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

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ABSTRACT

Research has shown that the quality of mother-infant interactions, as measured by mother-infant synchrony, 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. 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 this association. In this study we investigated the association between father-infant synchrony and infants' vagal tone in 77 dyads made up of fathers and their 3-month-old infants, considering the moderating roles of dyadic time and social time. Results revealed no direct associations between father-infant synchrony and infants' vagal tone. Moderation analyses revealed that more social time increases the association between synchrony and vagal tone. This result indicates a potential influence of family interactive processes.

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Synchrony; father-infant interactions; emotion regulation; vagal tone; infancy

Key findings

- Father-infant synchrony is not associated with infants' vagal tone in father-infant interactions.
- The time that fathers share with infants facilitates associations between father-infant synchrony and infants' vagal tone during father-infant interactions.
- Further investigations should explore whether interactive processes during shared family time influence dyadic father-infant interactions and the infant's physiological emotion regulation at 3 months.

Introduction

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

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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, Gee, De Los Reyes, & Seager, 2016; Berking & Wupperman, 2012; Crespo, Trentacosta, Aikins, & Wargo-Aikins, 2017; Ekas, Lickenbrock, & Braungart-Rieker, 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, Tronick, Cohn, & Olson, 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, Martin, & Dennis, 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, Steinberg, Silk, Myers, & Robinson, 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, Tronick, Adamson, Als, & Wise, 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, daSilva, & Bertenthal, 2021; Lindsey, Cremeens, Colwell, & Caldera, 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 10th 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, Doussard-Roosevelt, & Maiti, 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, Koslov, Akinola, & Mendes, 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, Singer, Kanat-Maymon, and Feldman (2015) found that mother-infant synchrony correlates positively with vagal withdrawal and predicted vagal withdrawal. Feldman, Singer, and Zagoory

(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, McHale, & Crouter, 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, Laverty, & Ramchandani, 2020; Crouter & Crowley, 1990; Larson, Richards, Moneta, Holmbeck, & Duckett, 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, Mosley, & Thayer, 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.

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.

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

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

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.

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.
**$p < .01$. *$p < .05$.

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. The results showed that the effects of father-infant synchrony on the infant's RMSSD were strongest when fathers

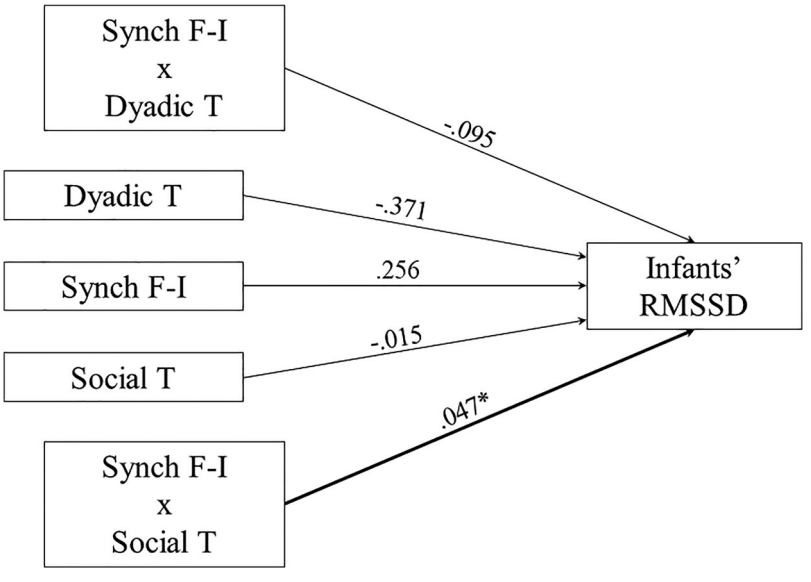

Figure 1. Graphical representation of moderation model values.

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. * $p < .05$.

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.

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. **$p < .01$. *$p < .05$.

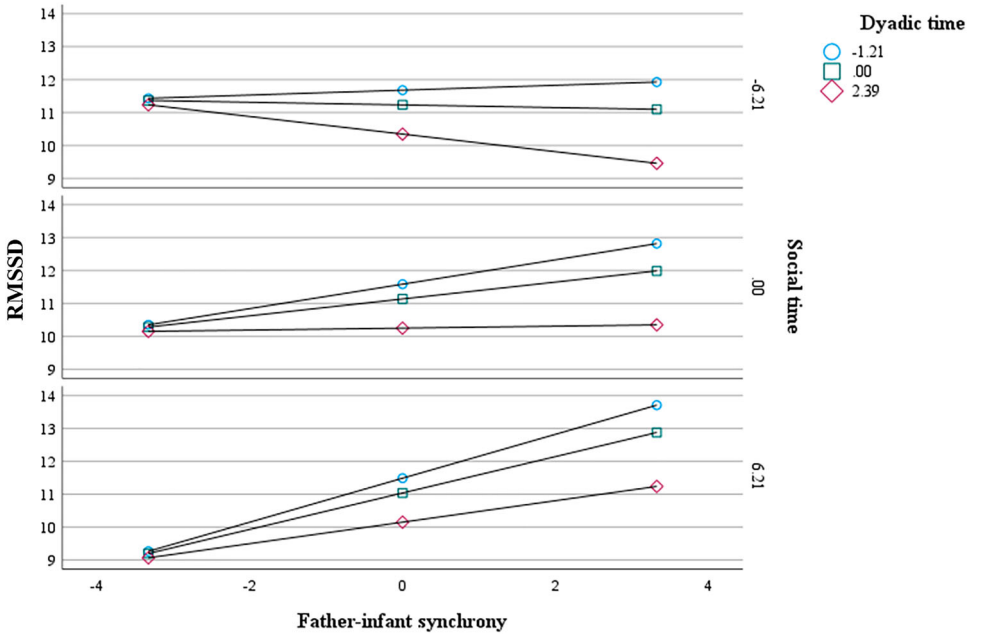

Figure 2. Graphical representation of conditional effects of father-infant synchrony at values of dyadic time and social time.
Note: RMSSD = root mean square of successive differences.

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, Fitzgerald, Bradley, & Roggman, 2014; Frascarolo-Moutinot, Favez, Tissot, & Fivaz-Depeursinge, 2020; Youngblade, Park, & Belsky, 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, Lewis, & Calkins, 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.

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Data availability

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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