mobilization (e.g., fight–flight behaviors), and immobilization (e.g., feigning death, vasovagal syncope, and behavioral shutdown; Beauchaine et al., 2007). The most recent subsystem, unique to mammals, is the social communication one, associated with the ventral vagal branch. The second is the mobilization subsystem, linked with the dorsal vagal branch. The last, notably the most primitive, is the immobilization subsystem associated with the dorsal vagal branch.

The activation of these subsystems is hierarchically organized, as stated by the theory of dissolution (Jackson, 1958), according to which more recent subsystems inhibit the older ones. This means that the next subsystem takes over when the recent subsystem does not permit responses adapted to the events in the environment. Since the simultaneous operation of these neurophysiological subsystems is incompatible, the polyvagal theory (Porges, 2007) proposes the same incompatibility of simultaneous functioning between subsystems to describe the organization of the ANS's responses to environmental challenges. Once the environment is perceived as secure, the ANS exerts a parasympathetic influence on the heart by activating the vagus nerve (Porges & Furman, 2011). Therefore, increased vagal tone will be associated with reduced heartbeat and a calm state that fosters social engagement (Porges et al., 1994). However, vagal tone decreases when faced with a stressful event, leading to diminished parasympathetic influence (i.e., deactivation of the social communication subsystem). This allows the SNS to intervene, mobilizing metabolic resources necessary for the appropriate response (fight–flight, or freezing behavior if fight–flight fails) to the situation. Once the stress is reduced, the vagal tone is quickly restored to inhibit the SNS's influence (Muhtadie et al., 2015). As vagal tone reflects

changes in the body's needs, increasing or decreasing its influence, it is seen as an indicator of stress and the body's ability to organize its physiological resources appropriately (Porges & Furman, 2011). A low vagal tone index, if prolonged over time, can have adverse psychological and somatic effects such as inflammation, depression, chronic anxiety, negative moods, heart attacks, and strokes (Porges et al., 1994).

The vagal tone is more than a specific individual's way of functioning, allowing the explanation of vulnerabilities and socio-emotional difficulties. Indeed, due to its strong relational component, the vagal tone plays a crucial role in the development of ER. It enhances physiological arousal modulation and facilitates positive social interactions by regulating various parts of the body involved in communication, for instance, facial muscles and vocal cords (Porges & Furman, 2011). In a way, the vagal tone is representative of the influence of the environment —including the social environment— on the individuals, as well as the individual's capacity to respond to environmental demands. The influence of social interactions on vagal tone is at the core of this study.

3.2. The quality of parent-infant interactions and vagal tone

In early interactions, parental behaviors set the context for the quality of the infant's social experience, with consequences for ER behaviors. Besides the behavioral level, social and interactive experiences between the parent and the infant may impact the infant's development of ER at the physiological level. In line with the principles of the polyvagal theory (Porges, 2007), the study of vagal tone in parent-infant interactions, predominantly in the mother-infant dyad, has shown that the vagal tone decreases in presence of negative social and interactive experiences and increases when interaction return to "normal" to support the child's behavioral

organization during social involvement (e.g., gaze sharing and shared attention; Bazhenova et al., 2001; Feldman, 2003; Feldman et al. 2010; Field & Diego, 2008; Ham & Tronick, 2006; Lunkenheimer et al., 2020; Moore & Calkins, 2004). However, there are interindividual variations among children in how they physiologically regulate themselves, which could be explained by the quality of mother-infant interactions to which the child is exposed. The influence of the quality of interaction has been demonstrated as distinct from the impact of the characteristics of the interactive situation, for instance, in those studies using the Still-Face paradigm[1] (SF paradigm; Tronick et al., 1978) and measure of interactive synchrony. Children experiencing less synchrony in mother-infant exchanges have shown greater difficulty regulating themselves physiologically during the SF paradigm (Moore & Calkins, 2004). These children do not decrease their vagal tone during the stressful episode (i.e., the SF episode) and show no significant physiological differences between the different parts of the paradigm. In their study of infant physiological reactions during the phases of the SF paradigm, Pratt et al. (2015) have found that among low-reactive infants, synchrony builds a social repertoire for managing

[1] The SF paradigm consists of three phases, each lasting two minutes. The first phase is a “normal” dyadic interaction between an adult, usually the parent, and the infant. During the second phase, the proper Still-Face phase, the parent no longer responds, adopts a neutral facial expression, and remains silent. In the third phase, the parent returns to behaving normally. From comparing the "normal" mother-infant dyadic interaction with the interaction containing an SF episode (in the SF phase), it has been observed that an infant discerns that something different is happening and adjusts their behavior accordingly. Typically, during the SF phase, an infant initially tries to “get the mother back” using various strategies, soliciting her, then making brief smiles before turning away and throwing glances. Since these strategies do not work, an infant eventually disengages. Some infants may disengage or display high distress when the parent returns after the SF episode. However, there are interindividual variations in the infant’s reactions. For example, infants of depressed mothers, who are often exposed to unadjusted parental behaviors, show fewer behaviors aimed at “getting the mother back” in the SF phase, as if they are accustomed to this situation (Field et al., 2007); and they show fewer positive reactions in the third phase, the reunion with the parent (Field et al., 1995).

interpersonal stress, while in highly reactive infants, it constructs a platform for repeated repair of momentary interactive "failures" and reduces the natural tendency of stressed infants to disengage from the source of stress. Similarly, Provenzi et al. (2015) have observed a higher frequency of affective state matching and repair in dyads with optimal vagal functioning. While previous studies have demonstrated the contribution of mother-infant interactions to the physiological regulation of emotions through vagal activity, less is known about the contribution of the quality of father-infant interactions. This is particularly true when considering father-infant interactive synchrony and the infant's vagal tone.

4. Gaps in the literature and aims of the study

This study has two aims. The first aim is to investigate the association between the quality of father-infant interactions (measured by interactive synchrony) and the infant's physiological regulation of emotions (measured by vagal tone). The second aim is to investigate the impact of some factors influencing parental behaviors during the perinatal period—notably parental prenatal depressive symptoms and father-infant shared time—on the association between the quality of interactions and the physiological regulation of the infant’s emotions in early infancy. These two aims are based on some gaps identified in the literature, as mentioned in the introductory paragraphs of this thesis. These gaps are summarized below.

First, ER abilities are crucial for socio-emotional functioning. The quality of interactions between the infant and parents influences the infant's regulation of emotions, which is observable at a physiological level. The quality of interactions can be measured through interactive synchrony, which refers to the parent and infant's way of being in synchrony during interactions. Past studies have shown that both mother-infant and father-infant interactions influence the

development of ER abilities. However, to date, no studies have investigated, unlike those focusing on mothers, the influence of interactive synchrony between father and infant on the physiological regulation of the infant's emotions. Investigating the influence of father-infant interactive synchrony, besides mother-infant synchrony, will allow for a better understanding of the physiological regulation of infants' emotions. Second, previous studies have shown that parental prenatal depressive symptoms and the time a parent spends with the infant have emerged as influential factors of parental behaviors during the perinatal period. However, these findings are primarily focused on mothers, with fathers often overlooked. With an emphasis on both parents, investigating these influencing factors will contribute to a better understanding of their impact on the association between the quality of interactions and the physiological regulation of the infant's emotions in early infancy.

METHODS

5. Methodological aspects of the research

This study was conducted following the guidelines of the Declaration of Helsinki. This study used data from a primary study on infant ER and family functioning that received approval from the Ethical Committee of the State of Geneva and support from the Swiss National Science Foundation (grant no. 10531C_179442). The main aims of the primary study were, first, to monitor the infant's vagal tone (as an index of emotion regulation) during a sequence of mother-father-infant interactions and to assess the extent to which the infant's vagal activity is related to the quality of triadic interactions (assessed in terms of family alliance), and, second, to assess the links between infant's vagal tone and infant's psychosocial outcomes (e.g., sleep and eating behaviors). Various measurement methods have been used in the primary study to pursue its main aims, notably observational (e.g., interactive behaviors), physiological (e.g., infant's electrocardiogram), and self-reported methods (questionnaires filled out by parents). The primary study was a longitudinal study with three measurement points: T1, between the 36th and 38th week of pregnancy, to recruit parents and to collect data through questionnaires; T2, between three and four months postpartum, to record mother-father-infant interactions, to collect infant's vagal tone during interactions, and to assess several variables through questionnaires; and T3 at 18 months postpartum, to collect infant's and family outcomes data through questionnaires. This study focused on measures at T1 (i.e., prenatal) and T2 (i.e., three months post-partum) to assess, first, the extent to which the infant's vagal activity is related to the quality of father-infant interaction besides mother-infant ones, and, second, the influence of perinatal parental variables (i.e., prenatal depressive symptoms, parent-infant shared time) on parenting behaviors, ultimately influencing the quality of parent-infant interactions.

5.1. Recruitment and sample

Recruitment occurred from December 10, 2018, to September 1, 2021, and involved 119 families. At T1, a midwife recruited parents at the maternity unit of the Geneva University Hospitals (HUG), during routine check-ups, in the waiting room, or at birth preparation classes. The midwife explained to the parents that the study's focus was the infant's emotions. She presented the research objectives and then gave the parents a consent form that the interested participants had signed. The average age was 33.6 (SD = 4.1) for mothers and 35.8 (SD = 5.6) for fathers. About 50.6% of parents were married, while others were in informal partnerships, some having experienced divorce or separation from a previous relationship. Most mothers (64.9%) and fathers (52.4%) had attained an academic degree, and 79.8% of mothers and 91.7% of fathers were actively employed. Between T1 and T2, 20 families dropped out of the longitudinal research without providing a specific reason, and we had to cancel the participation of 4 families due to the Covid lockdown. Consequently, the final sample comprises 95 families, 46 girls and 49 boys. The families included in the study represent a convenience sample, as the only requirement for inclusion was an adequate understanding of the French language to complete diverse questionnaires.

5.2. Procedure

5.2.1. Prenatal

The initial phase of the study took place at HUG. Between the 36th and 38th week of pregnancy, the couple (or the mother individually) attended a consultation with the midwife in charge of recruitment. During this consultation, fetal cardiac monitoring was conducted for five minutes while the mother lay in a calm environment. This ensured a check for any cardiac issues

in the infants. Families were informed during this consultation that they would receive a set of online questionnaires to complete before childbirth. These questionnaires covered sociodemographic information, prenatal stress, depression, and marital satisfaction.

5.2.2. Three months post-partum

The study's second phase occurred at Uni-Mail, University of Geneva, between the third and fourth month after childbirth. Two researchers of the Unit of Clinical Psychology of Interpersonal Relationships (in French, Unité de Psychologie Clinique des Relations Interpersonnelles [UPCRI]) contacted families approximately two months after birth to schedule an appointment. During the meeting, one of the researchers welcomed the families and managed the consultation. In contrast, the other researcher handled technical aspects such as videos and physiological signals, observing everything from the control room. At the beginning of each meeting, both researchers introduced themselves and explained their roles to the families. Initially, a discussion moment was dedicated to summarizing the overall context of the study, describing the appointment procedure, and addressing any questions. Once the parents and the infant were ready, the infant was placed on a changing table and undressed to allow the application of three pediatric electrodes on the chest to record the electrocardiogram (ECG). After placing and connecting the electrodes, the parents positioned themselves around the infant. At the same time, a baseline heart rate recording was performed while a researcher transmitted the instructions. The researcher asked the parents to interact with the infant following an adapted version of the Lausanne Trilogue Play paradigm (LTP; Fivaz-Depeursinge & Corboz-Warnery, 1999). The adapted version included four parts of 2 minutes each. In the first part, one parent played with the infant while the other was outside the room. In the second part, the parents

changed roles. We counterbalanced the order of the parts to have an equal distribution between the mothers and fathers who interacted first. In the third part, the two parents played with the infant during a triadic interaction. Finally, in the fourth part, the parents had a discussion, leaving the child on his or her own for a short while. Before starting the interactions, the researchers indicated the position of the cameras. They specified that the experiment could be interrupted if the infant showed excessive fatigue or distress. The researchers instructed the parents to interact with the infant as usual, avoiding objects if possible. At the end of the interactive play, interested parents were offered an additional meeting for a debriefing in the form of video feedback. Additionally, parents were provided with a link to complete online questionnaires.

We modified the original LTP paradigm to overcome challenges in collecting physiological data. In the initial setup, the infant's position on a chair interfered with the ECG signal. To address the interference of the ECG signal, we opted for a changing table, a setup validated for family assessments (Rime et al., 2018). Additionally, we adjusted the first two phases of the LTP to analyze the dyadic and triadic interactions separately. As discussed in the introduction, parental behaviors of one parent toward their infant are influenced by the other parent, particularly in the initial phases of the original LTP setup, where the second parent is present but not actively involved. Thus, we modified the original paradigm by incorporating two exclusively dyadic interactions. This adjustment enables us to analyze the quality of these interactions without interference from the second parent's presence. In this study, we considered only the first two parts of the adapted LTP paradigm: each parent's interactions with the infant.

5.3. Measures

5.3.1. Observational measures

Interactive synchrony

We assessed mother- and father-infant interactive synchrony at T2 with the Child-Adult Relationship Experimental Index (CARE-Index; Crittenden, 2006). The CARE-Index is an adult-infant interaction assessment that can be used from birth to 25 months. The coding system assesses global dyadic synchrony, that is, parents' sensitive behavior and infants' cooperative behavior, within the context of parent-infant interactions. Scores ranged from 0 to 14, with higher scores indicating better dyadic synchrony. To ensure inter-rater reliability, a random sample of 23.8% of the video recordings (20 videos of 84[2] families at T2) was initially coded by two researchers of the UPCRI team, both trained and certified as research raters in February 2022. The intraclass correlation (two-way random absolute agreement) on the synchrony scores was excellent, with a coefficient of .982 (Koo & Li, 2016). The entire sample of parent-infant interactions was coded from March 2022 to August 2022. Coders were blind to the results of the other analyses presented in the following sections.

5.3.2. Physiological measures

Vagal tone

An ECG was recorded during the baseline and the three subsequent parts of the interactive play. However, in this study, we focus on ECG recorded during the mother-infant and

[2] The number of videos mentioned in this section may differ from those reported in the articles due to the sample selection used for the analyses.

father-infant interactions. Physiological data were collected with a Biopac MP160 system (Biopac Systems, Inc.) and recorded on AcqKnowledge 5.0 software (Biopac Systems, Inc.). The infants' cardiac activity was processed on Kubios HRV v2.2 software to obtain heart rate variability measures reflecting vagal tone. Analyses allowed us to derive the root mean square of successive differences (RMSSD), which represents the activity of the parasympathetic system and is widely considered a valid measure of vagal activity (Laborde et al., 2017). A high RMSSD indicates significant heart rate variability, with larger and more variable intervals between consecutive heartbeats, suggesting increased parasympathetic nervous system activity. This variability is often interpreted as an indicator of healthy cardiac regulation, highlighting the body's ability to adapt and respond effectively to the surrounding environment. In contrast, a low RMSSD indicates reduced heart rate variability, suggesting lower parasympathetic nervous system activity.

5.3.3. Questionnaires

In each of the three phases of the longitudinal study, parents were invited to respond to a series of online-accessible questionnaires (further details in Figure 1). This study focuses on a questionnaire at T1 related to parental depressive symptoms and on one at T2 concerning fathers' shared time with the infant. Although other questionnaires were not extensively analyzed in this study, they will be discussed in the final section of this thesis. This will allow considerations for possible supplementary analyses concerning the results obtained in this study.

Figure 1. Questionnaires in each phase of the longitudinal study

	Phase I (prepartum)		Phase II and III (postpartum)	
Variable	Questionnaire	Nb of items	Questionnaire	Nb of items
Maternal Stress	APSI	19	PNPSI	19
Depression	EPDS	10	EPDS	10
Marital satisfaction	RAS	7	RAS	7
Parental self-esteem	-	-	BAP	12
Romantic attachment	-	-	ECR-R	36
Involvement in childcare	-	-	PICQ	14
Gatekeeping	-	-	PGS	9
Coparenting	-	-	PAM	20
Infant behaviors	-	-	IBQ	37
Infant sleep	-	-	BISQ	10

Note. APSI = Antenatal Perceived Stress inventory (Razurel et al., 2014); EPDS = Edinburgh postnatal Depression Scale (Cox, Holden, & Sagovsky, 1987; Guédeney & Fermanian, 1998); RAS = Relationship Assessment Scale (Hendrick, 1988); PNPSI = PostNatal Perceived Stress Inventory (Razurel, Kaiser, Dupuis et al., 2013); BAP = Being a Parent (Johnston & Mash, 1989); ECR-R = Experiences in Close Relationships-Revised (Favez, Tissot, Ghisletta, Golay, & Cairo Notari, 2016; Fraley, Waller, & Brennan, 2000); PICQ = Parental Involvement in Childcare Questionnaire (Hossain & Roopnarine, 1994); PGS = Parental Gatekeeping Scale (Fagan & Barnett, 2003; Favez, 2015); PAM = Parenting Alliance Measure (Abidin & Konold, 1999); IBQ = Infant Behavior Questionnaire-Revised, very short form (Putnam, Helbig, Gartstein, Rothbart, & Leerkes, 2014); BISQ = Brief Infant Sleep Questionnaire (Sadeh, 2004).

Parental prenatal depressive symptoms

We assessed mothers' and fathers' depressive symptoms at T1 through the Edinburgh Perinatal/Postnatal Depression Scale (EPDS; Cox et al., 1987). The EPDS is a 10-item self-report scale that assesses the symptoms of depression between 28–32 weeks in all pregnancies and 6–8 weeks postpartum. Responses are scored from 0 to 3. The lowest and the highest scores to be obtained from the scale are 0 and 30. Items 1, 2, and 4 are scored from 0 to 3, but items 3, 5, 6, 7, 8, 9, and 10 are in reverse score order. The EPDS has been validated in women and men (Areias et al., 1996; Massoudi et al., 2013; Matthey et al., 2001). A cut-off of 14/15 was found to

be optimal for prenatal screening for major depression (Murray & Cox, 1990). In this study, we used the French version of the test (Guedeney & Fermanian, 1998) and computed a total score for mothers ($\alpha = .81$, $n = 86$) and fathers $\alpha = .79$, $n = 77$) by summing the item scores at T1. The French version of the test established a cutoff score of 11 points for clinical depression; however, in the present study, our primary focus was on the continuous scores on the scale. The higher the score, the more prenatal depressive symptoms were reported by the parent.

Father-infant shared times

At T2, both parents filled out questionnaires to report fathers' involvement in day-to-day care in terms of the number of parts of the day per week (morning, afternoon, evening, night) that they spend with the infant (either alone or accompanied by the infant's mother or other persons, such as grandparents, nanny, others). Given the aims of this study, we focused on the sum of the parts in which the father shared time alone with the infant to calculate the dyadic time shared with the infant and the sum of the parts in which the father was involved together with the mother to calculate the social time shared with the infant. Measuring the amount of dyadic time and social time allowed us to estimate the recurrence of these two times and, regarding the aims of this study, how their recurrence influences the associations between the quality of interactions and the infant's physiological regulation of emotion. Although fathers were shown to be reliable reporters of their involvement with young children (Wical & Doherty, 2005), we controlled fathers' reports of father-infant shared time by comparing them to mother-reported data. As we did not find any significant differences between fathers' and mothers' reports, we used only fathers' reports of their involvement in this study.

THE EMPIRICAL SECTION

6. Introduction to the empirical section

This study consists of four articles submitted to or published in scientific journals. There are two main aspects common to the four articles. Firstly, they share a common focus on the associations between parental behaviors, the quality of interactions with the infant, and the regulation of the infant's emotions. Secondly, they highlight the influence of fathers. Overall, these aspects contribute to a better understanding of fathers' impact on the physiological regulation of the infant. Moreover, they provide greater insight into parental behaviors within the family.

The four articles are as follows:

- The first article is a literature review on the associations between father involvement—both in terms of quality and quantity—and child ER during early childhood (0-5 years).

The second, third, and fourth articles present and discuss scientific data collected within the longitudinal research described in the previous section:

- The second article investigates the association between father-infant synchrony and infant vagal tone, examining whether father-infant shared times moderate this link.
- The third article investigates the associations between interactive synchrony and vagal tone during mother-infant and father-infant interactions, considering mutual influences among family members.
- The fourth article investigates how the prenatal depressive symptoms in mothers and fathers relate to the quality of parent-infant interactive synchrony at three months

post-birth. It investigates two effects: the influence of each parent's depressive symptoms on their interactive synchrony with the infant (actor effect) and the impact of their partner's depressive symptoms on their interactive synchrony with the infant (partner effect).

Article I

Father involvement and emotion regulation during early childhood: a systematic review

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This article is under review in the *BMC Psychology* journal.

Abstract

Father involvement, defined in terms of both the quantity and quality of father-child interactions, affects the child's development. How specifically father involvement links to emotion regulation during early childhood (0–5 years) is, however, less clear. This literature review synthesizes research on the links between father involvement and emotion regulation during early childhood, as well as the measurement methods used to assess them. Ten relevant studies were identified via four databases (up to August 2023). Results showed no significant direct links, but significant links appeared between high father involvement and better emotion regulation when moderated by variables related to the assessment of father involvement and emotion regulation, as well as the characteristics of the father and the child. Future research should continue to use observational measures of father behaviors and child emotion regulation, increase the use of physiological measures of emotion regulation, and consider the influence of maternal and family variables.

Keywords: father involvement, father behaviors, emotion regulation, early childhood, father-child relationship.

Father Involvement and Emotion Regulation during Early Childhood: A Systematic Review

Over the last 40 years of research, father involvement has emerged as a determining factor in children's social and emotional development. Defined in terms of both the quantity and quality of father-child interactions, father involvement is acknowledged as a factor that influences the development of emotion regulation (ER) capacities in children, which are central processes in their early socio-affective development (Blandon, 2015; Cabrera et al., 2007; Lang et al., 2014). ER can be defined as "the extrinsic and intrinsic processes responsible for monitoring, evaluating, and modifying emotional reactions, especially their intensive and temporal features, to accomplish one's goals" (Thompson, 1994, pp. 27–28). The development of ER is a central process, as the competence of a child to regulate emotions may prevent several mental health disorders and sustain the development of positive skills (e.g., prosocial behaviors and the ability to cope with stress; Barnett et al., 2021; Chen et al., 2015; Cole et al., 2009; Djambazova-Popordanoska, 2016, Morris et al., 2010). Some studies in the field have, however, yielded contrasting results regarding the nature of the contribution of father involvement to ER development in children. To date, no review has been dedicated to synthesizing findings on this topic regarding children during early childhood (0–5 years), despite ER being of paramount importance during the first years of life. The aim of this review was thus to fill this gap by synthesizing the results of previous studies and the measurement methods that have been used.

Father Involvement and Early ER in Children

Despite growing recognition of the role of paternal involvement in children's development, there are fewer studies on its influence compared with that of maternal

involvement, especially in early childhood (Blandon, 2015; Cabrera et al., 2007). Several factors may explain this difference. First, for several decades (until 1970–1980), studies on parenting, especially in the early childhood period, focused only on mothers, primarily because most households were traditionally organized according to specialized roles, with mothers taking care of the child(ren) and fathers being the breadwinners. Since the 1970s, sociocultural changes in the conception of fatherhood and family organization have led to a general increase in the involvement of fathers during early childhood in Western countries. An imbalance between women and men in family life still exists, however, and mothers, whether working or not, still assume the role of primary caregiver for children in most families (Goldscheider et al., 2015). Indeed, there is far more variation in father involvement than there is in mother involvement toward children. This imbalance is also spurred by family policies in many Western countries, where mothers are encouraged to take (or receive) maternity leave, whereas paternity leave remains marginal or even nonexistent in some countries (Huebener et al., 2019). Although imbalance persists, the fact remains that father involvement with young children has increased steadily over the past 50 years. As a consequence, scholars have started to conduct more studies about father involvement and its influence on child development.

Research on fatherhood has shown that fathers play a unique role in children's development, as they exhibit distinct parenting behaviors compared with those of mothers. For example, fathers engage more in physical play, encourage children to take risks, are more likely to help children deal with scary situations, and elicit higher emotional arousal in children during interactions (Anderson et al., 2019; Baker, 2017). The unique parenting behaviors displayed by fathers have suggested that their involvement can have a unique influence on the cognitive,

social, and emotional development of their children. This suggestion has been highlighted by previous studies, whose results have been synthesized in several reviews, although they did not specifically focus on ER (Adamson & Johnson, 2013; Amato & Gilbreth, 1999; Diniz et al., 2021, 2023; Rodrigues et al., 2021; Sarkadi et al., 2008). An exception is a recent literature review that specifically emphasized the role of fathers in the child's ER development during the first 18 years of life, revealing that "a good modelling of ER by fathers, supportive emotion-related parenting practices, and a positive father–child emotional climate were associated with higher ER skills in children" (Islamiah et al., 2023, p. 35). However, this review did not specifically focus on father involvement during the early childhood period (0–5 years), a pivotal period for socioemotional development during which the majority of self-regulatory abilities are built and parents' involvement is crucial in shaping them (Bariola et al., 2011; Volling et al., 2002). During the early childhood period, children typically move from reactive, coregulated emotions during interactions with adults (primarily parents in the early years) to more advanced forms of emotional, cognitive, and behavioral self-regulation in different life environments (e.g., family, and school; Kim & Cicchetti, 2010; Rutherford et al., 2015). The progression toward more advanced forms of self-regulation is a continuous process that can significantly be influenced by challenges experienced in the early years (e.g., the transition from home to formal schooling; Chen et al., 2015; Cole et al., 2009; Djambazova-Popordanoska, 2016). Father involvement may increase or decrease the quality of the children's ability to self-regulate. In summary, the early years of life are crucial for children's socioemotional development as they become progressively able to self-regulate. Within this period, the active involvement of fathers

plays a crucial role in the ongoing process of developing ER skills, as children depend on others, especially the parents, to learn how to self-regulate emotions.

Models and Measures of Father Involvement and Child's ER

The fields of research on father involvement and ER are marked by methodological, conceptual, and theoretical heterogeneity. This heterogeneity within both fields poses challenges in forming a clear picture about which aspects of father involvement relate to those of ER. Regarding the field of research on father involvement, a first observation is that there is no consensus on a model conceptualizing father involvement and that many conceptual and theoretical models have been formulated and serve as conceptual bases for operationalizing father involvement in research (e.g., Lamb, Pleck, & Levine [1987] tripartite model; Paquette's [2004] theory of the father–child activation relationship; Pleck's [2012] multidimensional model of father involvement; Cabrera and colleagues' [2014] heuristic model; Palkovitz & Hull's [2018] resource theory of fathering; Volling & Cabrera's [2019] developmental ecological systems framework). Although these models partially overlap each other, each may contain a different set of central dimensions (e.g., direct engagement, accessibility, warmth, control, responsibility, presence/absence of fathers, frequency of caregiving, physical and cognitively stimulating activities, indirect care), which may make it difficult to synthesize the results of studies in the field (Cabrera, 2020). A second observation is that there is no clear consensus on the naming of phenomena related to father involvement. For example, interchangeable terms, such as "father involvement," "father engagement," and "fathering," have been used to refer to "father involvement" (Rowbotham et al., 2011). Nonetheless, there is a relative consensus that fathers can be involved in different ways (such as directly interacting with the child, overseeing

activities, and meeting their needs) and that the concept of father involvement can be defined either in terms of quantity (time spent with the child) or quality (the nature of paternal behavior during interactions with the child; Cabrera, 2020; Lamb, 2000; Pleck, 2012). However, this consensus is less generalized when it comes to determining how to measure the quantity and quality of father involvement. Indeed, a third observation is that there is no clear consensus on the "optimal" method for assessing father involvement. This lack of consensus on assessment methodologies poses a significant challenge in synthesizing the results of the field. This is because different sets of surveys, behavioral observations, and interviews have been used in the research to assess the quantity and quality of father involvement. Survey-based research has mainly focused on the quantity of father involvement in order to assess, for example, the number of tangibles: concrete activities that fathers perform for or with their children and the amount of time (e.g., hours per day, days, or times per week) spent together (Cano et al., 2019; Gaertner et al., 2007). Through surveys or interviews, studies have also investigated the quantity of continued presence of fathers in the household, in the child's life, or in providing economic support to the mother (Dyer et al., 2011; Jampaklay et al., 2018). When researchers could not easily recruit fathers, they often used mothers to obtain information on father involvement in terms of the quantity and continuous presence of the father, which potentially leads to biased data (Adamsons, 2018; Dubeau et al., 2013). Conversely, observational measures have often been used to investigate the quality of father involvement as, for example, the quality of the father-child relationship or parenting style (Hirschler-Guttenberg et al., 2015; Pleck, 2010). Studies on the quality of father involvement have also resorted to surveys, observations, or interviews to assess overall indicators of father involvement. These overall indicators typically

encompass information on various domains of father involvement such as care, hygiene, nurture, discipline, learning, and play with the child (Amodia-Bidakowska et al., 2020; Betancourt et al., 2020; Wang & Liu, 2018; Wilson & Prior, 2010).

Similar to the field of research on father involvement, research on ER in young children has used several measures for assessing ER, leading to debates on how each measure may be the "gold standard" to assess children's ER (Adrian et al., 2011; Larsen & Prizmic-Larsen, 2006; Mazefsky et al., 2021). Previous reviews have highlighted three main methods to assess ER in young children, to which the present paper will refer: informant report (parent, teacher, or peer), naturalistic or laboratory observation, and physiological-biological indicators. As self-reports are not an appropriate method in early childhood because of the limited verbal capacities of infants and toddlers, researchers have frequently resorted to informant reports (mostly from parents). Informant reports have the advantage of being quick to administer and easy to analyze; however, they are subject to various biases, including extreme responses and social desirability influences (Paulhus & Vazire, 2007). Existing questionnaires (for a review, see Freitag et al., 2022) investigate different aspects of children's ER, such as the degree of emotion dysregulation, the use of regulatory strategies, or overall ER scores calculated from one or more subscales of a child's development questionnaire (for a review of different aspects of ER assessed by self- and informant reports, see Mazefsky et al., 2021). Naturalistic or laboratory observation measures have frequently been used to assess children's ER during early childhood. They often involve situations that elicit emotions of frustration, anger, or fear in the child (e.g., the mother disappears for a few minutes and the child remains alone in the room; Ham & Tronick, 2006). The behaviors that the child displays during these situations can be coded by the experimenter as

ER strategies, distress regulation, and recovery from a stressful situation. In non-stressful situations, (e.g., free play; Fox, 1989), designed to elicit no specific response from the child, the child's behaviors can be assessed as strategies of emotion management (Thompson, 2011). Although observational methods allow researchers to objectively measure ER in children, their administration and analysis are time-consuming. Physiological-biological indicators are also used to assess physiological or neural processes involved in ER (Calkins & Hill, 2007; Moore et al., 2009). These indicators (e.g., heart rate variability and cortisol; Dennis et al., 2012; Zeegers et al., 2018) provide an objective measure of the processes involved in ER, which are crucial in the modulation of ER behavior. However, each indicator allows for measuring one aspect of ER processes, and so it is recommended to use them in combination with other ER measures (Weiss et al., 2014). The heterogeneity of measures for assessing ER makes it necessary to summarize which have been used in relation to father involvement so that the links between the two constructs can be better identified, gaps highlighted, and future research guided.

Taking these considerations about father involvement and ER into account, in the present paper, we aimed to (1) synthesize the literature on the links between father involvement and ER during early childhood, (2) describe the methods used to study the link between father involvement and ER in children's first 5 years, and (3) identify and discuss gaps in the literature and provide directions for future research on the link between father involvement and children's ER in early childhood.

Method

The systematic review protocol was developed by following the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA; see Figure 1) recommendations (Moher et al., 2009).

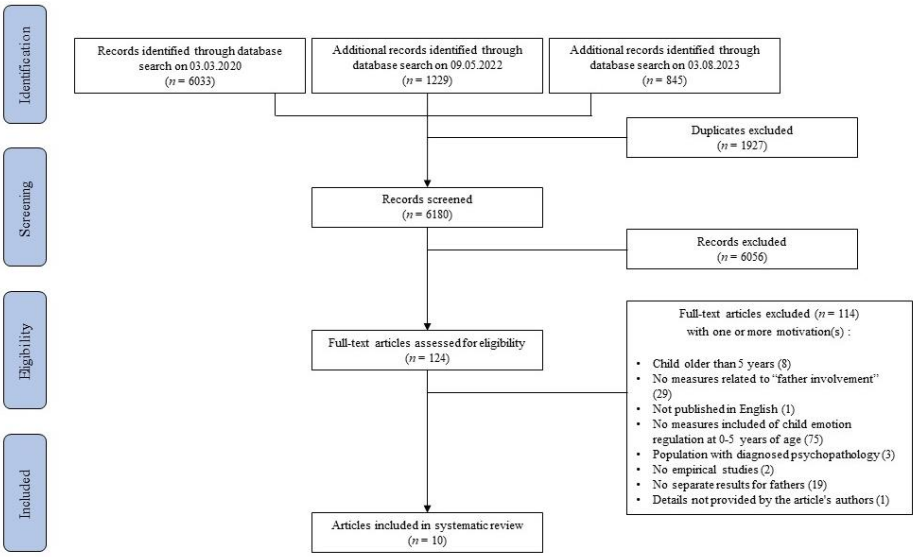

Figure 1. Prisma flow diagram of the article search and select process

A research algorithm was created with terms related to father involvement (e.g., "father accessibility," "father engagement") and ER (e.g., "socioemotional development," "affect regulation," "psychophysiology"). Search algorithms are available online as supplementary material in Appendix A. Four international web databases were searched (PubMed, PsycNET, EMBASE, and Web of Science) by the first author, with the first search conducted on March 3, 2020, the second on May 9, 2022, and the third on August 9, 2023. The articles were selected by the first and second authors according to the following criteria: (1) studies including men presented as involved paternal figures, despite marital status or biological relation; (2) studies involving 0- to 5-year-old children; (3) studies involving no fathers or children with a diagnosis

that affects ER; (4) studies with measures related to “father involvement”; (5) parenting studies that distinguished results for fathers from those for other caregivers (e.g., mother); (6) studies reporting at least one measure of child ER collected between 0 and 5 years of age; (7) studies published in a peer-reviewed journal; (8) studies published in English; (9) only empirical studies; and (10) no guidelines, syntheses, systematic or non-systematic reviews, meta-analyses, perspective articles, or theoretical or conceptual models.

Studies identified in database searches were exported to EndNote 20.1. Two reviewers (first and second authors) independently evaluated titles and abstracts, and then full texts. Consensus meetings were held at each stage to determine progression to the next stage, and the fourth author resolved discrepancies. Reasons for exclusion were documented in a spreadsheet and disagreements were resolved by consensus. A total of 8107 studies were found from the extended search. After duplicate articles were removed (n = 1927), 6056 non-relevant articles were excluded based on the title and abstract. The remaining 124 articles were screened based on the full text, and 114 studies were excluded according to the inclusion/exclusion criteria. Finally, 10 articles were included in the systematic review, with data derived from 10 studies. The extended details of the included articles are available online as supplementary material in Appendix B.

Results

We organized the results by grouping the studies according to the two categories in which father involvement can be defined, namely, quantity and quality of father involvement. For each of the two categories of father involvement, we present the studies that have measured ER as informant reports, naturalistic or laboratory observation, and physiological-biological indicators.

The extended details of data from the included articles are available as supplementary material in Appendix B.

Population

Several studies included in this review reported partial or incomplete information about the characteristics of their samples, thus limiting an accurate summary of available characteristics (see supplementary material in Appendix B). All studies were conducted in the United States, except for one (Italy). Of the 10 studies included, seven were longitudinal and three were cross-sectional. Fathers' education was diverse in most studies, ranging from no formal education to university education.

Although most studies did not consider or provide more details on the socioeconomic status of fathers, the available information indicates that a majority were middle-class fathers, except for three studies with a mix of lower-, middle-, and upper-class fathers, and one study with low-income fathers. In seven of the 10 included studies, fathers lived with the mother and their child. Children's mean age ranged from 3 to 42.36 months. Of the 10 studies included, three focused on infants (0–12 months), three on toddlers (13–35 months), and three on preschoolers (3–5 years), whereas one contained mixed ages. Fathers' mean age ranged from 25.51 to 35.86 years. Most of the included studies focused on fathers of mixed ages (i.e., range 35–64 years; n = 6), two studies focused on young fathers (18–35 years), and two studies did not mention the age of the fathers. The living arrangements of families were reported as follows: not specified (n = 2), married (n = 1), married or cohabiting (n = 2), mostly married (n = 3), mostly married or cohabiting (n = 2). All studies concentrated on different-sex parents (three of them explicitly mentioned focusing on heterosexual families). In six of the 10 included studies, there was a

disparity in the sample between female and male infants or toddlers. Eight of the 10 included studies were published after 2019, indicating a recent trend in investigating the links between father involvement and ER during early childhood. The data collection period was approximately deduced by using available information, such as the reported study's grant number, as none of the included studies explicitly indicated the years in which the data were collected. In two of the 10 studies, details about the data collection period were unavailable. In the remaining eight studies, data collection occurred before 1999 in one study, between 2000 and 2015 in three studies, and after 2016 in four studies. Considering the information about the publication years and data collection years in the included studies, we recommend that forthcoming research explicitly specify the years of data collection. This step could improve the interpretability of the results in the context of socio-cultural changes related to the conception of fatherhood and the roles assumed by "new" fathers.

Methodological Characteristics

Father Involvement. Of the 10 included studies, five considered father involvement in terms of quantity, four in terms of quality, and one in terms of both quantity and quality. In these studies, the quantity of father involvement was reported by fathers (n = 4), mothers (n = 1), or both parents (n = 1). In all five studies that assessed the quality of father involvement, researchers used direct observation of father-infant interactions. Among the included studies, the quantity and quality of father involvement were measured by referring to several aspects of father involvement, in many cases considering two or more aspects simultaneously. In most of the studies targeting the quality of father involvement, the authors considered a set of the fathers' behaviors during interaction with the child, computing global or subscale scores (e.g., the

average score of the father's positive emotions coded for each 30-s interval of interaction with the child) that indicated the quality of involvement during these interactions (n = 5). The remaining studies focused on the quantity of father involvement in diverse care, play, and teaching activities (n = 4). One study focused on father involvement as the quantity of fathering styles (e.g., fathers' authoritative and permissive parenting), and one study investigated father involvement as the father's continuous physical presence or absence. Of the 10 studies included, three assessed father involvement during the first 12 months of infants' lives, three when toddlers were between 13 and 36 months old, and three when preschoolers were between 3 and 5 years old. In the study that assessed father involvement in terms of both quantity and quality, the assessment of quantity was conducted within the infant's first 12 months of life, whereas the assessment of quality occurred once within the initial 12 months and then again when the toddler was 24 months.

Emotion Regulation. Most studies examined ER during naturalistic or laboratory observation (n = 4), and researchers assessed children's ER during interactions with fathers (n = 1), during interactions with both parents (n = 1), or during tasks with no parents involved (n = 2). Of the remaining studies, three investigated ER with informant reports (father's report, n = 1; mother's report, n = 1; both parents' report, n = 1) and three as physiological-biological indicators. Of the 10 studies included, three assessed ER during the first 12 months of infants' lives, four when toddlers were between 13 and 36 months old, and three when preschoolers were between 3 and 5 years old.

Narrative Synthesis of the Results

Quantity of Father Involvement

ER as Informant Reports. The only study that investigated informant-reported ER found no significant direct link between the variables, but significant links appeared that were based on the informant. Indeed, links between the greater quantity of father involvement and better child ER appeared when the mother, not the father, reported the quantity of father involvement (De Stasio et al., 2020). Although no definitive conclusion can be drawn, the results of this particular study encourage investigations of the links between the quantity of father involvement and the reported ER and how the informants may reveal these links.

ER as a Naturalistic or Laboratory Observation. Of the three studies that investigated observed ER, only one found significant direct links, notably between the greater quantity of father involvement and better child ER (Aquino et al., 2023). The other two studies found that significant links between the greater quantity of father involvement and better child ER appeared when other variables were considered: assessment time of ER and father's ethnicity (Bocknek et al., 2014), and assessment characteristics of ER and measured aspects of the infant's temperament (Planalp & Braungart-Rieker, 2015). In the first of the two studies, Bocknek et al. (2014) found positive links between mothers' reports of a more consistent father presence and greater child ER, as evaluated by researchers. Notably, these links were significant at 24 and 36 months, but not at 14 months. In addition, positive links were observed for fathers of Caucasian ethnicity, but not for fathers who were African-American or Hispanic. These findings highlight the cultural aspect inherent in the concept of involvement, as proposed by certain fatherhood models (Santis & Barham, 2017), and align with the idea that a father's influence evolves during

a child's development (Jeynes, 2016). Nevertheless, caution is warranted in interpreting the results of Bocknek et al.'s (2014) study due to the potential inclusion of separated couples in the sample. Specifically, half of the fathers either lived separately from or were not married to the mothers, suggesting the plausible presence of separated parents. In cases of separation or divorce, various factors could have influenced mothers' reports of father involvement, including parental conflicts, family organization, and economic challenges—especially considering the low-income fathers observed in the study by Bocknek et al. (2014). The impact of these factors, alongside the coexistence of families with both separated and non-separated parents, might have contributed to the weakening of significant direct links between the constructs of interest across the entire study sample. Future investigations should take into account these considerations and the influence of family variables, especially in the case of separated or divorced parents. In the second of the two studies, Planalp and Braungart-Rieker (2015) found that the fathers' report of their greater involvement at home influences infant ER during infant-father interactions. However, links were moderated by the assessment of ER and the infant's temperament. Indeed, only infants lower in surgency (a dimension of temperament) increased in self-distraction faster when father involvement was higher and slower when father involvement was lower. No links were found in the analyses that considered self-comforting as a regulatory behavior, and negative affectivity and regulation as infants' dimensions of temperament. These results highlight the pivotal role of children's temperament in shaping their regulation, emphasizing the need for future research to incorporate this aspect. In addition, they underscore the multidimensional nature of ER, suggesting that its links with the quantity of father involvement may vary based on the specific dimension of ER measured. Nevertheless, it is crucial to acknowledge that this was

the only study that exclusively depended on the father's reports of the infant's temperament, omitting input from the mother, for example. Moreover, regulatory strategies were observed during the Still Face Paradigm (Tronick et al., 1978), a scenario designed to specifically elicit frustration in infants, which might potentially constrain the generalizability of the findings to other emotions, such as fear. To address these considerations, future studies should include multiple measures of infant temperament (e.g., from multiple informants) and examine determinants of regulatory behaviors in various emotion-eliciting contexts.

When we compared the three included studies, we identified some variables that differed across studies and might have influenced the observed differences in their results: timing of data collection, sample size, assessment time of ER and father involvement, assessment characteristics of ER and father involvement, informant of father involvement, father's socioeconomic status, father's ethnicity, and age and gender imbalance between the samples of infants, toddlers, and preschoolers. Among these variables, two stand out, notably differing in the study that found direct links compared with the other two that identified indirect links between the constructs when accounting for certain variables. The first variable is the father's educational level. Aquino et al. (2023) found direct links in a sample of fathers who were mostly university graduates, whereas Bocknek et al. (2014) and Planalp and Braungart-Rieker (2015) reported indirect links in samples of fathers with diverse education levels (i.e., no formal education, primary, secondary, university). The existence of significant direct links, particularly among highly educated fathers, could suggest an influence of paternal education level. Alternatively, the strength of these direct links may be amplified by the higher probability of highly educated fathers taking paternity leave (Reich, 2011). This could enhance opportunities for fathers to exert

their influence through more frequent interactions with the infant from early infancy onward, thus reinforcing links between involvement and ER. Additional research is required to validate these speculative explanations. The second identified variable is the gender imbalance in the sample. Aquino et al.'s (2023) study is the only one among the three with an imbalance, in which 58% of the children were male. The gender distribution in the remaining two studies was roughly even, with about half of the participants being male and the other half female. The presence of significant direct links may thus be indicative of a gender difference. Nevertheless, this explanation is speculative and requires a more thorough investigation.

In summary, the results of these three included studies collectively suggest that direct links between the constructs are likely and that certain variables may moderate these links (assessment time of ER and father's ethnicity, and assessment characteristics of ER and measured aspects of the infant's temperament), leading to significant associations. However, the heterogeneity observed across the three studies makes it challenging to draw definitive conclusions, highlighting the need for further investigation.

ER as a Physiological-Biological Indicator. The two studies (Isaac et al., 2023; Richter & Lickenbrock, 2021) that looked at ER as a physiological measure found no direct links between variables, but significant links appeared between the quantity of father involvement and ER when certain variables were taken into account: assessment characteristics of father involvement and assessment time of ER. Isaac et al. (2023) found that greater children's physiological stress measured via hair cortisol concentration is positively associated with fathers' reports of more frequent authoritarian parenting and, more specifically, with fathers' reports of higher physical coercion. Links were absent when other fathering behaviors were considered

(fathers' authoritative and permissive parenting; fathers' non-reasoning/punitive behavior), thus revealing that they appeared according to the type of father involvement considered. Richter and Lickenbrock (2021) found links between fathers' self-reported higher involvement in caregiving (as opposed to play) and elevated average scores in infants' cardiac regulation, specifically respiratory sinus arrhythmia, during interactions with both mothers and fathers. This finding suggests that the links were influenced by the quantity of father involvement, indicating that children mobilized greater physiological resources to regulate themselves in the presence of both parents when fathers were more involved. In the same study, correlations between father involvement (in play and care) and infant's cardiac regulation were shown to vary in significance under certain conditions (i.e., time of measurement of the respiratory sinus arrhythmia), such that when fathers were more involved in play, infant's cardiac regulation increased at 4 months (and not at 8 months); when fathers were more involved in care, infant's cardiac regulation increased at 8 months (and not at 4 months), thus revealing that links appeared according to the time of the assessment of ER.

In summary, the results of these two studies suggest that direct links are unlikely and that considering certain variables may increase understanding of the occurrence of significant links between the two constructs. In light of these findings, we suggest that future studies further investigate the links between the quantity of father involvement and the physiological regulation of ER and should take into account the impact of the assessment characteristics of father involvement and the assessment time of ER.

Quality of Father Involvement

ER as Informant Reports. Of the two studies that investigated informant-reported ER, one found no links (Olofson & Schoppe-Sullivan, 2022) and one found no direct significant links between variables, but significant links appeared between the greater quality of father involvement and better child ER when the assessed aspects of father involvement and ER were considered (Altenburger & Schoppe-Sullivan, 2020). Specifically, Altenburger and Schoppe-Sullivan (2020) found a positive link between fathers' reports of children's regulatory capacity and only one of the three dimensions of father involvement measured during the interaction with the infant (positive affect, and not sensitivity and detachment). When comparing the two studies, we observed a notable degree of heterogeneity, underscoring the need for caution in formulating definitive conclusions. Specifically, as outlined by Olofson and Schoppe-Sullivan (2022) and Altenburger and Schoppe-Sullivan (2020), the two studies exhibit significant differences in terms of the age category of the sampled children (infants vs. toddlers), sample size (n = 182 vs. n = 62), timing of ER assessment (3 months vs. 12-18 months), and father involvement assessment (9 months vs. 12-18 months), as well as the designated informant for ER (father vs. mother). These variations, and their potential impact on the study outcomes, warrant thorough investigation by future research endeavors to elucidate the findings of this review. Despite their heterogeneity, the results of the two included studies suggest that direct links are unlikely, and significant associations emerge when specific aspects of father involvement and ER are considered. Consequently, there is a pressing need for further research to explore the associations between the quality of father involvement and a child's ER, as reported by informants.

ER as a Naturalistic or Laboratory Observation. Of the two studies that investigated observed ER, only one found direct links, notably between the greater quality of father involvement and better child ER (Aquino et al., 2023). Aquino et al. (2023) found that an increase in the quality of paternal behaviors during interaction with the child increased the child's ability to regulate with the father. In the other study, Lunkenheimer et al. (2020) found that higher quality of paternal behaviors during interaction with the infant positively influences the infant's ER, but only when the infant regulates during interaction with the mother. These findings underscore the need to consider the child's ER when interacting with each parent, as suggested by previous studies (for a review, see Rattaz et al., 2022). This approach will help identify direct links between the father and child, as well as shed light on indirect influences that may be related to maternal variables.

In comparing the two studies, we observed notable differences in two variables between them. These two variables may have acted as a moderator on the links found in each study, and we suggest further research to consider their influence on the investigated links. The first variable was the assessment time of both constructs. Aquino et al. (2023) found direct links when assessing the two constructs when the child was between 8 and 24 months old, whereas Lunkenheimer et al. (2020) conducted assessments at 36 months. This suggests that a direct link may be more likely in children who are less than 2 years old. The second variable was the characteristics of the ER assessment. Aquino et al. (2023) found direct links in a study that observed ER during a frustrating task and in the absence of both parents. Conversely, in Lunkenheimer et al.'s (2020) study, in which the child interacted with both parents in a non-stressful situation, no direct links were found. We speculate that in more arousing situations (e.g.,

those that are stressful), the child may activate regulatory processes learned during shared moments with the father, making links more likely to be significant. This explanation, requiring further investigation, is inspired by theories suggesting that fathers contribute to more challenging and stimulating interactions (social role theory; Eagly, 1987) and engage in more physically stimulating and unpredictable play (theory of the father-child activation relationship; Paquette, 2004).

In summary, despite definitive conclusions being limited by the heterogeneity of the two included studies, their results suggest the likelihood of direct links and indicate that certain variables, such as the person with whom the child interacts, may moderate these links, leading to significant associations.

ER as a Physiological-Biological Indicator. The only study that investigated the physiological regulation of emotions found significant links between the greater quality of father involvement and poorer ER (higher total cortisol output; Burniston et al., 2023). The results of this particular study make it challenging to draw any conclusions. We encourage caution in interpreting them, as the physiological indicator of ER (cortisol) was measured during interactions with mothers, limiting our understanding of how father involvement directly influences children's ER. In this study, the negative links found might reflect more of the influence of maternal variables than paternal ones, such as the impact of maternal behavior on children's physiological ER during interactions with their mothers. Given these considerations, we recommend further research to provide deeper insights into the links between the quality of father involvement and a child's physiological ER. Moreover, these future investigations should assess physiological indicators of ER when the child interacts with the father.

Discussion

The results of this review on the associations between father involvement and ER in early childhood are heterogeneous. However, some general conclusions may be drawn about these associations and the measurement methods used to assess them. We discuss below the available information about the results by referring to the category of father involvement (i.e., quantity and quality) and ER (i.e., as informant reports, naturalistic or laboratory observation, and physiological-biological indicators).

Overall, the studies we have reviewed indicate that the quantity and quality of father involvement are not directly associated with a child's ER during early childhood. Indeed, only one study reported direct associations between the quantity and quality of father involvement, on the one hand, and the child's ER, on the other hand. Different explanations can be put forward to explain this lack of direct associations between the variables. A first reason could be that, although father involvement may be adequate, it may not be equivalent to the level of maternal involvement during early childhood. Despite societal and cultural shifts promoting increased father involvement, traditional family roles, in which fathers work full time and mothers serve as the primary caregivers, remain prevalent during early childhood (Shorey et al. 2019). This arrangement can affect the quantity and quality of father-child interactions, which, though adequate, may not be as influencing as mother-child interactions in reinforcing direct associations between parental involvement and ER (Deans, 2018; Klimes-Dougan et al., 2007). Future studies should consider investigating nontraditional family configurations, which were notably absent in this review. This exploration could help ascertain whether the strength of associations between the two constructs increases when fathers assume the primary caregiver

role. For instance, a comparison between fathers who take on the primary caregiver role and work part-time or not at all could offer deeper insights into the results of this review, although recruiting such fathers may pose challenges.

Although this review showed weak direct associations between the target variables, many included studies reported significant indirect associations between greater involvement and better ER in children, that is, when other variables were taken into account (for detailed information and consideration about how these variables moderate the investigated associations, see Section 3.3, Narrative Synthesis of the Results). These variables, which may relate to the assessment of father involvement and ER (e.g., time, what was measured), as well as the characteristics of both the father and the child (e.g., gender and ethnicity), seem to moderate the associations between these two constructs. Further exploration of these moderating variables could offer deeper insights into their influence on the associations between father involvement and ER during early childhood.

Regarding measurement methods, this review confirms that previous research exhibits a certain heterogeneity in the assessment of father involvement and the child's ER, notably during early childhood. Concerning the associations between these two constructs, this review suggests that the outcomes of the included studies vary based on the methodology, as the presence or absence of links between them appears to depend on the chosen measurement methods. For instance, the use of observational measures of ER seems to increase the likelihood of finding direct links with the quantity and quality of father involvement. This result underscores the importance of careful consideration in selecting methodologies and taking into account their potential impact on the investigated links. Taken together, the results of the included studies

suggest certain trends in the methods used to study the associations between father involvement and ER in children's first 5 years of life. Building on these trends, we propose considerations that merit further investigation. First, most of the results of this review relate to studies that investigated the associations between either the quantity or the quality of father involvement and the observed child's ER during interactions, notably in interactions in which the mother is absent. This finding seems to highlight that contemporary fathers may be less difficult to recruit than those of the past, as they are more available to report their involvement with the child and to take part in research involving the extended periods required to record direct interactions with children (Mitchell et al., 2007). Moreover, the increasing prevalence of observational measures in more recent research seems to reflect scholars' effort to observe fathers' influence on their children's ER during interactions, despite the advantages derived from the use of questionnaires that are convenient and easy to administer and analyze (Patten, 2016). Second, physiological measures of ER were uncommon in the included studies that focused on investigating the associations with the quantity of father involvement, and even less common in studies that investigated the quality of father involvement. When physiological measures were used to investigate associations with the quality of involvement, it appeared that the child tends to have a greater need to physiologically regulate emotions during interactions with a more involved father. However, this greater need to regulate emotions was found during interaction with the mother and never assessed with the father. Taken together, these findings about physiological measures of emotions indicate that future research should continue to investigate how both the quantity and the quality of father involvement seem to be associated with the need for children to physiologically regulate their emotions during interactions. Furthermore, when placed in

perspective with previous research on mother-child interactions, the findings of this review about physiological regulation may suggest a future direction for research. Although previous studies on mother-child interactions have often demonstrated associations between higher interaction quality and better physiological regulation of emotions in children (Moore & Calkins, 2004), the results of this review seem to suggest that higher quality paternal behaviors reduce the child's ability to physiologically regulate emotions with the mother. To fully understand whether a child's physiological responses adapt differently depending on the involved parent and the paternal variables considered, future research must further explore patterns of child physiological regulation during interactions with each parent. Third, in the majority of the included studies, both parents provided reports on their child's emotional regulation, with fathers serving as the primary informants regarding their involvement with the child. These included studies consistently revealed that increased father involvement generally did not show associations with the child's ER. However, in one study, the associations appeared when considering both mother and father reports of father involvement (Aquino et al., 2023). This finding suggests that the utility of questionnaires might be limited by individual biases and that the likelihood of associations notably increases when using both parents' reports of father involvement. One factor that might have influenced the lack of associations is how the questionnaires assessing father involvement and ER combined various aspects into overall scores. Indeed, the results of the included studies show that previous research has used global indices of involvement and ER (perhaps in an attempt to capture all the different aspects of both constructs) and generally found no associations between them. Given that both constructs have multiple dimensions, it is plausible, although further research is needed, that aggregating diverse dimensions into a single

score might constrain the understanding of each dimension and their interconnections. Future research should clarify these considerations by investigating which of these aspects of father involvement and ER (aggregated together to produce general indices) are the most informative for the associations between the constructs of interest. Finally, among the included studies, few investigated the association between the constructs of interest by using two or more measures to assess their multiple dimensions, instead focusing, for example, on the association between one dimension of father involvement and one dimension of ER (as categorized for both of them in this review). Future research should make greater use of multiple types of measures to assess the multidimension of both constructs of interest and thus fill the gaps in previous research.

Limitations

This literature review entails a few limitations. First, cultural representativity is almost nonexistent due to the quasi-majority of studies having been conducted in the United States. Moreover, it is important to note that only one of the included studies used both parents to report father involvement. Future research should include measures of both parents from other countries to control possible bias that is specifically due to the mother, father, or cultural context. The categories used to synthesize the results, although useful for the aims of this review, could underrepresent the multidimensionality of both father involvement and ER, and may therefore be non-exhaustive. A certain heterogeneity in the theoretical framework in the included articles, the methodology, and the approach used to investigate the constructs of interest, as well as the absence of nontraditional family configurations, might limit the generalizability of the results and the possibility to draw clear conclusions.

Conclusions

This literature review synthesizes existing findings in the literature about the associations between father involvement and ER during early childhood, as well as the measurement methods used to assess them. The information available in this review underscores what has been done and highlights what warrants further investigation (e.g., associations within nontraditional family configurations). In particular, this review points out that the included studies on the quantity and quality of the father's involvement reported no direct influence on the child's ER during early childhood. However, the positive influence of greater father involvement on ER during early childhood appeared when studies considered variables related to the assessment of father involvement and the child's ER (e.g., time, what was measured) and to fathers and children (e.g., gender and ethnicity). Future investigations should include these variables and clarify their moderating influence on the association between the father's involvement and the child's socioemotional developmental outcomes. The findings of this review are mostly based on included studies that used observational measures of ER. More measures of involvement and ER reported by both parents are needed to provide insight and reduce possible bias due to the reported measures of only one parent. This review emphasizes the scarce use of physiological measures in studying children's ER, especially in research examining how the quality of father involvement relates to it. Indeed, only one study delved into the influence of the quality of involvement in the physiological regulation of emotion. This particular study did not involve father-child interactions. Hence, we recommend that future research encompass these interactions along with mother-child interactions. This broader approach would offer a more comprehensive understanding of how a father's involvement affects a child's ER by taking into

account potential influences between family members and considering measures related to both parents. Considering that the majority of the included studies were conducted within the last two decades and primarily relied on observational measures for both constructs, this review highlights a burgeoning trend of contemporary fathers actively engaging in research related to early childhood fatherhood. This trend may reflect fathers' growing interest in understanding their role during this crucial developmental stage and, more generally, their awareness regarding the influence of their involvement on children's socioemotional development.

Article II

Father-infant synchrony and infant vagal tone as an index of emotion regulation: father-infant shared times in Switzerland as moderator

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This article has been published in *Early Child Development and Care.*

Puglisi, N., Tissot, H., Rattaz, V., Epiney, M., Razurel, C., & Favez, N. (2023). Father-infant synchrony and infant vagal tone as an index of emotion regulation: father-infant shared times in Switzerland as moderators. *Early Child Development and Care*, *193*(15-16), 1714–727. https://doi.org/10.1080/03004430.2023.2274287

Abstract

Research has shown that the quality of mother-infant interactions, such as the way the mother and the infant are in synchrony during interactions, is associated with infants' vagal tone, a physiological indicator of emotion regulation. However, little is known about the association between the infant's vagal tone and the quality of father-infant interactions. The existing literature suggests that the greater quantity of time a father spends with the infant, either alone (dyadic time) or with others (social time) may strengthen the association between the quality of father-infant interactions and infant emotion regulation. In this study, we aimed to investigate the association between father-infant synchrony and infants' vagal tone during interactions and whether dyadic time and social time have a moderating role. Fathers ($N = 77$) and 3-month-old infants were observed interacting and the infants' electrocardiogram was recorded to compute indices of vagal tone. Fathers reported dyadic and social time in questionnaires. Results showed that father-infant synchrony has no direct associations with infants' vagal tone. Moderation analyses revealed that more social time increases the association between synchrony and vagal tone. This study suggests that the interactive processes during shared family time may influence dyadic father-infant interactions and the infant's vagal regulation.

Keywords: synchrony, father-infant interactions, emotion regulation, vagal tone, infancy

Father-Infant Synchrony and Infant Vagal Tone as an Index of Emotion Regulation: Father-Infant Shared Times in Switzerland as Moderator

Studies have shown that the quality of mother-infant interaction is associated with the infant's emotion regulation, which has been assessed at a physiological level through changes in the infant's vagal tone during the interactions. However, little is known about the links between the infant's vagal tone and the quality of father-infant interactions. The amount of time that fathers share with their children can foster the father-infant relationship, with consequences for their interactions and the infant's emotion regulation during these interactions.

Emotion Regulation as an Interpersonal Process

Emotion regulation can be defined as the 'process responsible for monitoring, evaluating and modifying emotional reactions, especially their intensive and temporal features, to accomplish one's goal' (Thompson, 1994, p. 27). Poor emotion regulation is associated with difficulties in social-emotional functioning and with externalizing and internalizing symptoms (Aldao et al., 2016; Berking & Wupperman, 2012; Crespo et al., 2017; Ekas et al., 2013). Emotion regulation consists of both intrinsic and extrinsic processes within the individual, with a strong influence from and on the environment. In early infancy, the immature infant needs adults, in particular the parents, to learn how to regulate emotions, so that in the first months of life, emotion regulation occurs as a result of co-regulation between the infant and caregiver(s) (Weinberg et al., 1999). According to the theories of mutual regulation (e.g., Tronick & Reck, 2009) or bio-behavioural synchrony (e.g., Feldman, 2012), there is an emotional communication system between infant and parent(s) in which they co-construct their interactive behaviours during moment-to-moment interactions as they proceed, with changes at a physiological level

(e.g., the infant's arousal). The quality of the parent-infant communication system thus influences the infant's emotion regulation during interactions. The parents' and infants' ease in co-constructing the interaction increases the quality of their interactions, helps regulate physiological arousal related to behavioural organization, and positively sustains the infant's emotion regulation. Conversely, difficulties in co-constructing the interaction may reduce the quality of the interaction, impair the regulation of physiological arousal related to behavioural organization, and make the infant's emotion regulation more likely to be difficult. Thus, during interactions with parents, the infant, who may need to regulate a physical or emotional state, uses his or her behaviour as a signal to indicate intrapersonal (e.g., signalling hunger) or interpersonal (e.g., signalling wanting to interact) goals to the parents (Cole et al., 2004; Tronick & Cohn, 1989). The parent's ability to recognize and respond to signals from the infant influences the infant's emotional experience and arousal, and contributes to the quality of interaction. Through the repetition of these processes, the infant learns to recognize internal states and how to self-regulate emotions. These regulatory processes between parent and infant show that emotion regulation has a strong interpersonal component and that the quality of parent-infant interactions, as a marker of the quality of co-regulatory processes between the infant and caregiver(s), is crucial in the development of emotion regulation abilities (Cole et al., 2004; Morris et al., 2007).

Parent-Infant Co-regulation: The Role of Interactive Synchrony

One important feature of the co-regulatory processes at work during parent-infant interaction is 'interactive synchrony,' defined as the joint efforts of parent and infant in interaction to increase or decrease mutual involvement and positive arousal (Feldman, 2012). Parent-infant synchrony takes both the parent's and infant's behaviours in dyadic interactions

into account and considers the parent-infant relationship as bidirectional. Synchrony has temporal characteristics of 'correspondence' or 'co-occurrence,' that is, the temporal relation of correspondence and co-occurrence between the behaviours (e.g., social age, vocalizations) and affective states (e.g., matching of arousal level) of parent and infant, which favour the maintenance of synchronous interactions between them (Brazelton et al., 1975; Papousek, 1995). When correspondence or co-occurrence between the behaviours and affective states are lacking, interactions are considered non-synchronous. During non-synchronous interactions, interactive errors may be present between parent and infant, at both the level of response type and the level of temporal characteristics (Abney et al., 2021; Lindsey et al., 2009; Tunçgenç & Cohen, 2018). For example, interactive errors could be present when a parent continues to stimulate a highly aroused infant or, conversely, when a parent provides little stimulation to an infant who is awake and willing to interact. When interactive errors occur, the parent fails to regulate the infant, with negative consequences for the infant activation state and the need to increase infant regulatory efforts. In these cases, if the parent reacts to interactive errors in a rapid, flexible, and adaptive manner, the interaction is repaired and the infant may reduce regulation efforts and be calmer and more attentive to the parent, with positive consequences for the infant's activation state. From an emotion regulation perspective, greater parent-infant synchrony allows the infant to maintain an optimal state of activation during interactions, reduce regulatory efforts, and be more engaged during interactions. In contrast, when interactions are repeatedly non-synchronous, the infant must rely on greater regulatory efforts to maintain an optimal state of activation (Abney et al., 2021; Feldman, 2017; Palumbo et al., 2017).

Vagal Tone as a Physiological Index of Emotion Regulation

An appropriate way to measure emotion regulation in infants is to measure vagal activity, as the vagus nerve contributes to the physiological mechanisms of the autonomic nervous system related to emotion regulation. According to the polyvagal theory (Porges, 2007), there is an association between autonomic regulation (e.g., reduced vagal influence and increased sympathetic influence on the heart) and social, emotional, and communicative regulation during interactions. Porges (2007) states that the sympathetic nervous system and the parasympathetic nervous system—two branches of the autonomic nervous system—support adaptive behavioural strategies. The activity of these two systems is measurable through changes in vagus nerve activity (i.e., the 10^{th} cranial nerve). The vagus nerve is part of a bilateral system that regulates emotions and modulates organ activity, as afferent and efferent vagus fibres are part of a dynamic regulatory system between the brain and the organs (Montirosso et al., 2014). The fibres of the vagus nerve come from a dorsal and a ventral branch. The dorsal branch is associated with the regulation of visceral functions (i.e., respiration and digestion). The ventral branch is associated with motion, emotion, and communication processes. The polyvagal theory (Porges, 2007) proposes that after the environment is perceived as secure, the autonomic nervous system exerts a parasympathetic influence on the heart through the activation of the vagus nerve (Porges & Furman, 2011). Therefore, the increased vagal tone will be associated with a reduced heartbeat and the occurrence of a calm state that fosters social engagement (Porges et al., 1994). With the occurrence of a stimulus perceived as a threat or a danger in the environment, vagal tone will decrease, leading to a diminished parasympathetic influence. This allows the sympathetic system to intervene to adopt an adaptative reaction to the situation in the form of a ‘fight-or-flight’

response and to mobilize the metabolic resources that are necessary to accomplish this response. After the stress is reduced, vagal tone is quickly restored to inhibit the sympathetic nervous system's influence (Muhtadie et al., 2015). As vagal tone reflects changes in the body's needs, by increasing or decreasing its influence, it is seen as an indicator of stress, as well as of the body's ability to organize its physiological resources appropriately (Porges & Furman, 2011). According to Porges' (2007) polyvagal theory, the variation in vagal tone relates to the experience and expression of social and emotional behaviour, so that vagal tone suppression is a physiological index for difficulties in social and emotional regulation. The quality of parent-infant interaction may have an influence on the vagal system, which, given its interpersonal component, improves the modulation of physiological arousal and enables the infant to regulate and engage in positive social interactions (Porges & Furman, 2011). The quality of mother-infant interaction, specifically mother-infant synchrony/non-synchrony, has been shown to be associated with infants' vagal regulation. Pratt et al. (2015) found that mother-infant synchrony correlates positively with vagal withdrawal and predicted vagal withdrawal. Feldman et al. (2010) reported that vagal tone correlates positively with tactile synchrony and negatively with tactile mis-synchrony. Finally, Provenzi et al. (2015) observed that a dyadic matching of affective states and interaction repair more frequently in dyads with optimal vagal functioning.

To our knowledge, no studies to date have investigated the associations between the quality of father-infant interactions and physiological indicators of emotion regulation. Although the studies that compared early mother-infant and father-infant interaction patterns showed similar levels of synchrony, some differences in arousal levels were reported: Neutral or low arousal seemed to more frequently characterize mother-infant interactions, whereas more points

of high arousal associated with exciting and animated moments of the interactions seemed to characterize father-infant interactions (Feldman, 2003; Kokkinaki & Vasdekis, 2015; Neri et al., 2017). Thus, interactions with the father are an opportunity for the infant to interact with a different social partner than the mother and to experience another type of interaction and regulation, with different consequences for the infant's arousal. The first aim of this study was thus to assess the associations between father-infant interactive synchrony and the infant's vagal tone as an index of emotion regulation.

Father-Infant Synchrony and Infant Emotion Regulation: Father Involvement as a Moderator

During the first months, most infants in Switzerland have few opportunities to interact with their father because they spend most of their time with their mother who is still on maternity leave, whereas paternity leave lasts only 2 weeks (Swiss Civil Code, 2021). The father spending a greater amount of time with the infant may support the father-infant relationship by influencing the perception of intimacy, closeness, and mutual support, with consequences for father-infant interactions and the infant's effort to regulate during them. The functionalist perspective of emotion regulation may provide a further explanation of how father-infant shared times could influence the associations between interactive synchrony and infants' vagal regulation in father-infant dyads. According to the functionalist perspective of emotion, the infant's emotion regulation, supported by the activation of physiological patterns, would regulate the infant's emotional reactions and promote goal achievement during interactions with parents (Thompson, 1994). At 3 months, the infant is more likely to achieve everyday goals (e.g., being comforted, fed, or changed) during recurrent interactions with the mother and thus to develop physiological

patterns of emotion regulation in this context. With a less accessible father (due to the short paternity leave), the 3-month-old infant may have limited experience with how to achieve goals and how to regulate him- or herself during interactions with the father, with consequences for the activation of physiological patterns of emotion regulation. In other words, the 3-month-old infant who has more opportunities to interact with the father may better understand how to achieve goals when with the father and develop appropriate physiological patterns of emotion regulation in response to what happens with the father. In the first months of life, the father and the infant may share two main types of time: dyadic time (father and infant interact alone) and social time (father and infant interact in the presence of the mother) (Bryant & Zick, 1996; Lam et al., 2012). Beyond developing additional social and regulatory abilities to those developed with the mother, dyadic time also provides occasions to foster father-infant relational intimacy with likely influences on the quality of their interactions and the regulation of the infant's emotions (Amodia-Bidakowska et al., 2020; Crouter & Crowley, 1990; Larson et al., 1996, Palkovitz, 2019). Father-infant social time in the presence of the mother represents an opportunity for the infant to develop social and regulatory skills in the presence of more people (e.g., joint attention and request, laughing together, shared enjoyment), and for fathers, an opportunity to contribute to family processes that are important for the socioaffective development of the infant (e.g., the coordination and collaboration of the parents to raise their infant, and the amount and intensity of positive affection directed toward the spouse such as facial expressions, verbalizations with positive tone/content, or physical signs of affection in front of the infant). For the father, who generally spends less time with the 3-month-old infant than the mother does, the mother-father-infant shared moments can be an opportunity to observe and learn from the mother's experience,

that is, to observe and learn the mother's behaviours, gestures, and general ways of doing things with the infant.

Considering father-infant shared time as a facilitator of the father-infant relationship (Crouter & Crowley, 1990; Larson et al., 1996) and as an additional opportunity for the 3-month-old infant to develop emotion regulation abilities with a social partner other than the mother, the second aim of this study was thus to assess the extent to which shared time may moderate the links between father-infant interactive synchrony and infant's vagal tone, considered as an index of emotional regulation.

From the literature, we hypothesized that, during father-infant interactions, the infant's vagal tone would be positively associated with father-infant interactive synchrony. We also hypothesized that high shared time (both dyadic and social times) would increase the association between higher father-infant synchrony and increased vagal tone, whereas little shared time would decrease the association between higher father-infant synchrony and increased vagal tone.

Method

Participants

The participants were a sample of 77 father-infant dyads. The mean age of the fathers was 35.83 years (*SD* = 5.68) and of the infants was 15.40 weeks (*SD* = 1.27). The infants were 43 boys and 34 girls. The fathers (*n* = 61 due to missing data) were mostly university graduates (45.5%) and employed (76.6%), 62.3% of them full time (*n* = 59 due to missing data). The fathers (*n* = 61 due to missing data) were mostly married (35.1%) or in a free relationship (39%, some of them being divorced or separated from a previous relationship). Among the employed

fathers (n = 59 due to missing data), 5.1% reported having decreased their occupation rate after the birth of their infant.

Procedure

The data from this study on the father-infant dyad are part of a larger study on emotion regulation and family functioning. Participant families were recruited by a midwife around the 37th week of pregnancy at the maternity unit of the University Hospital of Geneva. After the research was presented to the parents, we asked those who were interested to sign a consent form. Three months after birth, we contacted the parents to schedule a visit to the lab when the infant was between 3 and 4 months old. On that occasion, the infant's heart activity was measured during family playtime. After reminding the parents of the context of the study and explaining the course of the experiment, we invited them to place the infant on a changing table. Three paediatric electrodes were installed on the infant's chest to record an electrocardiogram (ECG). We then asked the parents to play with their infant following a four-part situation inspired by the Lausanne Trilogue Play (LTP; Fivaz-Depeursinge & Corboz-Warnery, 1999). In the first two parts, each parent got to play with the infant for 2 min while the other parent was out of the room. In the third part, the two parents played together with the infant for 2 min. Finally, in the last part, the parents were asked to have a discussion for 2 min in front of the infant. Of these four-part situations inspired by the LTP, this paper uses data only from the father-infant part. The parents were aware that the interactions were filmed through cameras whose position in the room was indicated by the research team. The parents were instructed to interact as usual; to avoid, if possible, using objects; and not to carry, pick up, or place the infant in a sitting position on the changing table. At the end of the interactive session, we removed the

electrodes from the infant, and the parents were required to fill out a form to receive online self-report questionnaires. A debriefing in the form of video feedback was offered to parents who expressed interest. The present study was conducted according to the guidelines established by the Declaration of Helsinki, with written informed consent signed by parents for themselves and each infant before any evaluation or data collection. The study and its protocol were approved by the Geneva State Ethics Committee Ethics Committee.

Measures

Father-Infant Synchrony

We assessed father-infant synchrony with the infant CARE-Index (Crittenden, 2006). The CARE-Index is an adult-infant interaction assessment that can be used from birth to 25 months. The coding system determines a global dyadic synchrony score by assessing the interaction pattern of both parents and infants, that is, fathers' sensitive behaviour and infants' cooperative behaviour within the context of their interaction. Scores ranged from 0 to 14, with higher scores indicating better dyadic synchrony. The total sample of 77 father-infant interactions was coded from March 2022 to August 2022. To ensure inter-rater reliability, a random blinded sample of 25.9% of the video recordings (20 videos of a total sample of 77) was initially coded by the first and second authors, both certified by Crittenden as research raters in February 2022. The intraclass correlation (two-way random, absolute agreement) on the synchrony scores was excellent, with a coefficient of .982 (Koo & Li, 2016).

Vagal Tone

The infant's cardiac activity was recorded with an ECG during father-infant interactions. The data were collected with a Biopac MP160 system (Biopac Systems, Inc.) and recorded on AcqKnowledge 5.0 software (Biopac Systems, Inc.). The infant's cardiac activity was processed on Kubios HRV v2.2 software to obtain measures of heart rate variability, which reflects vagal tone. Analyses allowed us to derive the root mean square of successive differences (RMSSD), which represents the activity of the parasympathetic system and is therefore widely considered to be a valid measure of vagal activity (Laborde et al., 2017).

Father-Infant Shared Times

Both parents filled out questionnaires to report fathers' involvement in day-to-day care in terms of the number of parts of the day per week (morning, afternoon, evening, night) that they spend with the infant (either alone or accompanied by the infant's mother or other persons, such as grandparents, nanny, others). Given the aims of this study, we focused on the sum of the parts in which the father shared time alone with the infant to calculate the dyadic time shared with the infant, and the sum of the parts in which the father was involved together with the mother to calculate the social time shared with the infant. Measuring the amount of dyadic time and social time allowed us to estimate the recurrence of these two contexts, and regarding the aims of this study, how their recurrence relates to the infant's socioaffective development. Although fathers were shown to be reliable reporters of their involvement with young children (Wical & Doherty, 2005), we controlled fathers' reports of father-infant shared time by comparing them to mother-reported data. As we did not find any significant differences between fathers' and mothers' reports, we chose to use only fathers' reports of their involvement in this study.

Statistical Analysis

First, we computed descriptive statistics, bivariate correlations between study variables, and paired *t*-tests to compare dyadic time and social time. These analyses were conducted by using IBM SPSS Statistics 27 software (IBM Corp., Armonk, NY). We then used the PROCESS macro for SPSS (Hayes, 2012, 2017) to test for moderation effects. The model was run with the infants' RMSSD during father-infant interaction as the dependent variable, father-infant synchrony as the independent variable, and dyadic time and social time shared with the infant as the two moderators. We also considered the infant's and father's age and the infant's gender as potential control variables. To estimate the significance of the moderation effects, we used a bootstrapping procedure with 5,000 bootstrap samples to estimate 95% confidence intervals (CIs). The macro creates mean-centred variables to calculate the interaction product terms.

Results

Descriptive Statistics

The means and standard deviations for all study variables are presented in Table 1.

Table 1. Descriptive statistics of all study variables.

Variable	*n*	Min.	Max	*M*	*SD*
Father-infant synchrony	77	1	14	7.81	3.32
RMSSD father-infant	77	3.42	20.07	11.27	3.95
Dyadic time shared	77	0	9	1.21	2.38
Social time shared	77	0	22	12.92	6.21
Infants' age	77	13.14	17.85	15.40	1.27
Fathers' age	77	23	56	35.83	5.68
Infants' gender	77	1	2	1.56	.50

Note. RMSSD = root mean square of successive differences; infants' age refers to weeks after birth; gender: 1 = female, 2 = male.

The mean father-infant synchrony score was 7.81 ± 3.32, and the mean infants' RMSSD score was 11.27 ± 3.95. The mean values of the two moderators, dyadic time (1.21 ± 2.38) and social time (12.92 ± 6.21), were compared through a paired *t*-test to test whether significant

differences existed between them. The results of the paired *t*-test showed that the mean values of the two moderators were significantly different, $t(76) = -13.772$, $p < .001$, and that the effect size was large ($d = 0.99$). The analysis of the frequencies of dyadic time values showed that most of the fathers (68.8%, $n = 53$ of the full sample) reported spending 0 parts of the day per week (morning, afternoon, evening, and night) involved with the infant. The frequency analysis of the social time values showed different percentages of the frequency, with two peaks above 10%; that is, 20.8% of the fathers ($n = 16$ of the full sample) reported spending 18 parts of the day involved with the infant in the presence of the mother (i.e., about 4.5 days), and 11.7% ($n = 9$ of the full sample) reported 0 parts.

Correlational Analyses

Correlations between the variables can be found in Table 2.

Table 2. Correlation matrix for study variables.

Variable	1.	2.	3.	4.	5.	6.	7.
1. Father-infant synchrony	1						
2. RMSSD father-infantx	.182	1					
3. Dyadic time shared	−.043	−.169	1				
4. Social time shared	.112	.021	−.384**	1			
5. Infants' age	.038	−.048	.066	.036	1		
6. Fathers' age	−.156	.052	.056	−.228*	−.091	1	
7. Infants' gender	−.148	−.061	−.043	−.079	−.073	−.017	1

Note. RMSSD = root mean square of successive differences; gender: 1 = female, 2 = male.
**$p < .01$. *$p < .05$.

There was no correlation between father-infant synchrony and infants' RMSSD. Neither father-infant synchrony nor infants' RMSSD correlated with dyadic time and social time. A significant negative correlation was found between dyadic time and social time ($r = -.384$, $p < .01$). As the father's age was the only control variable to show significant correlations with target variables (i.e., with social time, $r = -.228$, $p < .05$), infant's age and gender were not entered in the moderation model in order to increase statistical power.

Moderation Analyses

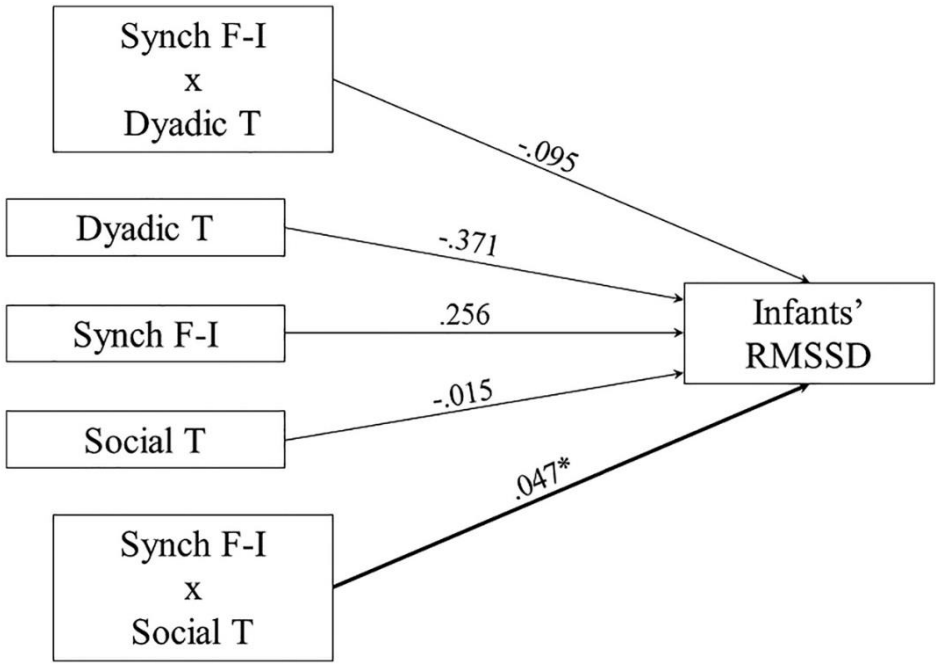

Figure 1. Graphical representation of moderation model values.

Note: Synch F-I = father-infant synchrony; Dyadic T = dyadic time; Social T = social time; RMSSD = root mean square of successive differences. The bold lines represent the significant influences of the independent variables on the dependent variable in the moderation model. * $p < .05$.

Results showed that the moderation model (see Figure 1) overall significantly predicted the infant's RMSSD during father-infant interactions (R =.437, R^2 = .191; df = 6, 28; F = 2.763, p = .181). Main effects in the model for fathers' age (b = .023, p = .769, 95% CI [-.133, .180]), dyadic time (b = -.371, p = .061, 95% CI [-.759, .017]), social time (b = -.015, p = .84, 95% CI [-.168, .137]), and father-infant synchrony (b =.256, p = .053, 95% CI [-.003, .516]) on infants' RMSSD during father-infant interaction were all nonsignificant, although the latter effect almost reached significance. The effect of the interaction between father-infant synchrony and dyadic time on infants' RMSSD during father-infant interaction was also nonsignificant (b = -.095, p = .089, 95% CI [-.204, .014]), although this effect was close to significance. We can conclude that the time father shared alone with the infant did not significantly increase the association between

father-infant synchrony and the infant's RMSSD during the interaction. Adding this variable to the model accounted for only a small and nonsignificant proportion in the variance of the infant's RMSSD, $F(1, 70) = 2.984$, $\Delta R^2 = .034$, $p = .089$. In contrast, the interaction effect between father-infant synchrony and social time was significant (b = .047, $p = .040$, 95% CI [.002, .093]), which suggested that the time that the father shared with the infant in the presence of the mother significantly increased the association between father-infant synchrony and the infant's RMSSD during the interaction. Adding this variable to the model accounted for a significant proportion in the variance of infants' RMSSD, $F(1, 70) = 4.360$, $\Delta R^2 = .050$, $p < .05$, although the effect size was small. The joint addition of both interaction effects together in the model accounted for a significant proportion of the variance of the infant's RMSSD, $F(2, 70) = 5.276$, $\Delta R^2 = .121$, $p < .01$, with a medium effect size.

To have a better understanding of these moderation effects, we examined the conditional effects of father-infant synchrony at 'low (-1 *SD*),' 'moderate (mean),' and 'high (+1 *SD*)' values of the moderators. The results are shown in Table 3 and presented graphically in Figure 2.

Table 3. Conditional effects of father-infant synchrony at values of dyadic time and social time.

Dyadic time	Social time	Effect	*SE*	*t*	LLCI	ULCI
−1.207	−6.214	.074	.215	.345	−.355	.504
−1.207	.0000	.371	.148	2.503*	.075	.667
−1.207	6.214	.668	.194	3.430**	.279	1.056
.000	−6.214	−.040	.188	−.213	−.417	.336
.000	.000	.256	.130	1.968	−.003	.516
.000	6.214	.553	.196	2.812*	.160	.945
2.386	−6.214	−.267	.200	−1.331	−.667	.133
2.386	.000	.029	.181	.163	−.332	.392
2.386	6.214	.326	.257	1.268	−.186	.839

Note. LLCI = the lower bound within the 95% confidence interval; ULCI = the upper bound within the 95% confidence interval.
**$p < .01$. *$p < .05$.

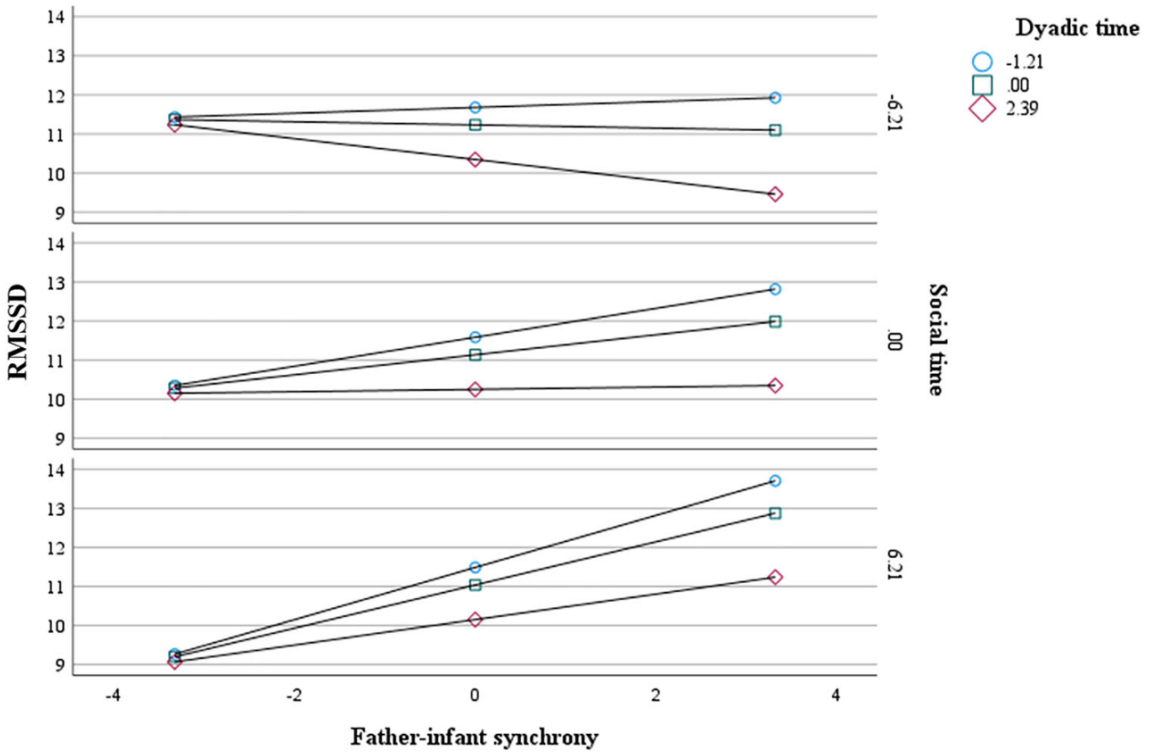

Figure 2. Graphical representation of conditional effects of father-infant synchrony at values of dyadic time and social time. Note: RMSSD = root mean square of successive differences.

The results showed that the effects of father-infant synchrony on the infant's RMSSD were strongest when fathers reported no dyadic time and moderate to high social time, as well as medium dyadic time and high social time. In other words, the association between synchrony and vagal tone increased when fathers reported spending rare dyadic time and much social time.

Discussion

The first aim of this study was to investigate the association between father-infant synchrony, an indicator of the quality of the interaction, and infants' vagal tone as an index of emotion regulation during interactions. Our hypothesis, according to which the infants' vagal tone would be positively associated with father-infant interactive synchrony during father-infant interactions, was not confirmed. The results showed that father-infant synchrony did not

significantly predict the infant's vagal tone during interactions with the father, although the positive association between the two variables almost reached significance. The second aim was to investigate whether father-infant shared times, both dyadic time (father and infant) and social time (father, infant, and mother), play a moderating role in the associations between father-infant synchrony and infants' vagal tone. Our hypothesis was partially confirmed. Moderation analyses revealed that the association between father-infant synchrony and vagal tone was moderated by social time (time spent by fathers in the presence of the mother), such that more social time increased the association between synchrony and vagal tone.

Results showing no significant main effect of father-infant synchrony and infant emotion regulation during father-infant interactions were surprising. They suggested that, when we controlled for the level of father involvement in day-to-day care in terms of time spent with the infant alone or in the presence of the mother, the association between father-infant synchrony and infant emotion regulation was weak. However, as this association was close to significance, it is possible that the size of the sample may have been too limited to reach significance. Further studies should thus be conducted in larger samples of father-infant dyads to estimate the significance of this association more precisely. They might yield significant results with increased statistical power.

Although father-infant synchrony and infant emotion regulation were weakly linked, the results of the moderation analyses gave us a glimpse of the conditions in which the links between both variables were stronger. Indeed, shared father-infant times at 3 months were shown to strengthen the association between the quality of interactions and the infant's emotion regulation competence, whereas shared father-infant times did not directly influence the quality of

interactions and the infant's emotion regulation during father-infant interactions. In a nutshell, the dyads in which fathers spend much time with the infant in the presence of the mother, but never alone with the infant, were those in which the association between interactive synchrony and the infant's vagal regulation during father-infant interactions was strongest. In the following paragraphs, we discuss these results and some explanatory leads.

Dyadic time was found to be a nonsignificant moderator, but it is difficult to draw conclusions because of the low variability of reports on dyadic time. Most fathers reported no dyadic time, and so further investigations that include fathers with different dyadic times are needed to understand how variations in dyadic time affect the father-infant dyad at 3 months. On the other hand, the father-reported social time was a moderator of the association between father-infant synchrony and the infant's vagal tone. These results suggest that family processes related to what happens during mother-father-infant times influence the father-infant dyad and the infant's physiological regulation during interactions with the father. This idea is in line with studies showing that family variables influence fathers' behaviours and infant socio-emotional development (Cabrera et al., 2014; Frascarolo-Moutinot et al., 2020; Youngblade et al., 1993). Father-infant synchrony is significantly and positively associated with infant emotion regulation only when fathers report rarely being alone with the infant and when the social time is medium to high.

We propose some tentative explanations for this result that warrant further investigation. The greater amount of shared time in which both parents care for the infant has a specific influence on the father-infant dyad, in particular when the father rarely shares time alone with the infant. Interestingly, correlation analyses also showed that the less that a father reported spending

time alone with the infant, the more he reported spending time with the infant in the presence of the mother. It is reasonable to assume that fathers reporting rare dyadic time with the infant will have fewer occasions to develop their own parenting style and may rely on mother-like behaviours observed during social time as being more suitable for the infant. These fathers may feel less competent in face-to-face interactions with the infant than the mother does, who has had more experience with the infant at 3 months. The infant of a father who uses mother-like behaviours may have found the father's behaviours 'familiar' during the interaction, thus activating regulatory responses similar to those habitually used (with the mother). In contrast, fathers who had more dyadic times may have relied less on mother-like behaviour observed during social time, preferring to use behaviour based on their own experiences alone with the infant. In this case, the associations between the physiological regulation and the father's behaviour may have been weaker because, whether adjusted or not, the father's behaviours are less similar than the mother's behaviours. At 3 months, the infant may be more used to relying on the mother to regulate him- or herself and be more sensitive to the mother's behaviour, appropriate or not, than the father's. Consequently, the infant might be less physiologically regulated during the interactions, regardless of the quality of paternal interactive behaviours or the level of the father-infant behavioural synchrony. Following this explanation, it is likely that even the most highly involved fathers in our sample may not spend enough time with the infant alone to develop their own parenting style, which the infant would be more used to. Indeed, the fathers who spent more time alone with the infant still reported little time alone with the infant (the maximum was nine parts of days by week) compared with that reported by mothers. Further studies should be conducted in samples of families in which the father is the primary caregiver,

although the relative rarity of such family configurations may hinder study recruitment and thus limit the study's sample size.

The latter explanation might in addition benefit from being considered in the context of the socioeconomic factors related to the country in which this study was conducted. In Switzerland, paternity leave of 1–3 days was available to fathers until January 2021. Since then, paternity leave has been extended to a total of 10 working days (i.e., 2 weeks). Despite this change, mothers in Switzerland continue to have longer leave (14 weeks) than fathers do (Swiss Civil Code, 2021). Furthermore, mothers in Switzerland spend more time with their infants and assume the role of primary caregiver in the first months of life, while fathers usually continue to work full time. Regarding the full-time employment rate between fathers and mothers of a 0- to 3-year-old infant in Switzerland, statistics in 2022 showed significant differences between the parents, with full-time employment rates for fathers of 79.6% and 16.3% for mothers (Federal Statistical Office, 2022). Thus, it is reasonable to think that, in Switzerland, fathers may have few occasions to interact alone with their infants in the first months of life and that those few occasions to interact, usually in the presence of the mother, may represent an opportunity to reinforce the association between the quality of father-infant interactions and the infant's physiological patterns of emotion regulation in the first 3 months. The ‘less expert’ father in day-to-day care activities may need more time to ‘leave a mark’ in the development of the emotion regulation patterns and help the infant regulate emotions.

This study has limitations and strengths. Among the limitations, first, the results are only marginally generalizable because most of the fathers in this study were highly educated and worked full time. A greater variety in the sample of fathers—such as fathers working part-time or

not employed, and fathers with different levels of education and economic statuses—would have increased the generalizability of the results of this study. Second, although vagal tone is often used in studies as the main indicator of emotion regulation, other indicators could have captured contextual and extrinsic factors crucial for the infant's emotion regulation. This consideration is important regarding the systemic nature of emotion regulation involving physiological, affective, and social mechanisms (Thompson et al., 2008). Thus, to further confirm the results of this study, additional studies are warranted that consider physiological processes as well as observational processes, for example, in addition to vagal tone, the behavioural aspects of emotion regulation and social regulation by parents. Third, the assessment of father-infant synchrony used in this study, although allowing for a global assessment of synchrony by considering the interaction behaviour patterns of father and infant, does not allow for analysis of the association between specific father-infant synchrony behaviours (e.g., sharing smiles, gaze direction toward the other partner, display of availability for interaction, and vocalizations in response to what the adult says) and changes in vagal tone. Future analysis of the association between father-infant synchrony behaviours and moment-to-moment changes in the infant's vagal tone during interactions could provide additional information. Despite these limitations, this is the first study to specifically investigate physiological regulation during 3-month-old infant–father interactions, including measures of the quality of interactions and the influence of two types of father-infant shared time. This study highlights that the quality of father-infant interactions may influence the physiological regulation of emotions when the father and infant share time in the first months of life. This study also suggests that early father-infant interactions are susceptible to the influence of shared time in the presence of the mother. Therefore, future research should include measures

of family processes to better understand how the quality of father-infant interactions is related to the infant's physiological emotion regulation at 3 months.

Article III

Interactive synchrony and infant's vagal tone as an index of emotion regulation: associations with each mother- and father-infant dyad and across dyads

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This article has been published in *Frontiers in Psychology.*

Puglisi, N., Favez, N., Rattaz, V., Epiney, M., Razurel, C., & Tissot, H. (2023). Interactive synchrony and infants' vagal tone as an index of emotion regulation: associations within each mother-and father-infant dyad and across dyads. *Frontiers in Psychology*, *14*, Article 129904. https://doi.org/10.3389%2Ffpsyg.2023.1299041

Abstract

Introduction: Studies have shown that infants' emotion regulation capacities are closely linked to the quality of parent-infant interactions. However, these links have been mostly studied in mother-infant dyads and less is known about how the quality of father-infant interactions contributes to the development of emotion regulation during infancy. In this study, we aimed to investigate the links between interactive synchrony (i.e., an index of the quality of parent-infant coordination of interactive behaviors) and infants' vagal tone (i.e., a physiological index of emotion regulation). To understand the respective contributions of both parents, as well as the interrelations between the functioning of both dyads within a family, we observed mothers and fathers from 84 families interacting with their infants.

Methods: Synchrony was assessed by using the CARE-Index; infants' vagal tone was derived from the analysis of infants' electrocardiograms recorded during the interactions. Moreover, to take the play's order into account, we counterbalanced the procedure, so that approximately half of the mothers played first. We specified a first structural equation modeling (SEM) model to investigate the associations between interactive synchrony and the infants' root mean square of successive differences (RMSSD), an index of vagal regulation, in the two successive parts of the play. We conducted a multigroup analysis in a second SEM model to investigate the associations of the first SEM model in two groups based on the order of interaction.

Results: The results of the SEM models showed that greater synchrony was related to greater infant RMSSD within mother-infant dyads and across one dyad to the other dyad in the full sample and in the group of fathers who interacted first with the infants. The associations between

synchrony and infant vagal tone within father-infant dyads never appeared to be significant, nor did any associations within each dyad and across dyads when mothers interacted first. Discussion: This study highlights that the links between interactions and infants' vagal tone are sensitive to family members' interdependencies and some conditions (the order of interaction).

Keywords: parent-infant interactions, emotion regulation, synchrony, vagal tone, infancy

Interactive Synchrony and Infant's Vagal Tone as an Index of Emotion Regulation: Associations with each Mother- and Father-Infant Dyad and Across Dyads

The Interpersonal Component of Emotion Regulation

The interpersonal component of emotion regulation is crucial in early infancy because, by interacting with parents, immature infants develop emotion regulation patterns that allow them to be progressively autonomous in recognizing their internal states and regulating emotions (Sameroff, 2004). Emotion regulation can be defined as a "process responsible for monitoring, evaluating and modifying emotional reactions, especially their intensive and temporal features, to accomplish one's goal" (Thompson, 1994, p. 27). This definition reflects a functionalist view of emotion regulation, according to which emotion regulation allows the infant to achieve goals in the surrounding environment (e.g., for the infant to be fed, comforted, or protected; Campos et al., 1994; Cole et al., 1994). Emotion regulation involves intrinsic and extrinsic processes within the individual, with a strong influence from and on the environment. At 3 months, the quality of early interactions with the parents, the infant's main social interactants, helps the infant to shape behavioral and physiological patterns of emotion regulation, with consequences for the infant's socioemotional development (Tronick & Cohn, 1989; Cole et al., 2004; Cabrera et al., 2014; Morris et al., 2017; Low et al., 2019).

One index of the quality of parent-infant interactions that has been previously linked with emotion regulation is interactive synchrony, which reflects the quality of the mutual regulation of the interaction by the parent and the infant (Tronick, 2007; Bernard et al., 2013; Nguyen et al., 2020). Provenzi et al. (2018) defined interactive synchrony as the "degree of congruence between trans-modal behaviors of two partners, which is lagged in time and which promotes

infants' learning of emotional regulation skills and the emergence of expectations on interactive repertoires" (p. 12). Interactive synchrony is linked with better cognitive development, fewer externalizing and internalizing symptoms, and adaptive self-regulation, with effect sizes ranging from small to large (e.g., Laible and Thompson, 2000; Kochanska et al., 2008; Feldman and Eidelman, 2009; Pesonen et al., 2010; Hinnant et al., 2013; Suveg et al., 2016). Interactive synchrony implies that the parent and the infant exchange and coordinate behavioral (e.g., gaze, affection, voice, and touch) and physiological (e.g., brain networks, affiliative hormones, and autonomic responses) signals, within each other, between each other, and between the physiology of one member of the dyad and the behavior of the other member (Tronick & Cohn, 1989; Feldman et al., 2010; Beebe et al., 2016; Provenzi et al., 2018). The repeated experience of synchronous exchanges during parent-infant interactions fosters the emergence of repetitive and rhythmic matched patterns within the dyad characterized by being "concurrent" (when the parent is happy, the infant is happy) and "sequential" (variations in the parent predict variations in the infant) between partners (Feldman, 2007a; Wass et al., 2020). During the perinatal period, synchrony is predominantly driven by the parent, who through direct glances, expressions of positive affect, vocalizations, and affectionate touch coordinates with the infants' attention during awake time. Later in infancy, the infant becomes an active social partner capable of co-constructing interactive synchrony with the parent(s) through the active coordination of gaze, affective expressions, co-vocalizations, and touch patterns (Feldman, 2007b, 2015). Although being in synchrony is desirable, synchrony in social interactions is most often difficult to achieve. The reason is that social interactions naturally contain mistakes or external perturbations and thus many possibilities for moments of miscoordination that reduce interactive synchrony

(Markova & Nguyen, 2022). For example, moments of miscoordination can occur when a parent misunderstands the infant's signals by being withdrawn when the infant is willing to interact or by trying to engage the baby when he or she is fussy. However, despite moments of miscoordination, both partners may maintain a certain degree of interactive synchrony when they implement behavioral and physiological changes appropriate to the signals coming from the other partner (Tronick & Gianino, 1986; Beeghly et al., 2011). For example, a withdrawn parent may stay involved in the interaction by making eye contact with the infant, or a parent with a fussy baby might gently pat the baby's hand to distract and maybe soothe the baby, avoiding overstimulating activities.

Interactive synchrony involves regulatory behaviors, observable during an interaction, and emotion regulation processes, measurable on a physiological level through vagal tone. Vagal tone is a valid index of physiological regulation; it reflects the vagus nerve's contribution to the autonomic nervous system mechanisms related to emotion regulation. According to Porges (2011, 2021) polyvagal theory, vagal tone variations relate to the experience and expression of social, emotional, and communicative regulation during interactions. High vagal tone in early childhood has been associated with better regulation and fewer externalizing, internalizing, and cognitive problems across development. Conversely, low vagal tone has been shown to correlate with difficulty in regulation, poorer sustained attention, more impulsiveness, and greater disinhibition (Feldman, 2006; Graziano & Derefinko, 2013; Provenzi et al., 2015; Wagner et al., 2021). The suppression of vagal tone is a physiological indication of difficulty in social regulation and emotion regulation processes. The study of vagal tone in parent-infant interactions has shown, predominantly in the mother-infant dyad, that physiological variations can be

observed depending on the quality of the interactions (Moore & Calkins, 2004; Lunkenheimer et al., 2020). When the quality of the interaction is high, with adaptive coregulation between parent and infant behavior, the infant vagal tone generally increases to support behavioral organization during social involvement (e.g., gaze sharing, shared attention). Conversely, when the quality of the interaction decreases, the lower coregulation generates a stress for the infant and is associated with lower vagal tone to support behavioral responses to a difficult interaction (e.g., avoidance of adult gaze, crying; Feldman et al., 2010; Provenzi et al., 2015). Pratt et al. (2015) found that mother-infant synchrony positively correlated with and predicted vagal withdrawal. In addition, mother-infant synchrony may strengthen vagal regulation in infants with high and low negative reactivity. Provenzi et al. (2015) observed a higher frequency of dyadic matching of affective states and dyadic repair in dyads with optimal vagal functioning. To summarize, infant's vagal tone is a crucial aspect to consider when investigating the interpersonal aspect of emotion regulation development.

The Interdependencies between Mother- and Father-Infant Interactions

During infancy, different adults (e.g., parents, grandparents, aunts, uncles, and professional caregivers) may shape social interactions with infants, thus contributing to the development of regulation patterns (Bronfenbrenner, 1974; Kokkinaki et al., 2012; Kokkinaki & Pratikaki, 2014). However, the most frequent interactions for infants occur with primary caregivers, that is, one or both parents, as they are closest to them and quickly provide them with the care they need to survive. Interactions with each parent allow the infant to experience different types of interactive synchrony, with different consequences on the coordination of physiological states and interactive behavior within each dyad (Lamb, Pleck, Charnov, et al.,

1987; Moore & Calkins, 2004; Skibo et al., 2020; Wu & Feng, 2020; Rodrigues et al., 2021). For example, during interactions with fathers, which often focus on highly stimulating physical play, interactive synchrony tends to involve the regulation of higher levels of positive arousal than it does during interactions with the mother, which often focus on the regulation of mutual gazes and vocalizations during face-to-face interactions (Feldman, 2003). In Western societies, mothers still mostly play the role of primary caregiver in early infancy, and thus previous research on the interpersonal components of emotion regulation in early infancy has largely focused on the mother-infant dyad. Furthermore, previous research has often considered the mother-infant dyad without taking into account other social interactions that might influence it (father-infant dyad) or encompass it (the whole family). Family system theorists, however, have long suggested that consideration of the connections between the different members of a family and their influence on the infants' functioning is necessary for a more accurate view of family influences on infant development. According to family system theory (Minuchin S., 1974; Minuchin P., 1985; Cox & Paley, 1997), the family system is composed of several subsystems, each of which has specific properties and the potential to influence and be influenced by the others. Minuchin (1985) argued that each subsystem can only be accurately understood in the context of its relationships with the others, as subsystems do not function in isolation from one another. What happens in one dyad (mother-infant) is likely to influence and be influenced by what happens in another dyad (father-infant). In sum, the infant's interactions with the mother and father are non-independent because complex interdependencies exist in a family.

The interdependencies in a family may function cumulatively during parent-infant interactions, so that adaptive or maladaptive functioning in one subsystem (e.g., parent-infant)

spreads to other subsystems (e.g., interparental), leading to multiple factors influencing the infant's emotion regulation. However, it is also possible that several subsystems may compensate for others. Thus, the maladaptive effect of one subsystem on the infant's emotion regulation may be compensated by the protective effect of another system. Examples of interdependencies in a family are the spillover effect and the crossover effect. The spillover effect refers to the impact of the emotional quality of the parent–parent relationship on the emotional quality of the parent(s)-child relationships (Stroud et al., 2011; McCoy et al., 2013). A parent might take less care of an infant by purposely not being at home to avoid facing the other parent. On the other hand, parents with a good marital relationship are more likely to collaborate in caring for their infant, allowing the infant to experience more positive interactions with the parent(s) (Sears et al., 2016). The crossover effect, which may co-occur with the spillover effect, refers to the transfer of emotions or behavior between individuals within a subsystem rather than between subsystems or domains. In other words, a parent's attitudes or experiences could influence the partner's functioning with the infant (Tissot et al., 2017; Tucker et al., 2017; Miragoli et al., 2018; Pu & Rodriguez, 2021). While caring for the infant, a parent with a partner in distress (e.g., due to the presence of depressive symptoms or burnout) might present reduced availability, difficulty concentrating, and increased irritability because of worrying thoughts about the partner's difficulties (Sutton et al., 2017). Conversely, parents who are less confident in infant care might interact with the infant with greater confidence in their gestures because they are reassured by their partners' supportive attitude toward their parenting skills (Udry-Jørgensen et al., 2016).

To date, many studies have brought evidence of links between the quality of parent-infant (mostly mother-infant) interactions and physiological outcomes of infants' emotion regulation in

an interaction. However, no study to our knowledge has ever investigated these processes in intact biparental families, taking both the mother-child and father-child dyads into account. In the present study, we aimed to fill this gap by investigating the associations between synchrony and vagal tone within mother-infant and father-infant dyads, as well as across dyads, that is, from one dyad to the other. In particular, we examined the links between mother-infant synchrony and infants' vagal tone during father-infant interaction, as well as the links between father-infant synchrony and infants' vagal tone during mother-infant interaction. In line with previous research, we expected to find within-dyad associations between the variations in the quality of interactions and the infants' physiological regulation during these interactions. Specifically, we hypothesized that high mother-infant synchrony would be linked with high infant vagal tone during the interaction with the mother. Although previous studies are scarce, we expected to find similar associations in father-infant dyads, such that higher father-infant synchrony would be linked with higher infant vagal tone during interaction with the father. As across-dyad associations have never been investigated in an empirical study to our knowledge, we formulated the exploratory hypothesis that we would find associations between high synchrony in one dyad and high infant vagal tone in the dyad, but that these associations would probably be weaker than within-dyad associations.

Method

Participants

The participants were a convenience sample of 84 mother–father-infant families. The mothers had a mean age of 33.75 years ($SD = 4.00$), the fathers had a mean age of 35.83 years ($SD = 5.68$; $n = 77$ due to missing data), and the infants had a mean age of 15.38 weeks

(*SD* = 1.25). The infants were 44 boys and 40 girls. Mothers were mostly university graduates (54.8.0%, *n* = 70 due to missing data) with 66.7% of them employed (*n* = 56 due to missing data), 38.1% full time. Fathers were mostly university graduates (41.7%, *n* = 65 due to missing data) with 73.8% of them employed (*n* = 62 due to missing data), 63.1% full time. Mothers (*n* = 70 due to missing data) were mostly married (44%) and in a cohabiting couple (35.7%; some of them were divorced or separated from a previous relationship). Among the fathers (*n* = 65 due to missing data), 36.9% were married and 35.7% were in a cohabiting couple. A socio-economic index (IPSE) was calculated by using the formula of Genoud (2011), which is calculated based on the education level and occupation of both parents. Regarding socio-economic status, 48.8% of families belonged to the middle-upper class, 13.1% to the middle class, and 11.9% to the upper class (*n* = 72 due to missing data).

Procedure

In this study, we used data collected from a larger study on emotion regulation and family functioning. A midwife recruited parents around the 37th week of pregnancy at the maternity unit of the University Hospital of Geneva. We presented the objectives of the research and then provided the parents with a consent form that the interested participants signed. The midwife explained to the parents that the study's focus was the infant's emotions. Three months after delivery, the research team contacted and scheduled a meeting with the parents when the infant was between 3 and 4 months old. At the beginning of the meeting, the researchers reminded parents of the context and the course of the study and invited them to place the infant on a changing table. To record the measurements of the infant's heart activity during family playtime in the study, one of the researchers placed three pediatric electrodes on the infant's chest to

record an electrocardiogram (ECG). The researcher asked the parents to interact with the infant following the family play of the Lausanne Trilogue Play paradigm (Fivaz-Depeursinge and Corboz-Warnery, 1999). In the first part, one parent played with the infant for 2 min while the other parent was outside the room. In the second part, the parents changed roles. Because in the first two parts of the play the infant interacted separately with each parent, we decided to counterbalance the order of the parts to have an equal distribution between the mothers and fathers who interacted first. Finally, in the third part, the two parents played together with the infant for 2 min. In this study, we considered only the first two parts, that is, the interactions of each parent with the infant. Before starting the interactions, the researchers indicated the position of the cameras and specified that the experiment could be interrupted at any time if the infant showed signs of excessive fatigue or distress. The researchers instructed the parents to interact, as usual, avoiding objects if possible and not to carry, pick up, or place the infant in a sitting position on the changing table to limit the recording of noise during the ECG. At the end of the interactive session, and after the removal of the electrodes from the infant, the parents were asked to fill out a form to receive online self-report questionnaires. A debriefing in the form of video feedback was offered to interested parents.

Measures

Parent-Infant Synchrony

We assessed mother- and father-infant synchrony with the infant CARE-Index (Crittenden, 2006). The CARE-Index is an adult-infant interaction assessment that can be used from birth to 25 months. The coding system assesses global dyadic synchrony, that is, fathers' sensitive behavior and infants' cooperative behavior, within the context of parent-infant

interactions. Scores ranged from 0 to 14, with higher scores indicating better dyadic synchrony. The total sample of 84 parent-infant interactions was coded from March 2022 to August 2022. To ensure inter-rater reliability, a random sample of 23.8% of the video recordings (20 videos in a total sample of 84) was initially coded by the first and second authors, both trained and certified as research raters in February 2022. The intraclass correlation (two-way random absolute agreement) on the synchrony scores was excellent with a coefficient of 0.982 (Koo and Li, 2016). Coders were blind to the results of the ECG analyses (see next Section).

Vagal Tone

An ECG was recorded during baseline, mother-infant interaction, and father-infant interaction. During the 2-min baseline, the ECG was recorded while the researchers explained the instructions of the experiment, and the parents were not directly involved with the infant. Physiological data were collected with a Biopac MP160 system (Biopac Systems, Inc.) and recorded on AcqKnowledge 5.0 software (Biopac Systems, Inc.). The infants' cardiac activity was processed on Kubios HRV v2.2 software to obtain heart rate variability measures, which reflect vagal tone. Analyses allowed us to derive the root mean square of successive differences (RMSSD), which represents the activity of the parasympathetic system and is widely considered to be a valid measure of vagal activity (Laborde et al., 2017).

Statistical Analysis

We computed first a set of descriptive statistics for the variables under study (see table 1).

TABLE 1 Descriptive statistics.

	Model 1					Model 2									
	Full sample					Mothers interacted first					Fathers interacted first				
Variable	*n*	*Min*	*Max*	*M*	*SD*	*n*	*Min*	*Max*	*M*	*SD*	*n*	*Min*	*Max*	*M*	*SD*
RMSSD M-I	84	2.95	19.80	11.20	3.48	41	3.61	19.80	11.67	3.59	43	2.95	16.90	10.76	3.36
RMSSD F-I	84	3.42	20.07	11.26	3.90	41	4.18	20.07	11.33	3.68	43	3.42	19.92	11.19	4.15
Synchrony M-I	84	1	14	8.31	3.36	41	1	14	8.71	3.53	43	2	14	7.93	3.20
Synchrony F-I	84	1	14	7.85	3.21	41	1	14	8.24	3.15	43	1	14	7.47	3.26

RMSSD, root mean square of successive differences; M, mother; F, father; I, infant.

The normality test was performed by using the Shapiro–Wilk test. We also tested for bivariate correlations between the variables under study, as well as for differences depending on the order of the parts in the play through the Student's *t*-test and the Mann–Whitney *U* test (non-parametric alternative to the Student's *t*-test used when the samples to be compared do not have a normal distribution). Missing data analysis was conducted, as there were missing data in two control variables: fathers' age ($n = 7$) and families' socioeconomic status ($n = 12$). There was no missing data in the target variables. The Little's Missing Completely at Random (MCAR) test was not significant, $\chi2 = 19.471$, $df = 20$, $p = 0.49$. Which indicates that data were missing completely at random. Then, we tested for associations between the target variables and the potential control variables (sex of the infant, age of the parents, and socioeconomic status) to be included in subsequent analyses. Because of the small size of our sample, we wanted to optimize statistical power by eventually including in multivariate analyses only those control variables that would have shown significant correlations with the target variables (see Table 2 for more details).

TABLE 2 Correlation matrix for the full sample.

Full sample, $N = 84$								
Variable	1.	2.	3.	4.	5.	6.	7.	8.
1. RMSSD M-I	1							
2. RMSSD F-I	0.734**	1						
3. Synchrony M-I	0.353**	0.246*	1					
4. Synchrony F-I	0.311**	0.164	0.524**	1				
5. I sex	−0.054	−0.033	−0.111	−0.165	1			
6. M age	−0.099	−0.119	−0.122	−0.175	−0.144	1		
7. F age	0.067	0.053	−0.123	−0.156	−0.017	0.537**	1	
8. SES	0.123	0.122	0.077	−0.075	0.061	0.276*	0.278*	1

** $p < 0.01$; * $p < 0.05$; RMSSD, root mean square of successive differences; M, mother; F, father; I, infant; Sex: 1 = female, 2 = male; SES, socio-economic status: 1 = lower, 2 = lower-middle, 3 = middle, 4 = middle-upper, 5 = upper.

As none of the control variables showed significant correlations with the target variables, they were excluded from subsequent analyses.

To test the main hypotheses of this study, we then used structural equation modeling (SEM) techniques to test the associations between the target variables, namely, parent-infant synchrony and the infants' RMSSD within each dyad and across one dyad to the other. In a first model (see Figure 1), we specified covariance paths between parent-infant synchrony and infants' RMSSD to investigate their association within each dyad (see Figure 1).

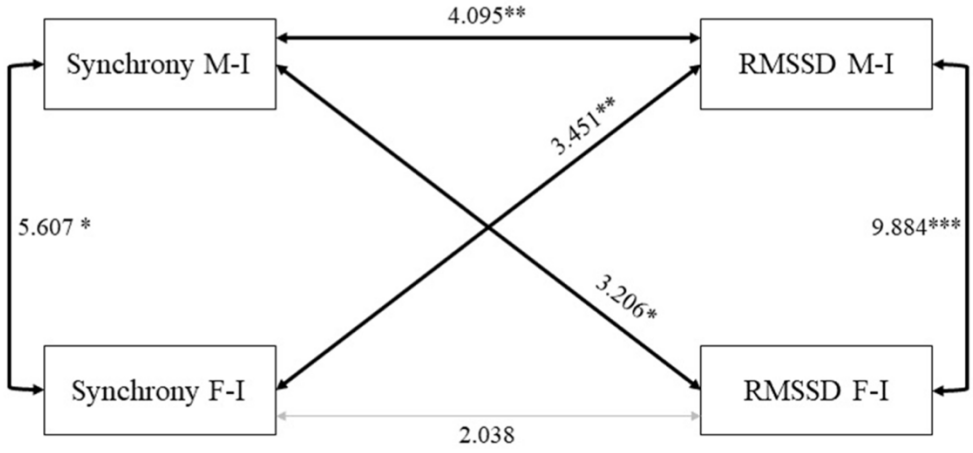

FIGURE 1
Graphical representation of the first SEM model in the full sample (= 84). *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; RMSSD, root mean square of successive differences; M-I, mother-infant; F-I, father-infant. Structural equation modeling (SEM) shows paths between mother-infant synchrony, father-infant synchrony, and infants' RMSSD during interactions with parents. Bold rows show significant paths between variables, and gray rows show nonsignificant paths.

We refer to these covariance paths as "within-dyad" covariances. Thus, there were two within-dyad covariances in this model, one between mother-infant synchrony and infants' vagal tone during mother-infant interactions, and one between father-infant synchrony and infants' vagal tone during father-infant interactions. To investigate the influence across one dyad to the other, we also specified covariance paths between parent-infant synchrony in one dyad and infants' RMSSD during the interaction in the other dyad. We refer to these covariance paths as "across-dyad" covariances. Thus, there were two across-dyad covariances in this model, one between mother-infant-synchrony and infants' vagal tone during the interaction with the father, and one between father-infant synchrony and infants' vagal tone during the interaction with the mother. As previous work suggested that the order of interaction (mother or father interacting first) in a family play situation may influence the parents' behaviors during the interactions (Frascarolo et al., 2003), we conducted a multigroup analysis in a second model to test whether the order of the parts in the play influenced the study results. In this second model, the relations between the variables were specified similarly to the first model, but the model was separately estimated in two groups according to which parent interacted first ($n = 41$ families with mother playing first and $n = 43$ with father interacting first). In this model, all the parameters were left free to vary between the two groups. In order to estimate the magnitude of the differences between the two groups, we created a third nested model in which we imposed difference and equality constraints on all parameters of the model.

The first, second, and third SEM models were estimated by using a maximum likelihood with robust standard errors estimator. Because the first and second models were saturated (0 degrees of freedom), the model fit was irrelevant, as the model was perfectly fitted to the data.

Information on model fit was in turn available for the third model, as it had 14 degrees of freedom. Chi-square tests and other fit indices (e.g., root mean square error of approximation [RMSEA]) were used to evaluate model fit according to the standard criteria defined by Hu and Bentler (1999). For the comparative fit index, values above 0.90 indicate a fair fit and values above 0.95 an excellent fit. For the RMSEA, values below 0.06 indicate an excellent fit and values between 0.06 and 0.08 an acceptable fit. Descriptive statistics, bivariate correlations, the Student's *t*-test, and the Mann–Whitney *U* test were computed in IBM SPSS Statistics 27 software (IBM Corp., Armonk, NY). Mplus 7.4 (Muthén and Muthén, 2016) was used to perform SEM.

Results

Descriptive Statistics

The mean and standard deviations of parent-infant synchrony and infants' RMSSD during the interactions with each parent were calculated in the total sample and the two groups based on the order of the parts in the play (mother or father interacting first; see Table 1).

The Shapiro–Wilk test was performed to verify the normal distribution of the study variables, revealing that the infants' RMSSD scores were normally distributed (with the mother, $p = 0.783$; with the father, $p = 0.331$) and that synchrony scores were not (mother-infant synchrony, $p = 0.017$; father-infant synchrony, $p = 0.009$). To investigate whether the mean scores for the target variables would vary according to the order of the parts in the play, we used the Student's *t*-test for the infants' RMSSD scores and the Mann–Whitney *U* test for parent-infant synchrony scores. Results revealed that the infants' RMSSD during the interaction with the

mother [$t(82) = 1.189$, $p = 0.23$] and the father [$t(82) = 0.165$, $p = 0.86$] and the synchrony scores with the mother (U: 761.000, $p = 0.27$) and the father (U: 747.000, $p = 0.22$) did not vary depending on the order of the parts in the play.

The normative values for RMSSD during infancy are predominantly rooted in 24-h ECG recordings (Massin & von Bernuth, 1997; Patural et al., 2019), which posed a challenge in their direct comparison with the 2-min segments used in the current study. However, previous investigations that focused on brief 10- or 2-min excerpts from ECG recordings during infants' restful periods (Zeegers et al., 2018; Arce-Alvarez et al., 2019) revealed values that were either similar or slightly higher than those observed in the present sample. This minor variance might be attributed to the recording circumstances—capturing the ECG during social interactions rather than in a resting state.

Correlational Analyses

The correlational analyses between target variables (parent-infant synchrony, and infants' RMSSD during the interaction with each parent) and the control variables (sex of the infant, age of the parents, and socioeconomic status) were calculated in the full sample (see Table 2). The infants' RMSSD during the interaction with the mother correlated positively and significantly with synchrony with both parents, so that, when the infants' regulation with the mother was higher, the synchrony with both parents was also higher. The infants' RMSSD during the interaction with the father correlated positively and significantly with mother-infant synchrony, so that, when the infants' regulation with the father was higher, the synchrony with the mother was also higher. There was a positive and significant correlation between both synchrony scores, so the higher the synchrony with the mother, the higher the synchrony with the father. Infants'

RMSSD scores correlated positively and significantly, so that the more regulated the infants were with the mother, the more regulated they were with the father. None of the control variables showed a significant correlation with the target variables.

Models Linking Parent-Infant Synchrony and Infants' RMSSD

The results of the estimation of the first model (Model 1; see Figure 1 for more details) showed that the within-dyad covariance was significant and positive in the mother-infant dyad and not significant in the father-infant dyad. In other words, greater mother-infant synchrony was related to greater infant RMSSD during the interaction with the mother. The across-dyad covariance was significant and positive between mother-infant synchrony and infants' RMSSD with the father and between father-infant synchrony and infants' RMSSD with the mother. In other words, mother-infant synchrony was positively related to infant regulation with the father, and father-infant synchrony was positively related to infant regulation with the mother. In turn, father-infant synchrony was not related to infant RMSSD during father-infant interaction. Finally, the covariance between synchrony with the mother and father was positive and significant, such that greater synchrony related to greater synchrony, and the covariance between the infants' RMSSDs with each parent was positive and significant so that greater regulation with one parent related to greater regulation with the other.

The results of the estimation of the second model (Model 2; see Figures 2, 3 for more details) showed that in both groups (Group 1: mothers interacted first, $n = 41$; Group 2: fathers interacted first, $n = 43$), there were three similarities: the covariance between synchrony and infants' RMSSD in the father-infant dyads was not significant, the covariance between synchrony with the mother and father was positive and significant so that greater synchrony

related to greater synchrony, and the covariance between the infants' RMSSDs with each parent was positive and significant so that greater regulation related to greater regulation.

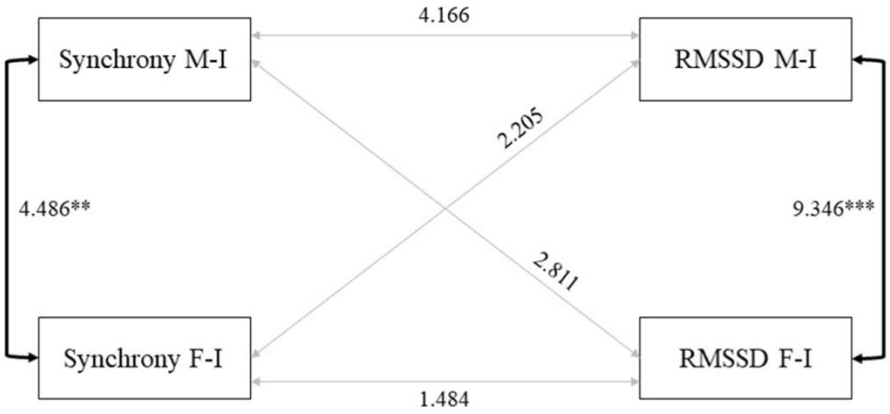

FIGURE 2
Graphical representation of the second SEM model in the group in which mothers interacted first (= 41). *** $p < 0.001$; ** $p < 0.01$; RMSSD, root mean square of successive differences; M-I, mother-infant; F-I, father-infant. Structural equation modeling (SEM) shows paths between mother-infant synchrony, father-infant synchrony, and infants' RMSSD during interactions with parents. Bold rows show significant paths between variables, and gray rows show nonsignificant paths.

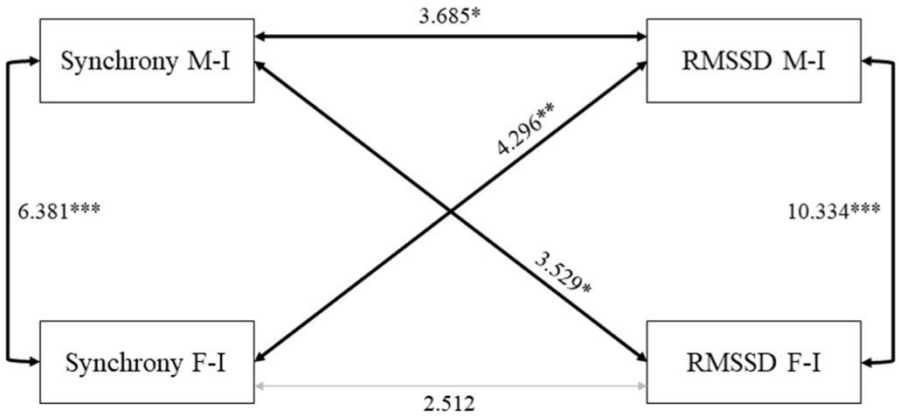

FIGURE 3
Graphical representation of the second SEM model in the group in which fathers interacted first (= 43). *** $p < 0.001$; ** $p < 0.01$; * $p < 0.05$; RMSSD, root mean square of successive differences; M-I, mother-infant; F-I, father-infant. Structural equation modeling (SEM) shows paths between mother-infant synchrony, father-infant synchrony, and infants' RMSSD during interactions with parents. Bold rows show significant paths between variables, and gray rows show nonsignificant paths.

Two differences between the groups appeared: For mothers who interacted first, the covariance between mother-infant synchrony and infants' RMSSD with the mother was not significant. Although the covariance (i.e., unstandardized) was not significant, the correlation (i.e., standardized) was ($r = 0.337$, $p = 0.034$). In turn, this covariance was significant when

mothers interacted second and fathers first. The second difference between the groups was that for mothers who interacted first, the covariance between mother-infant synchrony and infants' RMSSD with the father was not significant. In turn, this covariance was positive and significant when fathers interacted first, such that mother-infant synchrony was related to the infant's regulation with the father.

In the third model that aimed to test the magnitude of these differences, we imposed differences and equalities between groups on all the parameters of the second model. This model demonstrated a good fit: $\chi^2(14) = 10.802$, $p > 0.05$, RMSEA = 0.000, comparative fit index = 1. The finding that the chi-square test of the third model was nonsignificant suggests that the differences between the groups, if any, were minimal, as the fit of a model specified with equality constraints on all parameters was not statistically different from a model assuming between-group differences.

Discussion

In this study, we investigated associations between interactive synchrony (an indicator of interaction quality) and infants' vagal tone (an index of emotion regulation) during mother-infant and father-infant interactions, both within each parent-infant dyad (within-dyad) and across one dyad to the other (across-dyad).

Our hypotheses that associations exist between interactive synchrony and infants' vagal tone within each dyad were partially confirmed. The results showed that interactive synchrony has a significant association with infants' vagal tone within mother-infant dyads, such that variations in synchrony were related to variations in infants' vagal tone during mother-infant

interactions. Although this association was present in the whole sample (Model 1), the multigroup analyses (Model 2) revealed that this association is actually due to mother-infant dyads interacting second (i.e., after the father), as it disappears when the order of interaction is reversed. Our hypothesis that there are associations between interactive synchrony and vagal tone in infants within father-infant dyads was not confirmed in either the whole sample or subgroups based on the order of interaction. Although this lack of associations might lead to the assumption that fathers have a reduced influence on the infants' physiological regulation of emotion, we propose looking at the family organization at 3 months in Switzerland to potentially shed light on the reasons behind the lack of associations within the father-infant dyad. At 3 months, Swiss mothers are on mandatory maternal leave and assume the role of primary caregiver, spending more time with the infant than fathers do. Fathers indeed have a shorter leave (paternity leave 2 weeks) than mothers do (maternity leave 3.5 months) and tend to work full time during the first months after their infants' birth, reducing the opportunities for the father-infant dyads to interact (Swiss Civil Code, 2021; Federal Statistical Office, 2022). Therefore, it is plausible that the fathers in our study might have encountered limited chances for one-on-one interactions with their infants. The infrequency of these interactions could have hindered the formation of strong associations within the father-infant dyad, for which more shared time may be necessary for the development of mutual regulation. In simpler terms, increasing the duration fathers spend with their infants could have provided additional opportunities for infants to become accustomed to mutual regulation with their fathers. This, in turn, might have improved infants' physiological responsiveness to these interactive moments, much like what is observed with mothers who are consistently present during the initial 3 months. This understanding of our

results suggests that enhanced shared time during the early months may strengthen the impact of the father-infant relationship on children's social–emotional development. To confirm the influence of shared time, future research should investigate the associations between the variables in our study by comparing groups of fathers with paternity leave of different lengths.

Moreover, the existence of significant associations across the dyads suggests that fathers' influence may take another path, as suggested by the results. Our hypothesis that associations exist between the interactive synchrony in one dyad and infants' vagal tone in the other dyads was indeed confirmed. The results showed that the interactive synchrony in one dyad had a significant association with infants' vagal tone in the other dyad, such that variations in the quality of interactions in one dyad were related to variations in infants' vagal tone during interactions in the other dyad. These associations across dyads were present in the whole sample and in the group in which fathers interacted first, revealing that they were mainly due to those father-infant dyads interacting first and those mother-infant dyads interacting second. Specifically, our results showed that father-infant synchrony was significantly associated with the infants' RMSSD in the subsequent mother-infant interaction, whereas infants' RMSSD during father-infant interaction was associated with mother-infant synchrony in the subsequent interaction. These results thus seem to indicate that although fathers may not have an impact on the infant's physiological regulation during father-infant interactions, they have an indirect influence. The results across dyads in the group in which fathers interacted first suggest a way in which fathers might influence infants' physiological regulation of emotion by influencing mother-infant synchrony and the infants' RMSDD during mother-infant interactions. This across-dyad association in the multigroup analyses (Model 2) also suggests a potential causal

relationship because the interactions occurred in sequence. Moreover, the infants' physiological regulation of emotions during father-infant interactions might have subsequently influenced the variations in the quality of later mother-infant interactions. Further investigations are needed to assess these possible causal links.

In sum, interesting results emerged from the estimation of Model 2, in which we controlled for the influence of the order of the play, such that all within-dyad and across-dyad associations disappeared in the group of families in which mothers were asked to interact first. A speculative explanation may be proposed to explain the absence of association within mother-infant dyads when the mother interacted first. This explanation may also extend our previous explanation about the lack of associations within father-infant dyads, particularly for those father-infant dyads that interacted first. In our study, just before the start of the two parts of the play, the infants were barely stimulated by the parents engaged in listening to the researchers' instructions. Once alone with the first interacting parent, the infants had to "tune in" to the parents' request to interact. This moment of attunement may have delayed the establishment of coregulatory processes within the dyads and their associations with the physiological patterns of the infant, regardless of the dyads' increased habit of interaction at 3 months. Further investigation is required to delve into our speculative explanation, as well as to understand the reasons behind the absence of associations across dyads in the group in which fathers interacted second. Gaining a more comprehensive understanding of how the order of interaction affects parent-infant interactions could yield profound insights into the influences molding infant physiological regulation of emotion. In turn, this broader understanding will enhance the interpretation of the results of this study.

This study has some limitations. Most of the participants belonged to the middle-upper socio-economic class in the Swiss population and were university graduates. Furthermore, most of the study participants lived in a heterosexual two-parent family, so we had to limit our analysis to this group. Our results may therefore be different in other types of families. Although a global assessment of the interactive synchrony considers the behavioral patterns within mother- and father-infant dyads, it does not allow for the investigation of the association between specific interactive synchrony behaviors (e.g., sharing of smiles, the direction of gaze toward the other partner, demonstration of readiness for interaction, and vocalizations) and changes in vagal tone. The systemic nature of emotion regulation involves physiological, affective, and social mechanisms (Barrett, 2017; Thompson, 2019; Pruessner et al., 2020). Thus, although vagal tone is often used in studies as the main indicator of emotion regulation, other indicators could have captured the contextual and extrinsic factors crucial for infant emotion regulation. In addition to vagal tone, future studies should also consider the observed behaviors of emotion regulation during interaction so that the findings of this study can be further confirmed.

Our study is the first to consider the association between the quality of interactions and the vagal tone of 3-month-old infants, both within each parent-infant dyad and across one dyad to the other during subsequent interactions. Notwithstanding its limitations, our study shows the existence of associations between interactive processes and infants' physiological regulation of emotions within the mother-infant dyad and across dyads in a family. The associations across dyads provide evidence that the quality of father-infant interactions has a crucial influence on family relational dynamics, with consequences for the early physiological regulation of infant emotions. However, the significance of the associations may vary when controlling for the order

of interaction, demonstrating that interactive processes within and beyond the dyad are sensitive to contextual factors and interdependencies between family members. Future research with a systemic perspective of family relationships is needed to investigate the complex family influences on the socio-emotional development of the infant.

Article IV

Prenatal depressive symptoms and postnatal parent-infant interactive synchrony: An actor-partner interdependence model

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This article is under review in the *Journal of Family Psychology.*

Abstract

We examined how depressive symptoms reported by mothers and fathers before the infant's birth influence their own (actor effect) and their partner's (partner effects) quality of parent-infant interactive synchrony in the fourth month after birth. Parent-infant interactive synchrony is an indicator of the quality of dyadic interactions and refers to how the parent and infant are in synchrony during interactions. Using an actor-partner interdependence model, we analyzed data from 86 families. Both parents assessed their depressive symptoms between the 36th and the 38th weeks of pregnancy, and observations of parent-infant synchrony were conducted during a laboratory visit 3 months after birth. We found an actor effect between mothers' depressive symptoms and mother-infant synchrony, whereas a partner effect was prominent between fathers' depressive symptoms and mother-infant synchrony. Our results underscore the importance of involving both parents in research on parent-infant synchrony. This inclusion enhances the comprehension of the reciprocal influence among family members.

Keywords: actor-partner effect, prenatal, depressive symptoms, parent-infant synchrony, parent-infant interaction

Prenatal Depressive Symptoms and Postnatal Parent-Infant Interactive Synchrony: An Actor-Partner Interdependence Model

Early parent-infant interactions are important for the infant's development. Difficult parent-child interactions reflect difficulties in the relationship, which might jeopardize the child's mental health and psychological development. A risk factor for the reduced quality of early interactions is the presence of prenatal depressive symptoms in the parents, which reduces their capacity to adjust to their infant during interactions. Interdependencies exist between family members so that a parent's prenatal depressive symptoms can affect not only their own interactions with the infant, but also those of the partner with the infant. However, many studies on the determinants of the quality of parent-infant interactions have typically analyzed data from mothers and fathers separately, thus neglecting the interdependence and mutual influence between the two parent-infant dyads.

Parent-Infant Co-construction of Interactive Synchrony

In the early months of life, infants rely entirely on external caregiving, gradually gaining independence as they develop. Whether an infant grows physically and psychologically healthy depends significantly on how well the caregivers can understand, notice, and effectively respond to the infant's cues for assistance and support. Therefore, how primary caregivers, usually parents, interact with the infant and the overall quality of their interactions are crucial factors influencing the infant's health and well-being. Repeated interactions in daily life gradually organize themselves as patterns, which become stable over time and shape the parent-infant relationship and the infant's socioemotional, cognitive, linguistic, and neurological development (Winston & Chicot, 2016). One index of the quality of parent-infant interaction is interactive

synchrony (Bernard et al., 2013; Tronick, 2007). Interactive synchrony refers to the exchanges and synchronization of hormonal, behavioral, and physiological stimuli between parent and infant during social contact, providing critical inputs for the growth and development of the young (Rosenblatt, 1965; Schneirla, 1946; Wheeler, 1928). Interactive synchrony has been shown to be associated with child development, notably with enhanced cognitive development, reduced externalizing and internalizing symptoms, and adaptive self-regulation, with effect sizes varying from small to large (Hinnant et al., 2013; Kochanska et al., 2008; Suveg et al., 2016). The key elements of interactive synchrony can be outlined in four main aspects. The first is that interactive synchrony entails the exchange and synchronization of both behavioral (e.g., gaze, affection, voice, and touch) and physiological (e.g., brain networks, affiliative hormones, and autonomic responses) signals. The second is that the exchange and synchronization of the signals occur within each interactant and between the interactants and that it involves the interplay between the behavior/physiology of one interactant and the behavior/physiology of the other interactant (Beebe et al., 2016; Feldman, 2015; Provenzi et al., 2018; Tronick & Cohn, 1989). The third aspect is that the exchange and synchronization of the signals are characterized to be both "concurrent" (when the parent is happy, the infant is happy) and "sequential" (variations in the parent predict variations in the infant; Wass et al., 2020). The fourth aspect is that the respective contribution of parent and infant to the co-construction of interactive synchrony changes during infant development. In the perinatal period, parents primarily shape interactive synchrony during the infant's wakeful periods through direct glances, positive expressions, vocalizations, and affectionate touch. During infancy, parents and infants gradually start to contribute jointly to shape interactive synchrony as the infant becomes a more active social

partner, able to contribute actively to synchrony through the active coordination of, for instance, gazes, affective expressions, co-vocalizations, and touches (Feldman, 2015).

Interactive synchrony is a challenge at the behavioral level and even more so at the physiological level. The challenge is due to the inherent complexity of social interactions, which often involve mistakes or external disruptions. These mistakes and external disruptions contribute to numerous moments of miscoordination, diminishing the achievement of interactive synchrony (Markova & Nguyen, 2022). For instance, moments of miscoordination may manifest when a parent misinterprets the infant's signals by withdrawing during opportune moments for interaction or, on the contrary, by insisting on engaging when the infant needs rest or a break from interaction. Nevertheless, notwithstanding these moments of miscoordination, both partners can sustain a certain degree of interactive synchrony by adapting behavior and physiology in response to signals from the other (Beeghly & Tronick, 2011). For instance, a parent who withdraws from the interaction may still stay somewhat engaged by smiling at the infant. Similarly, a parent with a tired infant might use a soothing melody to distract and calm the child, avoiding overly stimulating activities.

Early Interactions and Prenatal Parental Depressive Symptoms

Previous studies have explored factors that can negatively affect parenting and parental behaviors toward infants, ultimately affecting parent-infant interactions and children's outcomes across development. These studies have demonstrated that both mothers' and fathers' depressive symptoms represent a risk factor for parenting and family interactions and, ultimately, for the children's well-being. Indeed, results of previous studies have shown that parental depressive symptoms are associated with the reduced ability of the parents to interact with the child, with

implications for the quality of parent-infant interaction, increased difficulties in the parent-child relationship, and a higher likelihood of negative interactions, including irritability and hostility toward the child (Lindstedt et al., 2021; Medina et al., 2022; Parfitt & Ayers, 2014; Sethna et al., 2015).

When considering interactive synchrony, previous studies have shown that parental depressive symptoms negatively impact synchrony (for a review, see Field, 2010, 2018; Golds et al., 2022; Wee et al., 2011; Wilson & Durbin, 2010). This result stems from studies that considered only postnatal parental symptoms, overlooking prenatal symptoms. The limited investigation of prenatal symptoms is surprising, as previous studies have shown that although prenatal and postnatal symptoms are similar in their manifestation, their effects may be independent (Evans et al., 2012; Pawlby et al., 2011). A recent meta-analysis (Golds et al., 2022) revealed that only a few studies, conducted on mothers only, investigated prenatal symptoms as predictors of interactive synchrony. The conclusions of these studies were inconsistent, as associations between maternal prenatal depressive symptoms and interactive synchrony after birth were negative in some studies and positive in others. Another striking result of this meta-analysis was the absence of research on fathers. Given these findings, it is crucial to further explore the effects of prenatal depressive symptoms in both parents, with a specific emphasis on fathers for many reasons. First, an increasingly broad body of research supports the idea that the father-child relationship is at least as meaningful as the mother-child relationship in the early months of life (Cabrera et al., 2007; Lamb & Lewis, 2004). Second, over the last 20 years, studies have found that a significant portion of fathers experience depression during the prenatal period (Barker et al., 2017; Top et al., 2016), indicating the need to consider, similarly to

mothers, the influence of prenatal symptoms in fathers on the father-child relationship. Lastly, maternal and paternal depressive symptoms correlate with each other in the perinatal period (Paulson & Bazemore, 2010), necessitating a double focus on maternal and paternal prenatal symptoms. This double focus resonates with the family-system approach, according to which interdependencies exist among family members (Cox & Paley, 1997; Minuchin, 1974).

The Influence of Family Interdependencies

The ecological models of parenting and the family-system approach guided this study. The ecological models propose that contextual, societal, and behavioral factors influence parenting (Abidin, 1992; Belsky, 1984; Bronfenbrenner, 1999). Furthermore, similar to the family-system approach, the ecological approaches emphasize that all family members are interconnected and part of a system, so that parents and children are best studied within this network (Belsky, 1984; Cox & Paley, 1997; Minuchin, 1974). Examples of interdependencies among family members are the spillover and the crossover effects. The spillover typically refers to the transfer or diffusion of emotions, feelings, behaviors, or experiences generated in one subsystem (e.g., the marital relationship) to another (e.g., the parent-child relationship; Engfer, 1988; Erel & Burman, 1995). For example, the health of the marriage causally influences the quality of the parent-child relationship, such as when parents transfer negativity in the marital relationship to their interactions with their children (i.e., scapegoating, detouring; Golds et al., 2022; Medina et al., 2022). The crossover effect refers to the transfer of experiences or affects between individuals. For example, a crossover effect occurs when parents support their children to compensate for the depressive symptoms of their spouse (Kouros et al., 2014; Nelson et al.,

2009) or when their interactions with the child are negatively affected by their spouse's symptoms (Goodman et al., 2014; Ponnet, Mortelmans, et al., 2013).

Although prior studies have investigated the links between perinatal depression and interactive synchrony, few studies have investigated the effects of a parent's depression on the relationship of the other parent with the child, especially during the prenatal period. Investigating these effects could provide insights into how parental prenatal symptoms affect interactive synchrony within the family system. A specific analytic framework that can be useful in investigating such effects is the actor-partner interdependence model (APIM; Kenny et al., 2020). It allows for the simultaneous estimation of actor and partner effects in dyads. An actor effect occurs when predictor variables from the respondent influence the outcome variables of the respondent, whereas a partner effect occurs when predictor variables from the partner's respondent influence the outcome variables of the respondent.

Aims of the Study

In this study, we focused on the prenatal depressive symptoms of both mothers and fathers as determinants influencing parent-infant interactive synchrony after the birth of the infant. The first aim was to explore how depressive symptoms reported by both parents before the infant's birth affect their own interactive synchrony with the 3-month-old infant. Drawing insights from previous research on postnatal depression (Ponnet, Wouters, al., 2013; Wilson & Durbin, 2010; Woody et al., 2016), we anticipated similar actor effects for prenatal symptoms of depression, expecting higher levels of depressive symptoms to be negatively associated with parent-infant synchrony. The second aim was to investigate how depressive symptoms reported by each parent before the infant's birth influence the partner's parent-infant interactive

synchrony 3 months after birth. Regarding partner effects, we expected that increased levels of depressive symptoms experienced by one parent would have an adverse impact on the partner's parent-infant interactive synchrony. The third aim was exploratory, aiming to test, through the APIM, the relative size of the actor and partner effects to discern four general patterns based on the interdependence theory (Kelley et al., 2003): actor-only, partner-only, couple, and contrast pattern (Kenny & Ledermann, 2010). In this study, the actor-only pattern was identified when a parent's interactive synchrony with the infant was solely influenced by their own depressive symptoms, without any influence from the partner's symptoms. Conversely, the partner-only pattern emerged when a parent's interactive synchrony with the infant was influenced by the partner's depressive symptoms but not by their own. In a couple-oriented pattern, both actor and partner effects carried equal weight, indicating that a parent's interactive synchrony with the infant was influenced equally by their own depressive symptoms and those of the partner. The contrast pattern occurred when actor and partner effects were equal in magnitude but exhibited opposite signs. For instance, father-infant interactive synchrony may be adversely affected by the father's depressive symptoms and positively influenced by the mother's depressive symptoms (Kenny et al., 2020; Kenny & Ledermann, 2010).

Method

Participants

We collected data in a convenience sample of 86 mother-father-infant families. The mothers had a mean age of 33.71 years (SD = 4.01; n = 73 due to missing data), the fathers a mean age of 36.09 years (SD = 5.81; n = 67 due to missing data), and the infants a mean age of 15.42 weeks (SD = 1.25; n = 73 due to missing data). One family discontinued participation after

childbirth without providing further information and was thus excluded from the sample. Among the remaining families, the infants comprised 44 boys and 41 girls. Mothers were mostly university graduates (64%) with 77.9% of them employed, 58.1% full time (n = 67 due to missing data). Fathers were mostly university graduates (51.9%, n = 77 due to missing data) with 93.5% of them employed (n = 77 due to missing data), 88.9% full time (n = 72 due to missing data). Mothers were mostly in cohabiting couples (54.7%; some of them were divorced or separated from a previous relationship) and married (45.3%). Among the fathers (n = 77 due to missing data), 49.4% were married and 50.7% were in a cohabiting couple (some of them were divorced or separated from a previous relationship). A socio-economic index (IPSE), specifically designed to assess the socio-economic status of people living in Switzerland (Genoud, 2011), was calculated from the education level and occupation of both parents. Regarding socio-economic status, 15.9% of families belonged to the upper class, 57.5% to the middle-upper class, 15.1% to the middle class, 8.2% to the middle-low class, and 4.1% to the low class (n = 73 due to missing data).

Procedure

In this study, we used data collected from a larger study on emotion regulation and family functioning. At T1 (i.e., prenatal), a midwife recruited parents at the maternity unit of the University Hospitals of Geneva. The midwife explained to the parents that the study's focus was the infant's emotions. We presented the research objectives and gave the parents a consent form, which the interested participants signed. We then collected data from parents through questionnaires. At T2 (i.e., 3 months after infant birth), the research team contacted and scheduled a meeting with the parents when the infant was between 3 and 4 months old. At the

beginning of the meeting, the researchers reminded parents of the context and the course of the study and invited them to place the infant on a changing table. The researcher asked the parents to interact with the infant following the scenario of the Lausanne Trilogue Play paradigm (Fivaz-Depeursinge & Corboz-Warnery, 1999). In the first part, one parent played with the infant for 2 minutes while the other parent was outside the room. In the second part, the parents changed roles. We counterbalanced the order of the parts to have an equal distribution between the mothers and fathers who interacted first. Finally, in the third part, the two parents played together with the infant for 2 minutes. In this study, we considered only the first two parts, that is, the interactions of each parent with the infant. Before starting the interactions, the researchers indicated the position of the cameras. They also specified that the experiment could be interrupted if the infant showed excessive fatigue or distress. The researchers instructed the parents to interact as they usually do with the infant, avoiding objects if possible. At the end of the interactive session, interested parents were offered an additional meeting for a debriefing in the form of video feedback. In addition, parents were provided with a link to complete online questionnaires. In this study, we considered only depressive symptoms reported by both parents at T1 because those at T2 were reported after the interactive session, thus challenging their interpretability as predictors of interactive synchrony assessed at the time of the interactive session. We obtained written informed consent from each infant's parent or guardian before any assessment or data collection. The study and its protocol received approval from the Ethical Committee of the State of Geneva.

Measures

Prenatal Parental Depression

The Edinburgh Perinatal/Postnatal Depression Scale (EPDS; Cox et al., 1987) is a 10-item self-report scale that assesses the symptoms of depression between 28 and 32 weeks in all pregnancies and between 6 and 8 weeks postpartum. Responses are scored from 0 to 3. The lowest and highest scores to be obtained from the scale are 0 and 30. Items 1, 2, and 4 are scored from 0 to 3, but items 3, 5, 6, 7, 8, 9, and 10 are scored in the reverse order. The EPDS has been validated in women and men (Areias et al., 1996; Massoudi et al., 2013; Matthey et al., 2001). A cutoff of 14 or 15 was found to be optimal for prenatal screening for major depression (Murray & Cox, 1990). In this study, we used the French version of the test (Guedeney & Fermanian, 1998) and computed a total score for mothers ($\alpha = .81$, $n = 86$) and for fathers ($\alpha = .79$, $n = 77$) by summing the item scores at T1. The French version of the test established a cutoff score of 11 points for clinical depression; however, in the present study, our primary focus was on the continuous scores on the scale. The higher the score, the more prenatal depressive symptoms were reported by the parent.

Parent-Infant Synchrony

We assessed mother- and father-infant synchrony at T2 with the infant CARE-Index; (Crittenden, 2006). The CARE-Index is an adult-infant interaction assessment that can be used from birth to 25 months. The coding system assesses global dyadic synchrony, that is, parents' sensitive behavior and infants' cooperative behavior, within the context of parent-infant interactions. Scores ranged from 0 to 14, with higher scores indicating better dyadic synchrony.

A sample of parent-infant interactions (n = 72 due to missing data) was coded from March 2022 to August 2022. To ensure inter-rater reliability, the first and third authors, both trained and certified as research raters, initially coded a random sample of 27.8% of the video recordings (20 videos of 72 families at T2) in February 2022. The intraclass correlation (two-way random absolute agreement) on the synchrony scores was excellent, with a coefficient of .982 (Koo & Li, 2016). Coders were blind to the results of the EPDS analyses.

Statistical Analysis

This study included two measurement points: between 36 and 38 weeks of pregnancy (T1) and at 3 months postpartum (T2). Because of the unequal participation of mothers and fathers at T1 and families dropping out at T2, we statistically controlled for missing data on the total sample (N = 86). Missing data analysis was conducted on the target variables and potential control variables (sex of the infant, age of the parents, age of the infant at the lab visit, and socio-economic status) to be included in subsequent analyses. Little's Missing Completely at Random (MCAR) test was not significant (χ^2 = 35.951, df = 36, p = .471), indicating that the data were missing completely at random. On the basis of the result of the MCAR test, we retained all 86 mother-father-infant families to optimize the sample size and the statistical power in subsequent analyses. We then computed a set of descriptive statistics for the variables under study (see Table 1).

Table 1

Descriptive Statistics

Variable	*n*	*Min*	*Max*	*M*	*SD*
Prenatal depression F	77	.00	18.00	4.51	3.85
Prenatal depression M	86	.00	24.00	6.81	4.45
Synchrony F-I	72	1	14	7.28	3.01
Synchrony M-I	72	1	14	7.76	3.23

Note. F = father; M = mother; I = infant.

The normality test was performed by using the Shapiro-Wilk test. We also tested for bivariate correlations between the variables under study, as well as for differences between the scores of mother- and father-infant synchrony, depending on the order of the parts in the play, through the Student's *t*-test and the Mann–Whitney *U* test (non-parametric alternative to the Student's *t*-test used when the samples to be compared do not have a normal distribution). Because of the small size of our sample, we wanted to optimize statistical power by eventually including only those control variables that would have shown significant correlations with the target variables in multivariate analyses (see Table 2 for more details).

Table 2

Correlation Matrix

Variable	1	2	3	4	5	6	7	8	9
1. Prenatal depression F	1								
2. Prenatal depression M	.059	1							
3. Synchrony F-I	-.175	-.014	1						
4. Synchrony M-I	-.215	-.282*	.433**	1					
5. I sex[a]	.107	.105	-.207	-.149	1				
6. I age	-.083	-.024	.118	.027	-.025	1			
7. F age	.136	.025	-.123	-.124	-.033	-.075	1		
8. M age	.087	.036	-.185	-.143	-.152	.043	.566**	1	
9. SES[b]	.129	-.092	-.078	.090	-.002	.028	.298*	.294*	1

Note. $N = 86$. F = father; M = mother; I = infant; SES = socio-economic status.

[a]Sex: 1 = female, 2 = male; [b]SES: 1 = lower, 2 = lower-middle, 3 = middle, 4 = middle-upper, 5 = upper.

$^{**}p < .01$. $^{*}p < .05$.

As none of the control variables showed significant correlations with the target variables, they were excluded from subsequent analyses.

We specified an APIM within a structural equation modeling framework to test our research hypotheses. The model was specified with mothers' and fathers' depressive symptoms at T1 (i.e., prenatal) as independent variables and with mother-infant and father-infant synchrony at T2 (i.e., at 3 months after infant birth) as dependent variables. To examine whether the model was more actor-, partner-, couple-, or contrast-oriented, we followed the procedure described by Kenny and Ledermann (2010). The APIM test procedure consists of a three-step approach. In Step 1, we specified a first model to look for significant actor and partner effects. Model 1 was a saturated model. In Step 2, we specified a second model to provide information about the type of dyadic pattern that characterizes the effects reported in the model. Model 2 was a saturated model with a *k* parameter computed for each parent of the dyad. The *k* parameter represents the ratio of the partner (*p*) effect to the actor (*a*) effect (i.e., $k_1 = p_{21}/a_1$, and $k_2 = p_{12}/a_2$) or vice versa

if the partner effects are stronger than the actor effects ($k_1 = a_1/p_{21}$ and $k_2 = a_2/p_{12}$). Kenny and Ledermann (2010) propose using bootstrapping for a more insightful interpretation of *k* parameters. A bootstrap for confidence intervals (CIs) containing a *k* parameter close to 0 suggests the *actor-only* pattern (or *partner-only* when the ratio is reversed). A *k* near -1 indicates the *contrast* pattern, where actor and partner effects are similar in strength but opposite in direction. Conversely, a *k* near 1 supports the *couple* pattern, indicating actor and partner effects of comparable strength and in the same direction. Finally, in Step 3, we specified a third model (Model 3) with two constraint values of *k* (those found in Step 2). This step, as explained by Kenny (2013), improves the *k* parameter's interpretability and helps to determine if any interpretable *k* values (i.e., -1, 0, or 1) are included within the boundaries of the 95% CIs. Adding two constraints (i.e., the two *k* parameters found in Step 2, one for mothers, one for fathers) freed up 2 degrees of freedom, resulting in Model 3 being identified. This enabled us to use the model fit indices of the model (i.e., Model 3) for comparison with the saturated models (i.e., Models 1-2) to observe whether the constraints worsen the adjustment of the model.

We used a maximum likelihood estimator to estimate our models and performed a bootstrap on 5,000 samples. Although bootstrap CIs were necessary to compute the *k* parameters in Models 2 and 3, this method also allows one to deal with non-normal data and small samples, as this approach outperforms other methods under these conditions (Lai, 2018). We used bias-corrected bootstrap CIs to evaluate the significance of all parameter estimates. Because Models 1 and 2 were saturated, information about their model fit (e.g., root mean square error of approximation [RMSEA], comparative fit index [CFI], etc.) is uninformative, as they were necessarily perfectly adjusted to the data. Chi-square tests and other fit indices (e.g., RMSEA)

were used to evaluate the model fit of Model 3 according to the standard criteria defined by Hu and Bentler (1999). For the CFI and Tucker-Lewis index, values above .90 indicate an acceptable fit, and values above .95 indicate an excellent fit. For the RMSEA, values below .06 indicate an excellent fit, and values between .06 and .08 indicate an acceptable fit. Finally, the standardized root mean square residual ranges from 0 to 1.0, and values less than 0.05 indicate well-fitting models. However, values as high as 0.08 are deemed acceptable (Hu & Bentler, 1999).

Descriptive statistics, bivariate correlations, Little's MCAR test, the Student's *t*-test, and the Mann-Whitney *U* test were computed in IBM SPSS Statistics 27 software (IBM Corp., Armonk, NY). Mplus 7.4 (Muthén & Muthen, 2016) was used to conduct structural equation modeling analyses.

Results

Descriptive Statistics

The mean and standard deviations of mothers' and fathers' depressive symptoms at T1 and mother-infant and father-infant synchrony at T2 are provided in Table 1. The Shapiro-Wilk test was performed to verify the normal distribution of the study variables, revealing that only the mother-infant synchrony scores were normally distributed ($p = .228$). We then tested for a potential effect of the order of the parts in the play on the synchrony variables. From the results of the normality test, we used the Student's *t*-test for the mother-infant synchrony scores (normally distributed) and the Mann-Whitney *U* test for the father-infant synchrony scores (not normally distributed) to compare synchrony scores in the two conditions (mother playing first vs. father playing first). Results revealed that the synchrony scores with the mother, $t(70) = 1.507$,

$p = .136$, and the father (U: 529.500, $p = .178$) did not vary depending on the order of the parts in the play. Finally, we tested for significant differences between the prenatal symptom mean scores for mothers and fathers. Results revealed that the EPDS mean score was significantly lower for fathers than for mothers at T1, as attested by a paired-sample *t*-test, $t(76) = 3.303$, $p < .001$.

Correlational Analyses

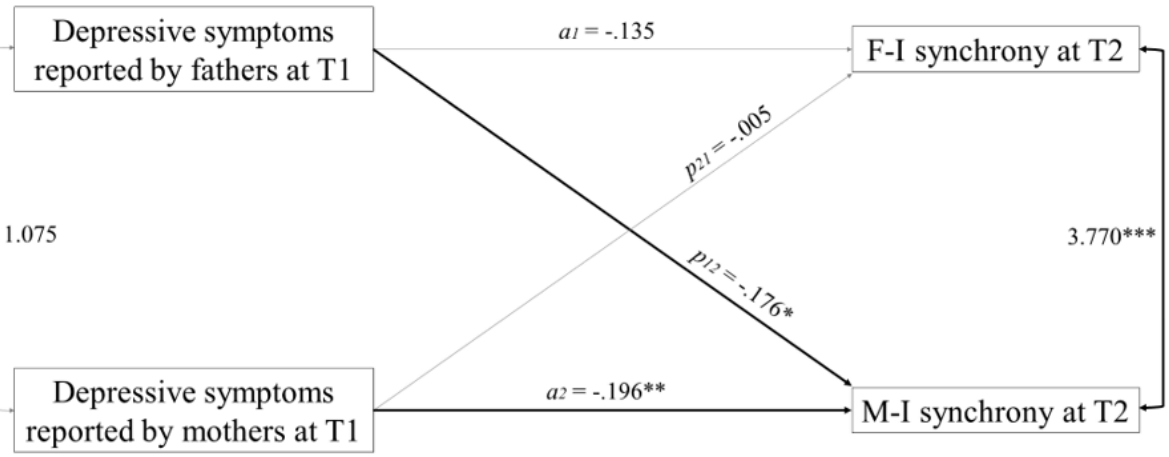
The correlational analyses between the target variables (prenatal mothers' and fathers' depressive symptoms, and parent-infant synchrony at 3 months postpartum) and the control variables (sex of the infant, age of the parents, age of the infant at T2, and socio-economic status) are provided in Table 2. The mother's report of prenatal depressive symptoms was shown to correlate only with mother-infant synchrony. This correlation was negative so that as depressive symptoms increased, synchrony decreased. The father's reports of prenatal depressive symptoms were not correlated with the target variables. None of the control variables was significantly correlated with the target variables.

The Actor-Partner Interdependence Model

The results of the estimation of Model 1 (Figure 1) showed that, between the two actor effects, only the maternal effect was significant (95% CI [-.308, -.084]).

Figure 1

The APIM With Estimates



Note. F = father; M = mother; I = infant; T1 = prenatal; T2 = 3 months after infant birth; *a* = actor effect; *p* = partner effect; 1 = father; 2 = mother. The Actor-Partner Interdependence Model shows paths between mothers' and fathers' depressive symptoms at T1 (i.e., prenatal) as independent variables and mother-infant and father-infant synchrony at T2 (i.e., 3 months after infant birth) as outcome variables. Bold rows show significant paths between variables, and gray rows show nonsignificant paths. Error terms are omitted to improve the visual clarity of the model. The 95% CI ranges were from -0.268 to 0.006 for a_1, from -0.308 to -0.084 for a_2, from -0.148 to 0.114 for p_{21}, and from -0.315 to -0.035 for p_{12}.

***p < .001. **p < .01. *p < .05.

More specifically, an increase in mothers' symptoms led to a decrease in mother-infant synchrony. Conversely, we did not observe any significant actor effect between fathers' depressive symptoms and father-infant synchrony (CI [-.268, .006]). Concerning the two partner effects, only the paternal effect was significant (CI [-.315, -.035]), as fathers' higher depressive symptoms were associated with lower mother-infant synchrony. No significant partner effect was identified between mothers' depressive symptoms and father-infant synchrony (CI [-.148, .114]).

As suggested by Kenny and Ledermann (2010), we verified that the absolute values of the standardized effects of the actors (a_1: |-0.173| = 0.173; a_2: |-0.270| = 0.270) were greater than 0.10, so that we could subsequently compute the *k* parameters.

The *k* parameters were estimated to be 0.03 for fathers (p_{21}/a_1 = -0.005/-0.135) and 0.89 (p_{12}/a_2 = -0.176/-0.196) for mothers. For fathers, the 95% CI of *k* included 0 and ranged from -1.203 to 2.240. This result supported the existence of an "actor-only" pattern for fathers, although this actor effect was not significant. For mothers, the CIs of the *k* parameter included 1, excluded 0, and ranged from 0.178 to 2.358. This result supported the interpretation of *k* for mothers as a "couple-oriented" pattern, which means that mother-infant synchrony at 3 months is affected by both parents' prenatal depressive symptoms.

Finally, to confirm the relevance of these patterns, we specified Model 3 with a *k* constraint of 0 for fathers and 1 for mothers. The results of the estimation of Model 3 showed that this model, although more parsimonious, was not statistically different than the saturated model, such as Model 2, χ^2 (2) = 0.023, p = .98. They indicated that Model 3 should be preferred over Model 2, which confirmed an "actor-only" pattern for fathers and a "couple-oriented" pattern for mothers.

Discussion

In this study, our investigations focused on the links between prenatal depressive symptoms reported by both mothers and fathers during pregnancy and parent-infant interactive synchrony—an indicator of interaction quality—observed in the third month after birth. Specifically, we investigated two effects: the effect of each parent's depressive symptoms on

their own interactive synchrony with the infant (actor effect) and the effect of their partner's depressive symptoms on their interactive synchrony with the infant (partner effect). We found that both parents' depressive symptoms before the infant's birth affected mother-infant synchrony at 3 months, whereas they did not influence father-infant synchrony. These results show the interest in investigating both parents' symptoms—as risk factors for the quality of parent-infant interactions—during the prenatal period.

First, mothers' prenatal depressive symptoms were negatively associated with mother-infant synchrony. This result is in line with prior studies highlighting the negative influence of mothers' depression on the quality of interaction with their children (Field, 2010, 2018). On the other hand, contrary to our expectations from previous research during the postnatal period (Field, 2010, 2018; Wee et al., 2011; Wilson & Durbin, 2010), no significant actor effect was observed for fathers. Three explanations may be proposed to explain why there is an actor effect in mothers while there is none in fathers. The first explanation involves this study's specific Swiss context. In Switzerland, infants of depressed mothers might be more sensitive to maternal than to paternal behaviors. Indeed, in the initial months, infants in Switzerland are more frequently exposed to maternal than to paternal behaviors, as most Swiss mothers benefit from a maternal leave of 14 weeks and become primary caregivers, dedicating more time to the infant compared with that for fathers. Because of the shorter paternity leave for fathers (2 weeks) and their common full-time work commitments (Swiss Civil Code, 2021), opportunities for one-on-one interactions with infants are limited during this period. Thus, more exposure to maternal behaviors possibly increases the infant's tendency to match the mother's affect and behavior. Consequently, paternal behaviors may not exert as much influence as maternal behaviors,

thereby reducing the strength of the association between fathers' prenatal depressive symptoms and father-infant synchrony at 3 months. The second explanation is linked to *masked depression* or *masculine depression* (Addis, 2008). Masked depression or masculine depression suggests that men's depression might be concealed because of gender norms that encourage some depressed men to avoid displaying typical and overt depressive behaviors, such as low mood and reduced activity. Instead, they may exhibit behaviors such as emotional stoicism, toughness, a tendency toward performance, and competitiveness (Addis & Cohane, 2005). This tendency to conceal depressive symptoms might be more likely in the prenatal period, especially as mothers receive more attention—especially medical attention—compared with that received by fathers. Indeed, fathers in the perinatal period often report receiving less attention and support, potentially making them less likely to seek help or share their difficulties (Lacharité, 2009). In this study, fathers reported fewer symptoms than mothers, which could be indicative of some fathers' tendency to mask depressive symptoms. The coexistence of masked-depressed, depressed, and non-depressed fathers could have weakened the link between symptoms and interactive synchrony, explaining the nonsignificant actor effect for fathers. The third explanation delves into the influence of parental concerns during the perinatal period. During this period, we speculate that fathers' concerns might redirect their attention away from symptoms, possibly lessening the influence of symptoms on fathering behaviors. In contrast, maternal concerns might increase awareness of depressive symptoms in mothers, resulting in a more significant negative impact on mothering behaviors. We base our explanation, needing further investigations, on some evidence about mothers and fathers during the perinatal period. Evidence suggests that mothers may experience intensified worries during the perinatal period about, for example, self-

care (e.g., hygiene, nutrition, weight loss, and perineal, incisional, and breast pains), infant care (e.g., feeding, soothing, identification of signs and symptoms of illness), and family relationships (e.g., other children's needs, marital/intimate relationship disruption, support received; for a review, see Fahey & Shenassa, 2013) and that these worries could lead them to heightened distress, potentially exacerbating maternal depressive mood and affecting the quality of mothering behaviors (Halsa, 2018; Razurel, Kaiser, Sellenet et al., 2013). In contrast, evidence suggests that paternal concerns during the perinatal period may prioritize the safety and well-being of the mother and infant, diverting attention away from depressive symptoms. A recent review by Darwin et al. (2021) indicates that fathers often prioritize the needs of their partners over their own symptoms during the perinatal period, possibly avoiding acknowledgment of their own struggles in order to appear strong for their partner. Furthermore, evidence suggests that paternal concerns during the perinatal period are often focused on managing immediate challenges, such as work commitments and financial concerns, rather than their own symptoms (Holmberg, 2022; Tamres et al., 2002). The influences of parental concerns on symptoms might extend to the partner's symptoms. This would imply that fathering behavior may be less susceptible to the influence of both the father's and the partner's symptoms than mothering behavior is. Although this speculative explanation about partners' symptoms requires further investigation, it aligns with our findings regarding partner effects.

Our partner effect hypothesis was partially confirmed: An increase in fathers' prenatal symptoms was associated with a decrease in mother-infant synchrony, while no significant partner effect was observed between mothers' depressive symptoms and father-infant synchrony. These findings align with a family systems approach, emphasizing that the family operates as a

complex, integrated unit, where issues within the family system, such as depression in one family member, can adversely affect others (Cox & Paley, 1997; Minuchin, 1974). A speculative explanation may be that paternal self-related negative feelings, coupled with paternal depressive symptoms, might have worsened concerns for expectant mothers, reducing maternal well-being and affecting behaviors. This reduction, in turn, might have led to a decreased quality of mother-infant interactions. This explanation is based on two considerations. First, depressive symptoms are usually experienced as self-related negative feelings (Goodman & Gotlib, 1999). Second, women who receive inadequate emotional support from their partners not only face an elevated risk of developing depressive symptoms during pregnancy, but also experience difficulties in parental functioning after infant birth (Jeong et al., 2013; Xie et al., 2009). In our study, fathers reporting higher depressive symptoms during pregnancy might have experienced an increase in self-related negative feelings. In turn, this negative feeling might have adversely affected fathering behaviors and the relationship quality with the pregnant mothers, who, in response, could have experienced insecurity about the support they received and the relationship with the fathers. In addition, the mothers may have perceived their partners as being, for example, incapable of providing support or contributing to a harmonious family atmosphere, thereby intensifying their concerns. The maternal concerns may have reduced the overall well-being of mothers, with a negative influence on maternal behaviors and interactions with the infant. This negative influence might have been stronger in those families where mothers themselves reported prenatal depressive symptoms.

On the other hand, we found no significant influence of the mother's depressive symptoms on the quality of father-infant interactions. A speculative explanation may be that

fathers' concerns about maternal symptoms were not significant enough to emerge in our analyses compared with other more influential concerns, such as protecting the mother and the infant, dealing with immediate challenges in the perinatal period, or masking their symptoms to appear strong (Holmberg, 2022; Tamres et al., 2002). This interpretation is based on two aspects of this study. First, most participants were members of non-referred families with a medium to high standard of living in a country with sufficient perinatal care opportunities. In these families, depressive symptoms may have had fewer deleterious and visible consequences compared with those in more disadvantaged families (Göbel et al., 2020). Therefore, although important, maternal symptoms might not have been severe enough to alert fathers or be perceived as worrisome by them, resulting in a nonsignificant influence on the father-child relationship. A second condition that might have reduced the effect of the maternal symptoms is the fathers dealing with their own symptoms. This is because fathers may have been more worried about managing (potentially concealing) their own symptoms instead of dealing with maternal symptoms. These explanations, which require further investigation, align with the results of the third aim, and notably indicate that the observed pattern for fathers was actor-only, while mothers showed a couple-oriented pattern.

The third aim was to test, through the APIM, the relative size of the actor and partner effects to discern four specific patterns: actor-only, partner-only, couple, and contrast pattern (Kenny & Ledermann, 2010). We found that the association between both parents' depressive symptoms and the quality of the mother-infant interactive synchrony was couple-oriented, meaning that mothers' interactive synchrony with the infant was influenced equally by their own depressive symptoms and those of the fathers. Conversely, we found an actor-only pattern for

fathers, although the actor effect for fathers was not significant. Despite the challenge of recruiting fathers, replicating this study with a larger sample size could increase the understanding of the patterns we found. In addition, using qualitative methods could help provide further insight into the characteristics of prenatal depressive symptoms and how they might be linked to parents' concerns during pregnancy. Taking a mixed-method approach—a quantitative analysis with a larger sample and qualitative insights—would provide a more comprehensive understanding of the nonsignificant actor-only pattern for fathers and the couple-oriented pattern for mothers found in this study.

Limitations

The results of this study must be interpreted while considering its limitations. The findings are specific to heterosexual families and are not generalizable to other family configurations. Although not intended, the sample predominantly consists of highly educated parents with a high quality of life, limiting generalizability to different populations. Lastly, despite the use of self-report being a convenient method for data collection, incorporating direct observations (e.g., the Structured Clinical Interview for DSM–IV Axis I; First et al., 1997) and independent evaluators could have offered a more insightful understanding of parental symptoms. However, the complexity of such an approach in terms of resources and time would likely have reduced the number of participants. This is particularly true during the perinatal period, when new parents often experience time constraints, fatigue, and heightened stress, making them less inclined to participate in research studies (Frew et al., 2014; Holmberg, 2022).

Conclusion

Despite its limitations, this study underscores that APIMs are a useful statistical method for investigating the effects of parents' prenatal depression symptoms and their partners' prenatal depression symptoms on the quality of parent-infant interactions at 3 months. Specifically, our findings suggest that the presence of depressive symptoms in both parents can detrimentally affect the quality of interactions between mothers and their infants. Additional research is required to gain deeper insight into the lack of associations between both parents' prenatal symptoms and the quality of father-infant interaction. This research could involve a more extensive sample of fathers and consider variations in paternity leave duration to better account for the influence of the time fathers and mothers spend with the infant during the initial months. Overall, the findings of this study underscore the presence of interdependencies within family members during the prenatal period, which influences the quality of parent-infant interactions in the initial months of life. Although fathers pose challenges in research participation, and the focus often remains on mothers and medical/obstetric aspects during pregnancy, this study underscores the need for investigations involving both parents with a systemic family approach. The implications for practitioners are noteworthy. By focusing on self-reported symptoms of prenatal depression rather than clinical diagnoses meeting the *Diagnostic and Statistical Manual of Mental Disorders* criteria (5th ed., text rev.; American Psychiatric Association, 2022), our study suggests that milder parental depressive symptoms as mood characteristics are associated with the quality of parent-infant interactions. Practitioners attentive to these milder symptoms during pregnancy may enhance the quality of parent-infant interactions after birth, with positive implications for child development.

DISCUSSION

7. Synthesis of the results

7.1. Article I

This literature review aimed to synthesize current knowledge within the scientific literature regarding the associations between father involvement—both in terms of quality and quantity—and ER during early childhood. In the scientific literature, this review is the first to focus on paternal influence during early childhood, a critical period when the quantity and quality of parental behaviors significantly impact the child's developing ability to self-regulate. Moreover, this review is the first to address the methodological, conceptual, and theoretical heterogeneity in previous research on father involvement and ER during early childhood. Indeed, it outlines how both constructs were assessed during early childhood and discusses whether the measurement methods relate to the findings in past research.

This review has allowed for some general conclusions despite the heterogeneity in the results of the ten included studies. The main finding is that father involvement's greater quantity and quality weakly influences better ER during early childhood. However, albeit indirectly, a more substantial impact appears when considering certain moderating variables. These moderating variables generally pertain to the assessment of both constructs (e.g., timing and what was assessed), as well as the characteristics of the father (e.g., ethnicity) and the child (e.g., gender). The review results indicate that the associations between constructs may be present or absent depending on the measurement methods, emphasizing their influence. For instance, using observational measures of ER increases the likelihood of finding direct associations with the quantity and quality of father involvement. This literature review outlines some trends in prior research. For example, regarding father involvement, the results of this review are primarily

based on studies involving fathers as the primary informants, often overlooking information from the mother. Concerning ER, most of the reviewed studies related to observational measures, and neglected physiological indices of regulation during father-child interactions. In conclusion, the results of this review highlight the necessity for additional research on the impact of fathers on child ER during early childhood, particularly for studies linking father-infant interactions and infant's physiological regulation. These investigations should control for the influence of the measurement methods.

7.2. Article II

The primary aim of the second article was to investigate the association between father-infant synchrony, an indicator of the quality of interaction, and infant vagal tone as an ER index during interactions.

Initially, we tested the hypothesis that better synchrony would predict higher vagal tone. Analyses did not confirm this hypothesis (although the positive association between synchrony and vagal tone almost reaches the significance threshold). Then, we tested the hypothesis that increasing two shared father-infant times—dyadic time (father and infant interact alone) and social time (father and infant interact in the mother's presence)—would strengthen the associations between synchrony and vagal tone. The analyses partially confirmed the second hypothesis as social time enhanced the association between synchrony and vagal tone, unlike dyadic time, which had no moderating effect. Additional analyses of the conditional effects, i.e., associations between synchrony and vagal tone for each combination of the levels of the two moderators, revealed that the strongest association between father-infant synchrony and infant vagal tone appeared when fathers shared a lot of social time with the infant, but only rare

moments alone with them (low dyadic time). The results of this study show that the quality of father-infant interactions does not influence infant physiological regulation. However, an impact is likely when the father and infant spend time together in the early months of life, especially in the mother's presence. Given the influence of shared times in the mother's presence, the results show the need to investigate further the impact of family processes on the associations between synchrony and infant vagal tone during father-infant interactions.

7.3. Article III

The primary aim of the third article was to investigate the associations between the quality of mother- and father-infant interactions and the infant's physiological regulation, considering mutual influences among family members.

Initially, we formulated two hypotheses. The first hypothesis was that there would be associations between greater interactive synchrony and higher infant vagal tone within each parent-infant dyad (within dyads). The second hypothesis was that there would be associations between greater interactive synchrony in one dyad and higher vagal tone in the other dyad (across dyads). Then, we tested both hypotheses in the whole sample and two groups based on the order of interactions, as we counterbalanced the order of the interaction between mothers and fathers. The results partially confirmed both hypotheses.

On the one hand, results indicated that greater synchrony was associated with higher infant vagal tone within mother-infant dyads and across dyads in both the total sample and the group where fathers interacted first with the infant. On the other hand, the results revealed that associations between synchrony and infant vagal tone within father-infant dyads were never significant, nor were any associations within each dyad or across dyads when mothers interacted

first. The results of this study offer valuable insights for future research. Firstly, they provide evidence of associations between interactive processes and the infant's physiological regulation within mother-infant dyads and across dyads within a family. Secondly, the findings across dyads indicate the crucial impact of the quality of father-infant interaction on family dynamics, with implications for early infants' physiological regulation. Lastly, the results of this study suggest that mutual influences among family members and some conditions, such as the order of interaction, play a role in shaping the associations between the quality of parent-infant interactions and the infant's physiological regulation.

7.4. Article IV

The primary aim of the fourth article was to investigate the influence of prenatal parental depressive symptoms—a risk factor for the quality of parent-infant interactions—on interactive synchrony at three months, considering mutual influences among family members.

Initially, we hypothesized that there would be an adverse effect of each parent's depressive symptoms on their own interactive synchrony with the infant (actor effect). This hypothesis was partially confirmed, as only the negative effect of maternal symptoms on mother-infant synchrony appears significant. Then, we hypothesized that there would be an adverse effect of the partner's depressive symptoms on the parent's interactive synchrony with the infant (partner effect). This second hypothesis was partially confirmed, as the father's prenatal depressive symptoms negatively influenced mother-infant synchrony, whereas father-infant synchrony was not affected by maternal symptoms. Additional analyses (i.e., *k* parameters for actor and partner effects) confirmed that the quality of mother-infant interaction was equally influenced by both maternal depressive symptoms and those of the fathers. The results of this

study demonstrate that the presence of depressive symptoms in both parents before childbirth can detrimentally affect the quality of interactions between mothers and their infants. In contrast, how both partners report their depressive symptoms before childbirth does not affect the quality of interaction between the father and the infant.

8. Perspectives on the results

In this chapter, we will put into perspective the results of the four articles in the empirical section of this thesis within a broader framework. This is because the findings from these articles, on the one hand, provide new evidence, and, on the other hand, they underscore the importance of reflecting on the field of study of early family interactions and their impact on infants' ER. We will delve into the contribution of our study to the evidence concerning the parent-infant interactions and their impact on the infants' ER at the physiological level. Our reflection will consider some pathways of influence through which fathers may have an impact on their infants' ER. These pathways of influence will be discussed in light of, first, the context and measures of our study; second, the mutual influences among family members; and third, the functionalist perspective of ER that we mentioned in the introductory paragraphs of this thesis.

8.1. Father-infant interactions and infant's ER

As mentioned in the opening paragraphs, prior literature on the links between the quality of interaction and physiological regulation of emotions has primarily focused on the mother-infant dyad. In alignment with this body of work, our study confirms that the quality of mother-infant interactions is linked to the infant's physiological regulation processes (Article III). This underscores the crucial role of the mother, who, despite the increasing involvement of fathers in today's society, remains the primary caregiver during the early months of an infant's life due to

biological factors (breastfeeding) and societal expectations (parental leave, gender norms). However, the influence of fathers is not negligible, as evidenced by previous studies demonstrating their impact on child regulatory processes. Our study shows that the quality of father-infant interactions is not linked to the infant's physiological regulation processes with the father (Articles II, and III). Instead, it appears that the quality of father-infant interactions is associated with the quality of mother-infant interactions and the physiological regulation of the infant during interactions with the mother (Article III) and that the father's prenatal depressive symptoms are associated with the quality of mother-infant interactions (Article IV).

Although our results do not allow us to conclude the direction of influence among the target variables, we cautiously interpret them by speculating on a potential causal relationship, notably from parents to infant physiological regulation. This is because, as mentioned in the initial paragraphs, parental behaviors primarily influence the quality of interaction at three months. From this, we can hypothesize that parents are more likely to significantly impact the physiological regulation of the 3-month-old infant rather than the opposite. In light of these considerations, our findings might be interpreted by speculating that fathers do not manifest directly their influence on infant physiological regulation. However, their influence may manifest indirectly through the father's impact on the quality of mother-infant interactions, as well as on infant physiological regulation during these interactions. From this speculative interpretation of our results, two important reflections emerge, one aimed at understanding the absence of direct influences and the other at the existence of indirect influences.

8.2. The absence of direct paternal influences on infants' ER

In the following two subsections, we will reflect on the absence of direct parental influences, found in our study, on the infant's physiological regulation of emotions. We will present two possible explanations. Firstly, prior literature has highlighted numerous similarities between maternal and paternal behaviors, but also several differences between them. Therefore, the first explanation of the absence of direct influences will focus on the differences in parental behaviors and reflect on the relevance of using the same variables to provide insights into each parent's contribution to the infant's functioning. Secondly, in the Swiss context where our study is conducted, fathers spend less time with infants than mothers in the perinatal period. Consequently, the second explanation of the absence of direct influences will focus on the impact of paternal involvement and the limited amount of time fathers dedicate to the infant in the perinatal period.

8.2.1. A critical view of the coding of interactive synchrony

As previously mentioned, past research has examined the behaviors of both parents, focusing on similarities and differences. Since all parents appear capable of coordinating with the infants and being responsive to their signals, we considered parental behaviors similar. However, the results indicated a lack of association between the quality of father-infant interactions and the infant's physiological regulatory processes. As mentioned in the theoretical background, there is evidence supporting sex-specific parental behaviors. These differences in mothers' and fathers' behaviors raise questions about using the CARE-Index coding system –initially developed for mother-infant interactions– to assess father-infant interactions. The CARE-Index was conceived with reference to the concept of maternal sensitivity, which is crucial for co-constructing

interactions with the infant. Sensitivity refers to the ability of the mother to accurately recognize and interpret the child's signals and respond appropriately (Ainsworth et al., 1974; Deans, 2018). Since maternal sensitivity is derived from a matricentric perspective and attachment theory (Bowlby, 1979), it is legitimate to question whether paternal sensitivity can be measured through measures conceived for maternal sensitivity. This reflection is particularly relevant, considering that parental behaviors differ and entail different consequences. About the CARE-Index, a score on a sensitivity scale is attributed based on seven aspects of maternal interactive behavior: facial expression, vocal expression, position and body contact, arousal and affection, turn-taking, control, and choice of activity. In each of these seven aspects, there is no explicit reference to aspects that evidence suggests to characterize the father-child interactions, such as “joint exploration and play” (Grossmann et al. 2002). As mentioned before, a significant aspect of the father's role as an attachment figure might be to provide security through sensitive and challenging support as a companion when the child’s exploratory system is aroused, thereby complementing the secure-base role of the mother as an attachment figure (Paquette, 2004). In light of this, it seems appropriate to emphasize the need to develop specific coding systems to assess fathers' behaviors in interaction with infants, as currently, there is no specific measure to assess father-infant synchrony (Birk et al., 2022). This would enable a deeper understanding and stimulate further reflections on this study's observed lack of direct associations.

8.2.2. Father-infant shared times matter

Another possible explanation for the absence of direct influences can relate to the context of this study. In Switzerland, paternity leave of 1–3 days was available to fathers until January 2021. Since then, paternity leave has been extended to 10 working days (i.e., two weeks).

Despite this change, mothers in Switzerland continue to have more extended leave (14 weeks) than fathers (Swiss Civil Code, 2021). Furthermore, mothers in Switzerland spend more time with their infants and assume the role of primary caregiver in the first months of life, while fathers usually continue to work full-time. Regarding the full-time employment rate between fathers and mothers of a 0- to 3-year-old infant in Switzerland, statistics showed significant differences between the parents, with full-time employment rates for fathers of 79.6% and 16.3% for mothers (Federal Statistical Office, 2022). Thus, it is likely that, in Switzerland, fathers may have few occasions to interact alone with their infants in the first months of life and that those few occasions to interact, usually in the presence of the mother, may represent an opportunity to reinforce the association between the quality of father-infant interactions and the infant's physiological patterns of ER in the first three months. In day-to-day care activities, the “less expert” Swiss father may need more time to “leave a mark” in developing ER patterns and helping the infant regulate emotions.

Evidence from research conducted in contexts other than Switzerland (e.g., the USA) supports the idea that extended paternal availability allows fathers to influence the child's development differently. Prolonged periods of paternal presence at home encourage greater paternal involvement in developmental and caregiving tasks during infancy and the child's early years. Additionally, an extended period at home after childbirth allows fathers to build strong bonds with their children, enhancing their ongoing involvement in the child's life (Pleck, 2010; Rehel, 2014). Another opportunity associated with extended paternity leave is an increase in fathers' chances to acquire parenting skills and gain confidence in their parenting role (Pragg & Knoester, 2017; Rehel, 2014). These findings are particularly significant, considering that

increased father involvement has been linked to positive outcomes in children and improvements in marital and parental relationships, which are crucial for child development (Lee et al., 2020).

We acknowledge that the access to diverse populations, more time, and resources would have allowed us to consider other factors (e.g., contextual, familial, and societal) that can contribute to understanding father-infant shared time and its associations with the infant's ER. In light of this consideration, we deem three reflections important. First, further studies with characteristics different from ours should be conducted. Second, these studies should investigate additional factors influencing families and their members. Third, these studies could provide further insights into our results and the Swiss context. For example, future research could investigate the effects of fathers' socioeconomic status (SES) and the stigma associated with extended paternal leave, especially in the Swiss context. This is because evidence suggests that a father's SES and perception of stigma shape the opportunities and challenges men face when considering and taking paternal leave. However, to our knowledge, their influence in the Swiss context needs to be further investigated, and our results seem to confirm this necessity.

Fathers with higher SES are more likely to have access to leave, take paternity leave, and opt for longer leave durations than fathers with lower SES (Huerta et al., 2014; Nepomnyaschy & Waldfogel, 2007). Conversely, low-income fathers with low-prestige jobs may be less inclined to request and obtain extended paternity leave (Melamed, 2014). Additionally, low-income fathers might need assistance in taking unpaid leave, making it less practical than for their higher-SES counterparts. However, this evidence does not reflect the reality of Swiss fathers in our sample. In our study, despite most fathers having a middle to upper-middle SES, they did not significantly increase the time spent with their infants, as one might expect based on previous

evidence. This observation suggests that further investigation is needed to provide insights into the associations between fathers' SES, time spent with infants, and extended paternal leave in the Swiss context.

Beyond income, the stigma associated with paternal leave in Switzerland may shed light on father-infant shared time. Evidence suggests that fathers requesting more extended paternity leave face lower performance evaluations, perceptions of inferiority, and potential future income reduction (Rege & Solli, 2013). These penalties seem to be more frequently applied to ethnic minorities and low-SES workers (Rudman & Mescher, 2013; Williams et al., 2013), potentially allowing white fathers and those with higher SES to avoid such stigmas. In light of this evidence, it could be informative for future studies to measure the perceived stigma among Swiss fathers regarding the decision to take paternal leave. These investigations could provide insights into our speculation that some fathers in our study might have been discouraged from taking extended paternal leave due to perceived stigma despite their middle-upper SES. We suggest that future investigations could delve deeper into our speculation by referring, for instance, to frameworks of psychological theories on social perception and behavior [e.g., Social Identity Theory (Tajfel & Turner, 1979); Stereotype Threat Theory (Steele & Aronson, 1995); Social Cognitive Theory (Bandura, 1986, 1992); Theory of Planned Behavior (Ajzen, 1991); Attribution Theory (Heider, 1958; Weiner, 1974)]. These theories could provide a framework for further understanding the psychological processes underlying social perception and behavior, which can help contextualize the influence of perceived stigma on Swiss fathers' decisions regarding parental leave and infant care.

8.3. The indirect paternal influences on infants' ER

As we mentioned, the results of our study suggest that fathers might indirectly influence infants' ER (Articles III and IV). In the following two subsections, we will reflect on indirect paternal influences on infants' ER by presenting two possible explanations. Firstly, the definition of ER in this study emphasizes the influence of the social environment on infant regulatory processes. Besides each parent's relationship with the infant, the relationship between parents shapes the infant's social environment. Therefore, the first explanation of indirect paternal influences will discuss the impact of the father-mother relationship on the quality of family interactions and infant functioning. The second explanation of indirect paternal influences will consider two aspects related to the functionalist perspective of ER mentioned in this thesis. Firstly, regulatory processes enable the infant to achieve goals in its environment. Secondly, in today's Western societies, the infant is more inclined to turn to the mother to meet its needs in the early months, as the father is generally less accessible in the perinatal period. Therefore, the second explanation of indirect paternal influence reflects how the infant might habitually turn to the mother for regulation. This habit would persist during or after interactions with the father.

8.3.1. The contribution of the mother-father relationship

The theoretical framework of this study highlights the influence of the environment and social interactions on regulatory processes. From this perspective, understanding children's socio-emotional functioning requires consideration of the diverse relationships shaping their environment. In addition to mother-child and father-child interactions, interactions between parents shape the children's environment and consequently influence the development of their regulatory capacities. In this view, the results of our study underline the need to consider the

influence of mother-father interactions and the relationship between parents. Indeed, although further investigation is needed, the results of this study suggest some speculations about the influence of the mother-father relationship. For example, the impact of father-infant shared time in the mother's presence (Article II) suggests that interactions between parents during these shared moments may influence the father and the infant, as well as the infant's regulatory processes. Furthermore, the absence of associations between the quality of mother-infant interactions and the infant's physiological regulation when mothers interact with the infant after fathers (Article III) suggests that the exchange of information between parents about the infant could enhance mother-infant interactions when mothers return after an absence. This is because, in our study, the group of mothers who interacted after the father waited their turn outside without prior knowledge of father-infant interactions. Once their turn arrived, these mothers interacted with the infant without having had the opportunity to share information with the father about previous interactions with the infant. We speculate that the lack of information between mothers and fathers may have diminished these mothers' ability to attune to the infant's state as usual, potentially impacting the strength of the associations with the infant's physiological regulation (observed in the group of mothers interacting first).

In the view that in addition to mother-child and father-child interactions, interactions between parents shape the children's environment, it is important to consider their influence on the development of the infant's regulatory capacities. The parent-parent relationship can either complicate or simplify interactions within the family, impacting the infant's social development and regulatory abilities. This idea aligns with prior studies demonstrating the influence of parents' marital relationship on parent-infant interactions and child development. When marital

quality is high, parental interactions with the child are better, whereas they tend to worsen in conflicted mother-father relationships (Cummings et al., 2004). Similar results have been found when investigating the link between the quality of the parent relationship before birth and interactions with the infant in the first two years of life (Tian et al., 2023). The impact of parental disagreements extends to physiological regulatory processes. Indeed, research has shown that the increased need for regulation in the presence of marital conflict is measurable even at the physiological level in the child as early as infancy (Hibel & Mercado, 2019).

In conflicts or low relational quality between parents, the child's regulatory processes are impacted in various ways. First, tensions between parents may reduce their ability to coordinate during interactions with the infant. Reduced coordination might expose the infant to over or understimulating parental behaviors, causing stress and requiring more significant efforts for regulation. Second, conflicting interactions expose the infant to conflicting parental behaviors that, when observed by the child, become a model for how to act and regulate during social interactions. These observed interaction models, in turn, influence other children's social relationships. Third, tensions between parents affect the child's need to learn how to regulate within a conflicted family climate. The child might be drawn into conflicts, excluded from conflicts, or be triangulated by the parents, with consequences for regulatory processes. Finally, parental conflict increases symptoms of distress in parents, reducing their well-being and the quality of parenting behaviors. This reduction, in turn, negatively impacts children's regulatory processes.

8.3.2. Insights from the functionalist perspective of ER

The functionalist perspective could provide insights into a better understanding of fathers' indirect influence on infant regulatory processes. According to the functionalist perspective, ER, supported by the activation of physiological patterns, allows individuals to achieve their goals within the surrounding environment (Thompson, 1994). From this standpoint, it is necessary to consider how individuals pursue their goals within the environment to understand better the regulatory processes at the physiological level.

In line with the most prevalent task repartition in Swiss families during the early months of an infant's life, we suppose that the infant tends to pursue daily goals during interactions with the mother, who is the primary caregiver. The mother's responses enable the infant to meet her needs and develop physiological patterns of ER that enhance the likelihood of satisfying these needs during interactions with the mother. On the other hand, the infant might be less inclined to turn to the father to fulfill her needs. As mentioned earlier, the reduced accessibility of the father in the early months of life (e.g., due to a limited paternity leave period) could limit the father's availability and ability to care for the infant. Furthermore, more frequent interactions with the father might be needed for the infant to develop physiological patterns of ER in response to what happens with the father. Therefore, the infant might need to turn to the mother to regulate, as they habitually do, in response to what happens with the father. This speculative explanation is in line with some evidence. Prior research has found that mothers more frequently engage in caregiving tasks related to comfort and consolation than fathers, and preschool-aged children are more likely to approach mothers than fathers when expressing distressed emotions (Umemura et al., 2013). Even when considering differences in involvement and attachment bonds, children

show a hierarchy in turning to the mother rather than the father to regulate emotions. Finally, Zimmermann et al. (2022) suggest that the quality of parent-child interaction and the effectiveness of ER might be significant in explaining the preference for mothers over fathers. While speculative, these reflections can guide further research and contribute to socio-cultural considerations on parenthood and parental roles in the lives of children.

8.4. Limitations of the study

The contributions of this study should be interpreted while considering its limitations. Firstly, we used a convenience sampling method, which may have contributed to reducing participant variability. Indeed, the sample mainly consisted of heterosexual families with highly educated parents, representing a non-clinical population. The overrepresentation of heterosexual families restricts the generalizability of the findings to other family configurations, as well as the high proportion of parents with advanced education levels limits the generalizability to families with lower educational backgrounds. Additionally, studying parent-infant interactions in a sample representative of a non-clinical population may further constrain the generalizability of our results. However, despite the characteristics of our sample, we observed significant associations among the variables under investigation. This confirmed some of our hypotheses and underscored the importance of the investigated associations within a non-clinical population with a certain educational level and in a country with a high quality of life, such as Switzerland. Secondly, the recruitment process and family information did not distinguish between first-time and multiparous families, potentially limiting additional insights. Lastly, with the use of self-reported questionnaires, there is a possibility of response biases, such as extreme responses or socially desirable attitudes, which may have influenced the data. Addressing such biases could

involve integrating direct observations and reports from independent evaluators, particularly regarding prenatal depressive symptoms of both parents (Article IV). However, this approach is complex and time-consuming and increases the risk of resistance to participation. This is particularly likely during the perinatal period when stress, fatigue, and adjusting to new family dynamics may limit parents' involvement in research.

9. Future investigations

The findings of our study contribute to research on family interactions, enhancing the understanding of the regulatory processes involved in the relationship between family interactions and child functioning. While our study offers insights, it also suggests various potential research directions based on further data analysis from the longitudinal study.

Results from Article II suggest that mother-father-infant interactions moderate the influence of fathers on the child's physiological regulation abilities. This raises the question of a potential mediating role of the quality of mother-father-infant interactions in linking father-infant interactions to the child's socio-emotional functioning. Since physiological regulation capacities are related to socio-emotional functioning and other crucial aspects of child development (such as sleep and feeding), an investigation into the moderating role of vagal tone during mother-father-infant interactions into the associations between father-infant interactions and the child functioning could provide valuable insights. For example, it could further understand how the infant's physiological regulation in the mother's presence affects the influence of the father's behaviors during interaction with the infant on the infant's socio-emotional functioning. Results from Article III underscore that family interactions are interconnected and suggest that what occurs with the father influences both what happens with the mother and the infant's regulatory

needs with the mother. These results raise the question of a potential moderating role of paternal behaviors in the link between mother-infant interactions and the child's socio-emotional functioning. The quality of paternal behaviors could amplify the effect of maternal behaviors, whether positive or negative. The results of Article IV demonstrate how the mother would be equally influenced by her difficulties and those of the father in terms of psychological well-being, highlighting the crucial influence of fathers. Article IV demonstrates that both parents' depression symptoms during the prenatal period are associated with the quality of mother-infant interactions after birth. As the transition to parenthood requires couples and families to adjust to the arrival of a new family member, future analyses could consider the moderating influence of couple (e.g., marital satisfaction) and family-related (e.g., coparental relationship) variables on the links between prenatal depressive symptoms and the child's socio-emotional functioning.

This study focused on some data measured at the first two measurement points of the longitudinal study. For future analyses, it would be insightful to consider investigations that involve data collected at all three measurement points. These analyses would provide a broader and longitudinal perspective on the relationships between the variables. For instance, they would enable evaluation of the mother's influence when the end of maternity leave and the return to work reduce her contribution as the primary caregiver, at least in the Swiss context. Additionally, future analyses would benefit from dynamically assessing vagal tone, which would add value to the analysis of moment-to-moment interactions (conducted but not used in the analyses of this study). These analyses would observe how the child regulates in real-time during interactions and identify which parental behaviors contribute to this regulation or surpass the child's regulatory capacities.

The findings of this work offer insights for the design of future studies. Firstly, it would be interesting to involve families where fathers benefit from paternity leaves similar to or longer than those of mothers. Furthermore, replicating this study, including less-explored family configurations such as same-sex parent families, would represent a significant step forward. Considering the previously mentioned aspects regarding the contribution of fathers and related societal issues, the study of same-sex parent families could provide information on gender roles and clarify biological or social influences.

Finally, although the current results offer an understanding of physiological regulation processes in children during interactions with parents, they still need to provide a complete picture of how the contribution of family interactions in physiological regulatory processes manifests in different contexts. Similar to investigations conducted on mother-infant interactions, future research should examine children's physiological regulation in stressful situations to understand the role of fathers beyond direct interactions. This is particularly interesting considering studies highlighting the influence of fathers in guiding children to explore and discover the surrounding environment. Overall, such investigations would allow exploration of how the family context influences physiological and behavioral regulation in various circumstances.

10. Clinical and societal implications

The results of our study contribute to the understanding of the associations between early interactions and children's socio-emotional development. In addition to advancing research, our findings may have significant clinical and societal implications for family well-being and infant socio-emotional development. In this paragraph, we discuss these implications with two aims.

Firstly, we aim to highlight how our findings might be linked to clinical and societal implications for family well-being and infant socio-emotional development. Secondly, we aim to contribute to reflections that promote family well-being and infant socio-emotional development at both clinical and societal levels.

As mentioned before, the results of this study underscore some aspects that have significant clinical and social implications for promoting family well-being and the socioemotional development of infants. First, they highlight the role of fathers in children's growth, emphasizing the need to allocate more time and attention to them (Sarkadi et al., 2008). Second, they confirm that family interactions are deeply interconnected, showing that what happens with one parent significantly impacts what occurs with the other parent and the infant, influencing overall family dynamics (Cassibba et al., 2017). Third, these results underscore the importance of considering the family context to comprehensively understand its effects on infant socioemotional development.

From a clinical and societal perspective, the results of this study show a need to further promote active fatherhood through educational programs involving fathers in daily activities related to infant care (Doherty et al., 2016). Moreover, they suggest paying attention to the psychological well-being of both parents before birth by implementing psychosocial support services, such as psychological counseling and support groups, which can help alleviate the emotional burden during the early stages of parenthood (Giallo et al., 2013). In line with supporting parents, the active involvement of family reference figures, such as grandparents, can enrich the family support network and assist parents facing psychosocial difficulties (Frost et al., 2020). Our results could support efforts to highlight the importance of fathers' involvement, for

instance, in neonatal healthcare professionals' training, to ensure fair and practical support to both parents (Wynter et al., 2021). In conclusion, further insights from other disciplines are needed to understand better the clinical and social implications of the results of this thesis. This may involve continuous research and interdisciplinary collaboration among psychologists, pediatricians, sociologists, and other experts in families. Overall, besides helping to understand the results of this study and family research findings in general, integrating multiple perspectives could contribute to creating clinical interventions and social programs that promote the well-being of infants, parents, and families.

CONCLUSION

In conclusion, I summarize the key findings from this study, which explores the impact of family interactions on the development of ER, focusing on father-infant interactions.

- The quality of father-infant interaction is not linked to the infant's physiological regulation during interactions with the father. However, the results suggest that this link is more likely for those fathers who report spending more time with the infant in the presence of the mother.
- The quality of father-infant interaction and the infant's physiological regulation with the father are both associated with the infant's regulatory processes during interactions with the mother, confirming the existence of mutual influences among family members.
- The results confirm that the quality of interactions with the mother is associated with the infant's physiological regulation.
- Prenatal depressive symptoms in both parents are associated with the quality of mother-infant interaction, confirming the existence of mutual influences among family members. Conversely, prenatal depressive symptoms in both parents do not show associations with the quality of father-infant interaction.

This study and the research project it is part of highlight the crucial role played by family interactions from the early months of life. Infant interactions with both parents significantly influence infants' socio-emotional functioning, emphasizing the need to consider interactions with each parent. As fathers take on a more active role in infant care and societal perceptions of fatherhood evolve, it becomes crucial to acknowledge the contribution of contemporary fathers. This is essential for understanding the infant's social environment and its influence on socio-emotional development. Beyond the infant's interactions with each parent, the mutual influences

among family members shape the infant's environment. It is crucial to view family interactions as interconnected to gain a more holistic understanding of the development of infant regulatory processes.

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ANNEXES

Appendix A - Search Algorithms

PubMed. ((((((("Fathers"[Mesh]) OR "Paternal Behavior"[Mesh])) OR (Cohabitation[Title/Abstract] OR "Father* Accessibility"[Title/Abstract] OR "Father* Engagement"[Title/Abstract] OR "Father* Involvement"[Title/Abstract] OR "Father* responsibility"[Title/Abstract] OR Fathers[Title/Abstract] OR Involvement[Title/Abstract] OR "Parental Investment"[Title/Abstract] OR Partner[Title/Abstract] OR "Partner* Accessibility"[Title/Abstract] OR "Partner* Engagement"[Title/Abstract] OR "Partner* Involvement"[Title/Abstract] OR "Partner* Responsibility"[Title/Abstract] OR "Patern* Accessibility"[Title/Abstract] OR "Patern* Engagement"[Title/Abstract] OR "Patern* Involvement"[Title/Abstract] OR "Patern* Responsibility"[Title/Abstract] OR "Paternal Behavior"[Title/Abstract]))) AND (((((((("Child Care"[Mesh]) OR "Child Rearing"[Mesh]) OR "Father-Child Relations"[Mesh]) OR "Infant Care"[Mesh]) OR "Parent-Child Relations"[Mesh]) OR "Parenting"[Mesh]) OR "Paternal Behavior"[Mesh])) OR ("Bab* Care*"[Title/Abstract] OR "Bab* Day* Care*"[Title/Abstract] OR "Care behavior"[Title/Abstract] OR "Caring Behav*"[Title/Abstract] OR "Child Care"[Title/Abstract] OR "Child Day Care"[Title/Abstract] OR "Child rearing"[Title/Abstract] OR "Child* Care*"[Title/Abstract] OR "Child* Day* Care*"[Title/Abstract] OR Childrearin*[Title/Abstract] OR "Childrearing Attitudes"[Title/Abstract] OR "Childrearing Practices"[Title/Abstract] OR "Father Child Communication"[Title/Abstract] OR "Father Child Relations"[Title/Abstract] OR "Father* Bab*"[Title/Abstract] OR "Father* Bab* Relation*"[Title/Abstract] OR "Father* Child*"[Title/Abstract] OR "Father* Child* Relation*"[Title/Abstract] OR "Father* Infant*"[Title/Abstract] OR "Father* Infant* Relation*"[Title/Abstract] OR "Father*-Bab*"[Title/Abstract] OR "Father*-Child*"[Title/Abstract] OR "Father*-Infant*"[Title/Abstract] OR Fathering[Title/Abstract] OR "Infant Care"[Title/Abstract] OR "Infant* Care*"[Title/Abstract] OR "Infant* Day* Care*"[Title/Abstract] OR "Parent Child Communication"[Title/Abstract] OR "Parent Child Relations"[Title/Abstract] OR "Parent* Bab*"[Title/Abstract] OR "Parent* Child*"[Title/Abstract] OR "Parent* Infant*"[Title/Abstract] OR "Parent*-Bab*"[Title/Abstract] OR "Parent*-Child*"[Title/Abstract] OR "Parent*-Infant*"[Title/Abstract] OR Parenting[Title/Abstract] OR "Partner* Bab*"[Title/Abstract] OR "Partner* Child*"[Title/Abstract] OR "Partner* Infant*"[Title/Abstract] OR "Partner*-Bab*"[Title/Abstract] OR "Partner*-Child*"[Title/Abstract] OR "Partner*-Infant*"[Title/Abstract] OR "Paternal behavior"[Title/Abstract] OR "Social[Title/Abstract] AND Interpersonal Measures"[Title/Abstract]))) AND ((((((((("Autonomic Nervous System"[Mesh]) OR "Electrocardiography"[Mesh]) OR "Emotional Adjustment"[Mesh]) OR "Emotional Regulation"[Mesh]) OR "Hypothalamo-Hypophyseal System"[Mesh]) OR "Parasympathetic Nervous System"[Mesh]) OR "Psychophysiology"[Mesh]) OR "Vagus Nerve"[Mesh])) OR ("Affect Regulation"[Title/Abstract] OR ANS[Title/Abstract] OR "Autonomic Nervous System"[Title/Abstract] OR "Cardiovascular reactivity"[Title/Abstract] OR "Cardiovascular response"[Title/Abstract] OR "Cortisol reactivity"[Title/Abstract] OR "Early Emotion* Experience*"[Title/Abstract] OR "Early Regulatory"[Title/Abstract] OR "Emotional Development"[Title/Abstract] OR ECG[Title/Abstract] OR EKG[Title/Abstract] OR "Electrocardio*"[Title/Abstract] OR Electrocardiogram[Title/Abstract] OR Electrocardiography[Title/Abstract] OR "Emotion regulation"[Title/Abstract] OR "Emotion*

adjustment"[Title/Abstract] OR "Emotional Adaptation"[Title/Abstract] OR "Emotional Adjustment"[Title/Abstract] OR "Emotional Control"[Title/Abstract] OR "Emotional Development"[Title/Abstract] OR "Emotional Regulation"[Title/Abstract] OR "Heart Rate Variability"[Title/Abstract] OR "HPA axis"[Title/Abstract] OR "HTPA axis"[Title/Abstract] OR "Hypothalamo-Hypophyseal System"[Title/Abstract] OR "Hypothalamus hypophysis system"[Title/Abstract] OR "Parasympathetic Nervous System"[Title/Abstract] OR Psychophysiology[Title/Abstract] OR "Regulat* emotion*"[Title/Abstract] OR RMSSD[Title/Abstract] OR RSA[Title/Abstract] OR "Self-Regulation"[Title/Abstract] OR "Socioemotional Development"[Title/Abstract] OR "Socioemotional Functioning"[Title/Abstract] OR "Vagal Functioning"[Title/Abstract] OR "Vagal Regulation"[Title/Abstract] OR "Vagal Suppression"[Title/Abstract] OR "Vagal tone regulation"[Title/Abstract] OR "Vagal Withdrawal"[Title/Abstract] OR "Vagus Nerve"[Title/Abstract] OR "Vagus Tone"[Title/Abstract]))

PsycInfo. (((Index Terms: ("Autonomic Nervous System") OR Index Terms: ("Cardiovascular reactivity") OR Index Terms: ("Electrocardiography") OR Index Terms: ("Emotional Control") OR Index Terms: ("Emotional Development") OR Index Terms: ("Emotional Regulation") OR Index Terms: ("Heart Rate Variability") OR Index Terms: ("Parasympathetic Nervous System") OR Index Terms: (Psychophysiology) OR Index Terms: ("Socioemotional Functioning") OR Index Terms: ("Vagus Nerve")) OR (abstract: ("Affect Regulation") OR abstract: (ANS) OR abstract: ("Autonomic Nervous System") OR abstract: ("Cardiovascular reactivity") OR abstract: ("Cardiovascular response") OR abstract: ("Cortisol reactivity") OR abstract: ("Early Emotion* Experience*") OR abstract: ("Early Regulatory") OR abstract: ("Emotional Development") OR abstract: (ECG) OR abstract: (EKG) OR abstract: ("Electrocardio*") OR abstract: (Electrocardiogram) OR abstract: (Electrocardiography) OR abstract: ("Emotion regulation") OR abstract: ("Emotion* adjustment") OR abstract: ("Emotional Adaptation") OR abstract: ("Emotional Adjustment") OR abstract: ("Emotional Control") OR abstract: ("Emotional Development") OR abstract: ("Emotional Regulation") OR abstract: ("Heart Rate Variability") OR abstract: ("HPA axis") OR abstract: ("HTPA axis") OR abstract: ("Hypothalamo-Hypophyseal System") OR abstract: ("Hypothalamus hypophysis system") OR abstract: ("Parasympathetic Nervous System") OR abstract: (Psychophysiology) OR abstract: ("Regulat* emotion*") OR abstract: (RMSSD) OR abstract: (RSA) OR abstract: ("Self-Regulation") OR abstract: ("Socioemotional Development") OR abstract: ("Socioemotional Functioning") OR abstract: ("Vagal Functioning") OR abstract: ("Vagal Regulation") OR abstract: ("Vagal Suppression") OR abstract: ("Vagal tone regulation") OR abstract: ("Vagal Withdrawal") OR abstract: ("Vagus Nerve") OR abstract: ("Vagus Tone")) OR (title: ("Affect Regulation") OR title: (ANS) OR title: ("Autonomic Nervous System") OR title: ("Cardiovascular reactivity") OR title: ("Cardiovascular response") OR title: ("Cortisol reactivity") OR title: ("Early Emotion* Experience*") OR title: ("Early Regulatory") OR title: ("Emotional Development") OR title: (ECG) OR title: (EKG) OR title: ("Electrocardio*") OR title: (Electrocardiogram) OR title: (Electrocardiography) OR title: ("Emotion regulation") OR title: ("Emotion* adjustment") OR title: ("Emotional Adaptation") OR title: ("Emotional Adjustment") OR title: ("Emotional Control") OR title: ("Emotional Development") OR title: ("Emotional Regulation") OR title: ("Heart Rate Variability") OR title: ("HPA axis") OR title: ("HTPA axis") OR title: ("Hypothalamo-Hypophyseal System") OR title: ("Hypothalamus

hypophysis system") OR title: ("Parasympathetic Nervous System") OR title: (Psychophysiology) OR title: ("Regulat* emotion*") OR title: (RMSSD) OR title: (RSA) OR title: ("Self-Regulation") OR title: ("Socioemotional Development") OR title: ("Socioemotional Functioning") OR title: ("Vagal Functioning") OR title: ("Vagal Regulation") OR title: ("Vagal Suppression") OR title: ("Vagal tone regulation") OR title: ("Vagal Withdrawal") OR title: ("Vagus Nerve") OR title: ("Vagus Tone"))) AND (PublicationTypeFilt: "Peer Reviewed Journal")) AND (((Index Terms: ("Child Care") OR Index Terms: ("Child Day Care") OR Index Terms: ("Child rearing") OR Index Terms: ("Childrearing Attitudes") OR Index Terms: ("Childrearing Practices") OR Index Terms: ("Father Child Communication") OR Index Terms: ("Father Child Relations") OR Index Terms: ("Infant care") OR Index Terms: ("Parent Child Communication") OR Index Terms: ("Parent Child Relations") OR Index Terms: (Parenting) OR Index Terms: ("Social and Interpersonal Measures")) OR (abstract: ("Bab* Care*") OR abstract: ("Bab* Day* Care*") OR abstract: ("Care behavior") OR abstract: ("Caring Behav*") OR abstract: ("Child Care") OR abstract: ("Child Day Care") OR abstract: ("Child rearing") OR abstract: ("Child* Care*") OR abstract: ("Child* Day* Care*") OR abstract: (Childrearin*) OR abstract: ("Childrearing Attitudes") OR abstract: ("Childrearing Practices") OR abstract: ("Father Child Communication") OR abstract: ("Father Child Relations") OR abstract: ("Father* Bab*") OR abstract: ("Father* Bab* Relation*") OR abstract: ("Father* Child*") OR abstract: ("Father* Child* Relation*") OR abstract: ("Father* Infant*") OR abstract: ("Father* Infant* Relation*") OR abstract: ("Father*-Bab*") OR abstract: ("Father*-Child*") OR abstract: ("Father*-Infant*") OR abstract: (Fathering) OR abstract: ("Infant Care") OR abstract: ("Infant* Care*") OR abstract: ("Infant* Day* Care*") OR abstract: ("Parent Child Communication") OR abstract: ("Parent Child Relations") OR abstract: ("Parent* Bab*") OR abstract: ("Parent* Child*") OR abstract: ("Parent* Infant*") OR abstract: ("Parent*-Bab*") OR abstract: ("Parent*-Child*") OR abstract: ("Parent*-Infant*") OR abstract: (Parenting) OR abstract: ("Partner* Bab*") OR abstract: ("Partner* Child*") OR abstract: ("Partner* Infant*") OR abstract: ("Partner*-Bab*") OR abstract: ("Partner*-Child*") OR abstract: ("Partner*-Infant*") OR abstract: ("Paternal behavior") OR abstract: ("Social and Interpersonal Measures")) OR (title: ("Bab* Care*") OR title: ("Bab* Day* Care*") OR title: ("Care behavior") OR title: ("Caring Behav*") OR title: ("Child Care") OR title: ("Child Day Care") OR title: ("Child rearing") OR title: ("Child* Care*") OR title: ("Child* Day* Care*") OR title: (Childrearin*) OR title: ("Childrearing Attitudes") OR title: ("Childrearing Practices") OR title: ("Father Child Communication") OR title: ("Father Child Relations") OR title: ("Father* Bab*") OR title: ("Father* Bab* Relation*") OR title: ("Father* Child*") OR title: ("Father* Child* Relation*") OR title: ("Father* Infant*") OR title: ("Father* Infant* Relation*") OR title: ("Father*-Bab*") OR title: ("Father*-Child*") OR title: ("Father*-Infant*") OR title: (Fathering) OR title: ("Infant Care") OR title: ("Infant* Care*") OR title: ("Infant* Day* Care*") OR title: ("Parent Child Communication") OR title: ("Parent Child Relations") OR title: ("Parent* Bab*") OR title: ("Parent* Child*") OR title: ("Parent* Infant*") OR title: ("Parent*-Bab*") OR title: ("Parent*-Child*") OR title: ("Parent*-Infant*") OR title: (Parenting) OR title: ("Partner* Bab*") OR title: ("Partner* Child*") OR title: ("Partner* Infant*") OR title: ("Partner*-Bab*") OR title: ("Partner*-Child*") OR title: ("Partner*-Infant*") OR title: ("Paternal behavior") OR title: ("Social and Interpersonal Measures"))) AND (PublicationTypeFilt: "Peer Reviewed Journal")) AND (((Index Terms: ("Fathers") OR Index Terms: ("Involvement") OR Index Terms: ("Parental Investment") OR

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Appendix B – Details of the included studies

ID of the article	Authors	Years	Marital status	Family configuration	Infants/toddlers' age	Infants/toddlers' category of age	Fathers' age	Fathers' category of age	Country of fathers' origins	Fathers' Race/Ethnic background	Fathers' education	Fathers' socioeconomic status (SES)	Mother and father living together	Study design	Sample size	Type of ER measure	ER measure	Assessment time of child's ER	Informant(s) of EM	Assessment characteristics of EM	Coder(s) of observed EM	Type of FI measure	FI measure	Type of FI measure	Assessment time of FI	Informant(s) of FI	Coder(s) of observed FI	Domains of FI	Main findings	Collection period of data
1	Altenburger & Schoppe-Sullivan	2020	Married or cohabiting	Heterosexual (N/A)	Infants, 3–9 months (52.8% male)	Infant (0–12 months)	Fathers, 30.20 years mean	Young adults (18–35 years)	USA	Majority European American	Majority university	Middle	Yes	Longitudinal	182	Informant-reports	A negative emotionality and an orienting and regulatory capacity scores from the Revised Infant Behavior Questionnaire – Very Short Form	3 months	Father	x	x	Quality	Father's parenting quality during 5-min dyadic play using Parent-Child Coding Manual	Observational	9 months	x	Researchers	Three parenting dimensions: sensitivity, detachment, and positive regard	Children's negative emotionality score does not correlate with paternal sensitivity, detachment, and positive affect. Children's orienting and regulatory capacity score correlate with positive affect (r = .16, p < .05) and do not correlate with paternal sensitivity, and detachment.	2008-2010
2	Aquino et al.	2023	Married	Heterosexual (N/A)	Infants, 8 and 24 months(58% male)	Mixed ages	Fathers, 31 years mean	Mixed ages (i.e., range 14–63 years)	USA	Majority European American	Majority university	Mixed SES (i.e., a mix of lower, middle, and upper SES)	Yes	Longitudinal	124	Naturalistic or laboratory observation	Underregulation scale of the Children's Emotion regulation Scales	24 months	x	Two challenging and frustrating task in the presence of the only researcher	Researchers	Quantity and Quality	Quantity: Father's involvement in infant caregiving - Quality: (1) The Infant Caregiving Scales to assess fathers' emotionally disengaged interactions with the infant at 8 months, (2) The Parents' Responses to Children's Emotions	Quantity: report - Quality: observational	Quantity: 8 months - Quality: At 8 months, video-taped interaction of father with infant during home visits. At 24 month,	Quantity: mother and father.	Researchers	Quantity: care during week - Quality: Free play, cleanup, and puzzle-type task, feeding, changing clothes	Children of fathers who were disengaged during an interaction with them at 8 months displayed more emotional underregulation at 24 months (β = .27, p < .01). More displays of paternal minimizing responses were related to greater child emotional underregulation at 24 months (β = .41, p < .001). Greater father involvement was related to greater children's emotional underregulation at 24 months (β = .191, p < .05).	N/A
3	Bocknek et al.	2014	50% married, 6% in a no cohabiting romantic relationship with the biological father, 44% N/A	Heterosexual (N/A)	Child, 14–36 months(about 50% male)	Toddler (13–35 months)	Fathers, 25.51 years mean (at child's birth)	Mixed ages (i.e., range 14–63 years)	USA	Mixed	N/A	Low	Mix (i.e., parents living and not living together)	Longitudinal	1477	Naturalistic or laboratory observation	Emotion Regulation rating subscale during an assessment	14-, 24-, 36 months birthday	x	No interactions with mothers	x	Quantity	(1) Father lives with the child (yes/no); (2) quantity of contact with the child	Report	14-, 24-, 36 months birthday	Mother	x	Fathers' continuous physical presence/absence	Greater consistent biological fathers' presence correlates with greater child emotion regulation at 24 months (r = .06, p < .05), and 36 months (r = .07, p < .05), but not at 14 months. Consistent biological fathers' presence links to toddlers' regulatory development across toddlerhood, particularly among Caucasians as compared with African American toddlers (effect size not reported).	1996-1998
4	Burniston et al.	2023	85.5% married	Heterosexual (N/A)	Child, 42.36 months mean (about 57% female)	Pre-schoolers (3–5 years)	Fathers, age data not indicated	Age data not indicated	USA	Mixed	Mixed (i.e., no formal education, primary, secondary, university)	Middle	Mix (i.e., parents living and not living together)	Cross-sectional	42	Physiological-biological indicators	Children physiological stress responses	3-4 years	x	Stressing situation during visit with the mother. No father at time of the measure of cortisol	x	Quality	Fathers' supportive emotion socialization (ES) usage during a book reading task	Observational	3-4 years	x	Researchers	Reading book task	Greater paternal supportive ES fathers were significantly associated with children's higher total cortisol output (β = .31, p < .05).	2017-2020
5	De Stasio et al.	2020	N/A	Heterosexual	Child, 18–36 months (60% male)	Toddler (13–35 months)	Fathers, 34 years mean	Young adults (18–35 years)	Italy	N/A	Majority university	N/A	Yes	Cross-sectional	80	Informant-reports	The Lability/Negativity subscale and the Emotion Regulation subscale of the Emotion Regulation Checklist (ERC)	18-36 months	Both parents	x	x	Quantity	(1) Father involvement in everyday; and (2) bedtime care from the Social Provisions Scales (SPS)	Report	18-36 months	Father	x	Bedtime care routine	No correlations between paternal bedtime and global involvement with the paternal report of a child's emotional lability/emotion regulation. Correlations were present with the maternal report of the child's emotional lability/emotion regulation, such that when the father involvement was low, the greater were the emotion regulation difficulties reported by mothers (r = -.35, p < .01, bedtime involvement; r = -.27, p < .05, global involvement).	2016-2017
6	Isaac et al.	2023	90.7% Married or cohabiting	Heterosexual (N/A)	Child, 4 years mean (43.6% female)	Pre-schoolers (3–5 years)	Fathers, 35.86 years mean	Mixed ages (i.e., range 14–63 years)	USA	Majority European American	Majority university	Middle	Yes	Cross-sectional	98	Physiological-biological indicators	Children's physiological stress measured via hair cortisol concentration	Between 3 and 5 years	x	During lab visit, no interactions with parents	x	Quantity	Frequency of specific parenting practices through the Parenting Styles and Dimensions Questionnaire.	Report	Between 3 and 5 years	Father	x	Fathers' parenting style	Greater fathers' authoritarian parenting (r =.23, p < .05) and physical coercion (r = .26, p < .05) correlated with higher hair cortisol concentration. Fathers' authoritative and permissive parenting, and fathers' non-reasoning/punitive didn't correlate with children's physiological stress.	2016-2019
7	Lunkenheimer et al.	2020	88.5% Married	Heterosexual (N/A)	Child, 41.40 months mean (about 50% female)	Pre-schoolers (3–5 years)	Fathers, age data not indicated	Age data not indicated	USA	Mixed	Mixed (i.e., no formal education, primary, secondary, university)	N/A	Mix (i.e., parents living and not living together)	Longitudinal	173	Naturalistic or laboratory observation	Child negative emotion arousal with father and mothers during the dyadic block design task	3 years	x	With father and mothers during the dyadic block design task.	Researchers	Quality	Father's emotional responsiveness and expressiveness to child emotion cues during the dyadic block design task	Observational	3 years	x	Researchers	Fathers' parenting style	Higher paternal responsiveness and expressiveness were both not related to children's lower negative arousal with fathers. However, they were both related to children's lower negative arousal with mothers (r = -.295, p < .01, paternal responsiveness; r = -.237, p < .05, paternal expressiveness).	From 1999 (longitudinal data) - no information found about the end of the collection
8	Planalp & Braungart-Rieker	2015	N/A	Heterosexual (N/A)	Child, 3–7 months (52.6% female)	Infant (0–12 months)	Fathers, 30.79 years mean	Mixed ages (i.e., range 14–63 years)	USA	Majority European American	Mixed (i.e., no formal education, primary, secondary, university)	Mixed SES (i.e., a mix of lower, middle, and upper SES)	Yes	Longitudinal	135	Naturalistic or laboratory observation	Infant regulatory behaviors during the Still Face Paradigm (SFP)	3,5, and 7 months	x	Still Face Paradigm (SFP), with father	Researchers	Quantity	Diary-like checklist	Report	3,5, and 7 months	Father	x	Care, play, and teaching activities	Infants lower in surgency with a highly involved father increased self-distraction at a faster rate (but not in self-comforting regulatory strategy), particularly with highly involved fathers (effect size not reported).	N/A
9	Olofson and Schoppe-Sullivan	2022	Married or cohabiting	Heterosexual	Child, 16.37 months mean (64.51% male)	Toddler (13–35 months)	Fathers, 29.40 years mean	Young adults (18–35 years)	USA	Majority European American	Majority university	Middle	Yes	Longitudinal	62	Informant-reports	Dysregulation score of the Infant-Toddler Social-Emotional Assessment	12-18 months	Mother	x	x	Quality	Father's parenting behavior during a laboratory visit	Observational	12-18 months	x	Researchers	Fathers' parenting style	The father's parenting behaviors are not associated to mother-report of infant-toddler dysregulation.	2008-2014
10	Richter & Lickenbrock	2021	91.2% Married or cohabiting	Heterosexual	Child, 4–8 months (59.3% male)	Infant (0–12 months)	Fathers, 32.14 years mean	Mixed ages (i.e., range 14–63 years)	USA	Majority European American	Mixed (i.e., no formal education, primary, secondary, university)	Mixed SES (i.e., a mix of lower, middle, and upper SES)	Yes	Longitudinal	91	Physiological-biological indicators	Respiratory sinus arrhythmia (RSA)	4-8 months	x	Still Face Paradigm (SFP) and 3-min recovery task	x	Quantity	What I Did with My Baby Checklist (care and play)	Report	4-8 months	Father	x	Father's availability, care and play activities	At 4 months, infant cardiac physiology (i.e., RSA) correlates with father involvement in play (r = .22, p < .05), and does not correlate with father involvement in care. At 8 months, infant cardiac physiology (i.e., RSA) correlates with father involvement in care (r = .36, p < .01), and does not correlate with father involvement in play. Infants with highly involved fathers in care have higher baseline RSA (β = .34, p = .001), typically associated with better emotion regulation. Fathers' play is not significant.	2018-2021