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„Physiological synchrony in mother-infant dyads: The role of maternal touch and postpartum depression "

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Theoretical Background

The relationship between mother and child is usually the first relationship in an infant's life. Even though infants have a limited capacity to communicate before they develop language skills, mother-child interactions are shaped by the exchange of both the mother's and the infant's behavioral and physiological cues. Especially within the first years of life, infants are highly dependent on their caregiver to respond to their signals and are particularly sensitive towards their mother's touch, voice or body rhythms (Fleming et al., 1999). In these early social interactions, tactile contact represents an essential channel of communication. Mothers are thus equipped with affectionate touch and other caregiving behaviors, such as motherese or maternal gaze, to facilitate coordination processes with their child (Feldman & Eidelman, 2007). When these exchanges of cues between mother and infant are matched and temporally in concordance, we can speak of interpersonal synchrony (Feldman, 2007; Woody et al., 2016). Synchrony in mother-child dyads has been shown to positively contribute to children's development of self-regulatory processes, empathy and prosocial behavior, overall physical and mental health, and a positive mother-child relationship (Cirelli et al., 2014; Feldman, 2007; Leclère et al., 2014).

While synchrony in the behavioral domain typically describes the matching of gaze, affective states or touch, physiological synchrony relates to the matching of physiological markers between caregiver and child, like oxytocin or heart rhythms. Physiological synchrony has been studied in various contexts and age groups. Whereas previous research established that maternal behaviors can substantially shape the emergence and patterns of physiological synchrony (see Palumbo et al., 2017, for review), there remains uncertainty regarding the role of maternal touch for physiological synchrony, especially within the context of parental risk factors, such as maternal depression.

In the present paper, we examine synchrony of heart rhythms in mother-infant interactions, while considering maternal depression as a dyadic risk factor. As our main focus, we address the question if and how maternal touch and maternal depression, two particularly important maternal aspects in early mother-child interactions, impact physiological synchrony.

Physiological synchrony in mother-child interactions

Physiological synchrony, also often termed physiological coupling, attunement or linkage, indicates how the physiological activities, such as heart rhythms, of two or more partners are related to each other. The attunement of heart rhythms between mother and child

seems to emerge very early in life. Research assessing respiratory sinus arrhythmia (RSA) in mother-infant dyads showed that infants at the age of 1-8 weeks already attune their vagal tone in response to changes in their mother's respiration pace, while laying on the mother's body (Van Puyvelde et al., 2015). In face-to-face-interactions at 3 months of age, changes in infants' heart rhythms led to analogue changes in the maternal heart rhythms and vice versa within lags of less than 1 second (Feldman et al., 2011).

The coupling of physiological states is considered to be of high importance for infants' development of self-regulation and various other neurobehavioral and physiological functions (Feldman, 2007; Leclère et al., 2014). The possible pathways through which physiological attunement supports the organization of infants' physiology have been studied at several developmental stages. In prenatal development, the mother's cardiac rhythm is one of the earliest and most significant auditory cues for a fetus (Provasi et al., 2014). Feldman and colleagues (2007) suggest that the early attunement with maternal heart rhythms functions as a form of guidance framework for infants' still immature physiological systems and entrains their physiological regulatory capacities through biological rhythms. This entrainment to biologically based rhythms is also thought to be reflected in rhythmicity on a behavioral level, such as temporal coordination in interactions (Feldman, 2007; T. Field et al., 1989). This close intertwinement of physiological entrainment and behavior has been evidenced by a study documenting more successful interactional synchrony, in the vocal and affective modality, between mothers and their 3-month-old infants during phases of higher heart rhythm synchrony (Feldman, Magori-Cohen, Galili, Singer, & Louzoun, 2011). Furthermore, synchrony of heart rhythms has been linked to other positive behavioral and interactional aspects, for example infants' secure attachment style or lower levels of negative emotional parenting behaviors (Han et al., 2019; Zelenko et al., 2005).

A variety of theoretical and methodological approaches has been used to investigate caregiver-infant coupling on a physiological level. Many theoretical conceptualizations differentiate between concurrent and sequential forms of synchrony (Feldman, 2007; Markova et al., 2019; Wass et al., 2019). While both types of synchrony describe the linkage of physiological activities in two or more individuals, they aim at conceptualizing different temporal forms of this relation. Concurrent synchrony usually refers to a common co-fluctuation of physiological signals in caregiver and infant at a moment-to-moment level, e.g. co-fluctuation of maternal and infant RSA across a given task (Helm et al., 2018). On a behavioral level, this could be compared to mutual gaze or the matching of vocalizations. Sequential synchrony describes when changes in one person's signal predict changes in the

other person's signal or vice versa, analogous to turn-taking or infants following the mother's affective state on the behavioral level.

Summarizing previous research shows that coupling of physiological rhythms is most likely to occur during active interactions between caregiver and child, and is closely linked to behavioral patterns and specific dyadic characteristics (Suveg, Shaffer, & Davis, 2016; Woody et al., 2016). However, while various studies have covered synchrony quite extensively on the behavioral domain, further research on synchrony on the physiological level is needed to more precisely identify its mechanisms and determinants.

Postpartum depression as risk factor for physiological synchrony

As one of these determinants, parental factors, such as mental illnesses, can substantially affect parent-child relationships and dyadic synchrony. In the context of mother-child interactions, postpartum depression (PPD) is a specifically relevant factor, as it is one of the most prevalent mental disorders in mothers (Tronick & Reck, 2009). Symptoms of PPD typically involve lowered responsiveness and avoidant behavior in mothers, and affect both mother's and infant's functioning (Weinberg & Tronick, 1998). Children of depressed mothers are more likely to exhibit cognitive deficits or to develop psychiatric disorders (Priel et al., 2019; Weinberg & Tronick, 1998). Regarding mothers, PPD can impair maternal emotion regulation, social engagement and the ability to respond sensitively to the child's needs, which in turn negatively affect mechanisms and quality of mother-child interactions (Amole et al., 2017; Reck et al., 2004). These patterns are particularly harmful for the infant's physiological and emotional development during the first months of life, when infants depend most strongly on their parents' care and their caregiving behaviors (Granat et al., 2017). Given that PPD is also associated to impairments in maternal vagal functioning (Amole et al., 2017), the process of creating and maintaining physiological synchrony can be hindered in dyads involving depressed mothers. This was shown in studies investigating physiological rhythms in depressed and non-depressed mothers and their children (school and teenage age) during interactions. While the heart rate variability of non-depressed mothers and their children was positively correlated to one another during positive and negative discussion tasks, dyads with depressed mothers did not establish this form of synchrony and instead displayed tendencies towards negative (i.e. inverted) linkage of heart rhythms (Amole et al., 2017; Woody et al., 2016). During a discussion, mothers and preadolescent children showed positive physiological synchrony only in the low maternal depression group, while there was negative synchrony in the high depression group (Suveg et al., 2018).

However, the current state of research also shows that dyadic risk factors are not

necessarily associated to negative physiological synchrony or vice versa; that positive synchrony is not always linked to healthy or normal dyadic patterns. While positive synchrony in the behavioral domain (e.g. turn-taking, shared gaze) can mostly be interpreted as advantageous for the interacting dyad, positive synchrony on a physiological level does not always reflect successful inter-dyadic coordination or positive contexts (Suveg et al., 2018). This is evident in studies finding positive RSA-synchrony in dyads characterized by risk conditions or disruptions in the mother-child relationship, namely infants' insecure-resistant attachment or parental abusive behavior (Lunkenheimer, Busuito, Brown, & Skowron, 2018; Smith, Woodhouse, Clark, & Skowron, 2016). Other studies did not find any differences regarding physiological synchrony in dyads featuring depressed mothers as opposed to dyads with non-depressed mothers (Field, Healy, & LeBlanc, 1989).

A recent series of studies (Smith et al., 2019; Wass et al., 2019) assessed mother's and infant's arousal during a whole day and focused on maternal anxiety as a risk factor for dyadic synchrony. They found that physiological arousal in anxious mothers co-fluctuated more strongly with their infant's physiological signals, as compared to dyads with non-anxious mothers. More specifically, non-anxious mothers tended to only adapt their physiology during moments of very high arousal in their infant, whereas anxious mothers reacted strongly even to small fluctuations in the infant's arousal. It has been suggested that high physiological synchrony in these cases may be explained by exaggerated and unhealthy patterns of interdependence between caregiver and child (Suveg et al., 2018). Accordingly, it is important to note that negative synchrony on a physiological level should not be equated as "inherently adaptive or maladaptive" (Creavy et al., 2019) for inter-dyadic patterns or outcomes. Instead, negative or positive physiological synchrony primarily simply index the direction of linkage of two physiological signals. Current state of research has yet to find to clear conclusions as to what implications the direction of physiological synchrony carries for dyadic interaction and infant's socioemotional and physiological development. The present study attempts to help clarifying the role of maternal depression as a risk factor for physiological synchrony at infant age.

Maternal touch in early caregiver-infant interactions

In the context of examining the role of PPD in mother-child physiological synchrony, touch might play a crucial role. Early in life, touch between caregiver and infant is often considered to be the most fundamental form of communication and upholds various functions, from feeding and soothing an infant, to comforting, playing and expressing affection (Hertenstein, 2002). Touch and physical contact in caregiver-infant dyads thereby support the

development of infants' secure attachment, emotional management and stress regulation (Brauer et al., 2016; Hertenstein, 2002). More specifically, empirical evidence reports that touch helps in regulating infants' vagal response and decelerating their heart rates in stressful situations (Fairhurst et al., 2014; Feldman et al., 2010), especially when they perceive their caregiver as the source of touch (Aguirre et al., 2019). In many mammals, bodily contact and tactile stimulation are considered to be one of the main mechanisms driving bio-behavioral attunement between caregiver and infant (Champagne, 2008; Feldman et al., 2011; Hofer, 1995). These findings indicate maternal touch to be immediately linked to infants' physiological functions and rhythms, thereby underlying the importance of physical contact for the examination of physiological synchrony.

Especially touching behaviors that are directed towards expressing affection and that are characterized by slow pace and maintaining close physical proximity, seem to promote infants' development of bio-behavioral regulatory systems (Feldman & Eidelman, 2007; Stack, 2004). For example, preterm born babies display less behavioral distress and increased respiratory regularity when caregivers provide them with passive, gentle touch (e.g. resting hand on the infant's back or holding the infant), as compared to episodes without tactile contact (Harrison et al., 2000). These passive forms of touch or contact are often emphasized in literature as a component of affectionate maternal touch, as they signal to the infant the mother's calm and steady presence (Ferber, Feldman, & Makhoul, 2008). As opposed to active forms of touch, passive touching behaviors involve continuous contact and are often directed at soothing the infant or regulating their negative affect (Jean & Stack, 2009). Active touch, such as tickling, kissing or stroking the child, on the other hand can be described as more dynamic, often carries stimulating functions and is often used by caregivers to evoke orienting responses (Korner & Thoman, 1972) or specific emotions in an infant, such as smiling (Stack et al., 1996).

Several studies indicate that the presence of maternal psychopathology is reflected in both quantity and quality of maternal touching behavior. More precisely, mothers with depressive symptomatology tend to touch their children less frequently and keep greater physical distance to their children (Beebe et al., 2008; Feldman, 2011). Postpartum depressive symptoms shortly after birth also predicted lower levels of affectionate touch three months later in mothers' interaction with their child (Feldman & Eidelman, 2007). Empirical evidence further documented that depressed mothers touch their children more frequently in negative or restrictive manners (Crucianelli et al., 2018; Ferber et al., 2008) and use more overstimulating or intrusive types of touch, like rough tickling or finger-snapping (Beebe et al., 2008; Fergus,

Pickens, & Schmidt, 1998; for review see Stack, 2004).

Interpersonal proximity and contact seem to be particularly important for synchrony on a physiological level because physical closeness may facilitate the transfer of interpersonal rhythms (such as cardiac rhythms) between mother and child, and thereby enhance synchronization processes through touch (Feldman et al., 2011; Hoehl & Markova, 2018). Research on adults has provided empirical evidence for the effect of touch on physiological synchrony. In romantic couples, affectionate touch during an interaction (touching each other's hands) increases the concordance of electrodermal activity and heart rate variability between partners (Chatel-Goldman et al., 2014), as well as cardiac and respiratory synchrony during episodes of pain (Goldstein et al., 2017). Regarding infant age, mothers and their 12-month-olds showed enhanced covariation of physiological activities when the infant sat on the mother's lap during a reunion episode after a stressful event, as compared to when they did not have any physical contact (Waters et al., 2017). However, not enough studies have examined the role of touch in physiological synchrony, especially regarding infant age and naturalistic, non-stressful contexts.

Present study

Taken together, empirical evidence indicates that interpersonal touch is crucial for infants' physiological regulation and may promote physiological coupling between mother and infant. Previous research has also documented that maternal touch is often decreased in depressed mothers, and that mothers suffering from PPD tend to use different touching patterns, specifically that they use more overstimulating types of touch than non-depressed mothers. Stimulating types of touch, together with other dynamic forms of touch, were categorized as active touch in the present study, as opposed to static or passive types of touch (see Table 1 in methods section for details). While studies on dyadic or parental risk factors and physiological synchrony have yielded somewhat mixed results, studies focusing on maternal depression mostly found that physiological synchrony tends to be lower, or even negative in dyads including depressed mothers. Possibly, different patterns of touching behavior in depressed mothers might account for difficulties in establishing physiological synchrony with their child. The main aim of the present study therefore was to clarify the role of maternal touch and PPD for physiological synchrony in mother-infant dyads.

To this end, a naturalistic 5-minute face-to-face free-play session between mother and their 4-5-month-old infants was analyzed respective to concurrent synchrony in respiratory sinus arrhythmia (RSA) and maternal touching behavior, while taken into consideration

maternal self-assessed postpartum depressive symptoms. Based on previous research, the following hypotheses were derived:

H1: Higher maternal PPD is correlated to lower overall levels of maternal touch.

H2: Higher maternal PPD is correlated to higher rates of active touch, while controlling for overall level of touch.

H3: Physiological synchrony is predicted by higher levels of maternal touch.

H4: Physiological synchrony is predicted by lower levels of maternal PPD depression.

H5: The association between PPD and physiological synchrony is mediated by overall level of maternal touch.

Methods

Participants

The analyzed sample consisted of 27 mothers and their 4–5-months-old infants (16 female, 11 male infants; age M = 4 months, 25 days, SD = 19.80 days). This subsample was part of a larger study investigating longitudinal effects of bio-behavioral synchrony on mother-child attachment. Nine dyads of the originally 36 dyads tested during January to April of 2019 were excluded from analysis because of noisy physiological data (n = 2) or early termination of the experiment due to infant's fussiness (n = 7).

Mothers' age ranged from 24 to 44 years (M = 34.46, SD = 4.75). The sample was characterized by high educational status, with 70.4% of mothers with a university degree. Most mothers reported German to be the language mainly spoken at home (70.4%, n = 19), other mothers stated English (11.1%, n = 3), Bulgarian, Croatian, Italian, Romanian, Slovak, Spanish or Ukrainian (4%, n = 1, respectively). Three of the 27 mothers reported to be a single parent.

All participants were registered in the general database of the Department for Developmental Psychology (Wiener Kinderstudien, University of Vienna). Most of the mothers in this database were first recruited at the birthing station at Vienna General Hospital (Allgemeines Krankenhaus der Stadt Wien), while others were approached at mother-baby yoga classes, playgroups or similar events in Vienna. Parents that showed interest in participating in studies with their children were added to the database after haven given their written consent. They were later contacted via telephone when their child was in the

appropriate age for the study and were informed about the goals and procedures of the study. Mothers who agreed to participate were then scheduled for a testing session with their infant. The families received 6 euros and a toy for the infant for their participation.

Procedure

Mothers came with their babies to the Faculty for Psychology, University of Vienna and first were given time to clarify possible questions about the study procedure and to read and sign all information consent forms. Afterwards, they were led to the laboratory room and were familiarized with the equipment. Three electrodes for electrocardiographic measurements (ECG) were attached on both mother and infant to record cardiac activity. During the 5-minute free-play, infant and mother were seated facing each other (infant in a high chair). Mothers were instructed to play with their child as they would at home, without using toys or singing, in order to avoid entrainment through external rhythms. The whole session was recorded on video for later behavioral coding. Questionnaires assessing demographic data and depressive symptomology were filled out by mothers online before arriving to the laboratory. The experiment also included neural measurements (dual functional near-infrared spectroscopy), two video-watching conditions preceding the free-play episode and a heartbeat counting task at the end of the session. However, these aspects were not analyzed in the present paper and are therefore not described in greater detail.

Measures

RSA data acquisition and processing. Following previous research (e.g. Creavy, Gatzke-Kopp, Zhang, Fishbein, & Kiser, 2019; Van Puyvelde et al., 2015), we assessed the concordance of infant's and mother's RSA (respiratory sinus arrhythmia) to operationalize physiological synchrony. RSA captures the variability of heart rate across the respiratory cycle and is therefore an indicator for vagal tone. Being closely intertwined with parasympathetic and emotion regulation, RSA provides an insightful physiological marker in infant-parent dyads (Berntson et al., 1993; Porges, 1986).

Cardiac activity of mother and infant was measured with an ECG using three electrodes. For both infant and mother, a grounding electrode was placed below the right rib cage and two recording electrodes were placed below the left ribcage and the right clavicle, respectively. The ECG signals were recorded with a sampling rate of 500 Hertz. Using the tool ARTiiFACT (Kaufmann et al., 2011), we extracted interbeat-intervals from the ECG data, and manually controlled and corrected R-peak detection for both mother's and infant's cardiac signal. Movement artifacts were detected and corrected using Bernston detection and

cubic spline interpolation. Filtering, resampling and transformation of RSA values was conducted using the Porges-Bohrer Method, as suggested by Lewis, Furman, McCool and Porges (2012). This methodological approach accounts for stationarity of the data and uses a resampling rate of 5 Hz. Thus, this resulted in two time series for each dyad, containing approximately 1500 data points for the 5-minute free-play episode, of mother's and infant's RSA respectively.

Maternal touch. To assess maternal touch, video recordings of the free-play sessions were reviewed for behavioral coding using the software Mangold INTERACT. Three cameras (VideoSyncPro, Mangold) were used to film the experimental sessions at 25 frames per second. Maternal touching behavior was micro-analyzed by employing frame-by-frame coding of durations of maternal touch. All coding categories with descriptions are listed in Table 1. The aim of coding was to distinguish between periods of touch and no-touch (i.e. no physical contact), and within periods of touch, to further distinguish between passive and active maternal touching. Note that the categorization into passive vs. active touch is inspired by previous studies by Stack and colleagues (Jean & Stack, 2009; Moszkowski & Stack, 2007) that used ratings for maternal touching behavior, ranging from no touching, to short duration of passive touching, to passive/active touching lasting more than 50% of the

Table 1.

Description of categories used to code maternal touching behaviour.

Code	Description
No touch	No physical contact between mother and infant
Active touch	Dynamic and stimulating forms of touch, e.g. tickling, kissing, stroking, wiggling, lifting or moving infant's limbs
Passive touch	Passive or static forms of touch, e.g. resting hands on infant's body, passive bodily contact
Infant touch	Touch initiated by the infant
Functional touch	Touches used with instrumental intention, e.g. adjusting infant's clothing, wiping mouth, removing cables
Other	Not visible or uncodeable

interaction. Similar to our study, passive touching was defined as touch that is mainly static or involving very little movement and active touch was described as touching behavior that was stimulating, involved the movement of the infants' limbs or stroking and tickling touch forms. It is important to note that in contrast to many others studies on maternal touching behavior, we clustered stimulating and dynamic forms of touch into the categorization of active touch, in comparison to passive and static forms of touch, and therefore our categories do not fully correspond to previously used categories purely consisting of e.g. stimulating or affectionate touching forms (see e.g. Ferber, Feldman, & Makhoul, 2008). We also included codes for touching behaviors that did not fit into the main categories of interest, namely infant touch, functional touch and other. All touch categorizations were coded as mutually exclusive. To make sure the coding was reliable, a trained second rater double coded 25% of randomly chosen videos to establish inter-rater reliability (IRR). We calculated IRR using the kappa2 function in R, which resulted in overall $k = .79$ (Cohen, 1960). For analysis, we used the duration score for each code during free-play. To compose scores for each touching behavior, the total duration of each touch category was divided through the total time of free-play (i.e. duration of coded free-play) to be able to compare touch durations between dyads (following Crucianelli et al., 2018). Therefore, scores for each category could range between 0 and 1. This enabled an intuitive interpretation of touch scores, as they correspond to the percentage of time spent with the respective touching behavior during the free-play session (i.e. a score of 1 would indicate that 100% of time in the free-play session was spend with the respective touching behavior), while also accounting for minor variations in duration of coded free-play between dyads.

Edinburgh Postnatal Depression Scale. Postpartum depressive symptomatology in mothers was assessed with the German version of the Edinburgh Postnatal Depression Scale (EPDS; Bergant, Nguyen, Heim, Ulmer, & Dapunt, 1998; Cox, Holden, & Sagovsky, 1987). The EPDS assesses mood and depressive symptoms in mothers after the birth of a child through 10 self-report-items, such as "I have been so unhappy that I have been crying" with response options on a 4-point Likert scale ranging from 1 ("No, never") to 4 ("Yes, most of the time"). Overall scores could range between 0 and 30, with a score between 10 and 12 indicating a moderate risk, and scores of 13 or more a high risk for depression. The EPDS previously showed satisfactory sensitivity (79%) and specify (85%) for assessing depression in postnatal women (Cox et al., 1996).

Data analysis

To assess physiological synchrony between mother and infant from the RSA time series, we calculated cross-correlation functions (CCF) for each dyad using the .ccf function in R. CCF calculate the degree of concordance of two time series by quantifying the lagged associations (Feldman, 2007), i.e. of the mother's and the infant's RSA values during the free-play episode, and has been used to operationalize behavioral or physiological synchrony in various studies (e.g. Feldman, 2007; Han et al., 2019; Henning, Boucsein, & Claudia Gil, 2001; Smith et al., 2019). We were interested in concurrent synchrony between infant and mother, therefore we extracted the value at time lag = 0 from the CCF of each dyad (see figure 1 in the results section for an exemplary plot). The coefficient at lag 0 represents the common co-fluctuation of maternal and infant RSA across the whole free-play episode and can range from -1 to 1, indicating the degree to which maternal and infant RSA are linked with each other. A value of -1 would therefore indicate a negative or reversed link of maternal and infant RSA, e.g. when maternal RSA was high, infants' RSA tended to be low. Correspondingly, a value of +1 would indicate perfect positive concurrent synchrony. A concurrent synchrony of value 0 would reflect no association between maternal and infant RSA.

Statistical analyses were carried out using the program IBM SPSS Statistics 25 and R Studio Version 3.6.1 (for CCF analysis). We used an alpha level of .05 for all statistical tests. In order to control the type I error in multiple correlation comparisons, Bonferroni correction was used. A series of exploratory correlational analyses were conducted to check for possible associations of demographic variables with any of the study variables. To test the main hypotheses, we performed correlational analyses for PPD and maternal touch, as well as linear regression to test whether PPD and, or maternal touch would predict physiological synchrony, and to test the potential mediating role of maternal touch for the relation between PPD and physiological synchrony. Additionally, we investigated for possible differences in PPD and touch patterns by grouping the data respective direction of synchrony (i.e. negative vs. positive synchrony).

Results

Descriptive statistics and exploratory analyses of PPD and touch

EPDS scores ranged from 0 to 16, with mean score of 6.07 (*SD* = 4.61). Most mothers in this sample (85.20%, *n* = 23) scored lower than 10, indicating a very low or no risk for postpartum depression. Four women scored higher than 12, indicting a heightened risk for

postpartum depression. Exploratory analyses indicated an association between infant sex and maternal PPD. As the Shapiro-Wilk-Test indicated PPD to be not normally distributed (p = .02), the association between PPD and infant sex was examined with the nonparametric Mann-Whitney-U-Test. Results showed that mothers with male infants reported significantly higher PPD scores (Median = 8) than mothers with female infants (Median = 4), U = 42.50, p = .02, r = .44 (Cohen, 1992), indicating a medium-strong effect size. However, this effect should be carefully interpreted due to the small sample size.

Descriptive analysis of maternal touch showed that mothers spent an average of 94% of the free-play episode in physical contact with their infants. Active touch was the most used form of touch. All means, standard variations and ranges, as well as inter-correlations among the different categories for maternal touch are reported in Table 2. Exploratory correlational analyses with demographic variables indicated passive touch to be correlated to single parenting, but again this association should be interpreted with caution, as the variable single parenting was distributed rather unevenly (single mothers n = 3, non-single mothers n = 24) and a follow-up Mann-Whitney-U-Test yielded no significant difference in passive touch scores between single mothers and non-single mothers (p = .10). There were no other significant links of maternal touch or PPD to other demographic variables (all ps > .05).

Table 2.

Descriptive statistics and correlations among touch scores.

Touch category	*M (SD)*	Range	(1)	(2)	(3)	(4)	(5)
(1) Total touch	.94 (.08)	.69 – 1.00					
(2) Active touch	.67 (.15)	.31 – .90	.50				
(3) Passive touch	.25 (.12)	.05 – .59	.03	-.84*			
(4) Functional touch	.01 (.01)	.00 – .06	.14	-.07	.08		
(5) Infant touch	.01 (.01)	.00 – .05	-.43	-.64*	.43	-.15	
(6) No touch	.06 (.08)	00 – .31	-1.00*	-.50	-.03	-.14	.43

Note. Total touch score comprises the scores for active, passive, functional and infant touch and is therefore opposite to the No-Touch category.
* p < .003 (corresponds to p < .05, Bonferroni-corrected).

Descriptive statistics and exploratory analyses of concurrent synchrony. Figure 1 displays a graphical plot of a CCF analysis for an exemplary dyad. Concurrent (i.e. zero-lag) correlation coefficients resulted in a wide range, from strong negative synchrony to medium-strong positive synchrony between mother and infant (see figure 2, following Creavy et al., 2019), pointing to large inter-dyad differences in strength and direction of synchrony.

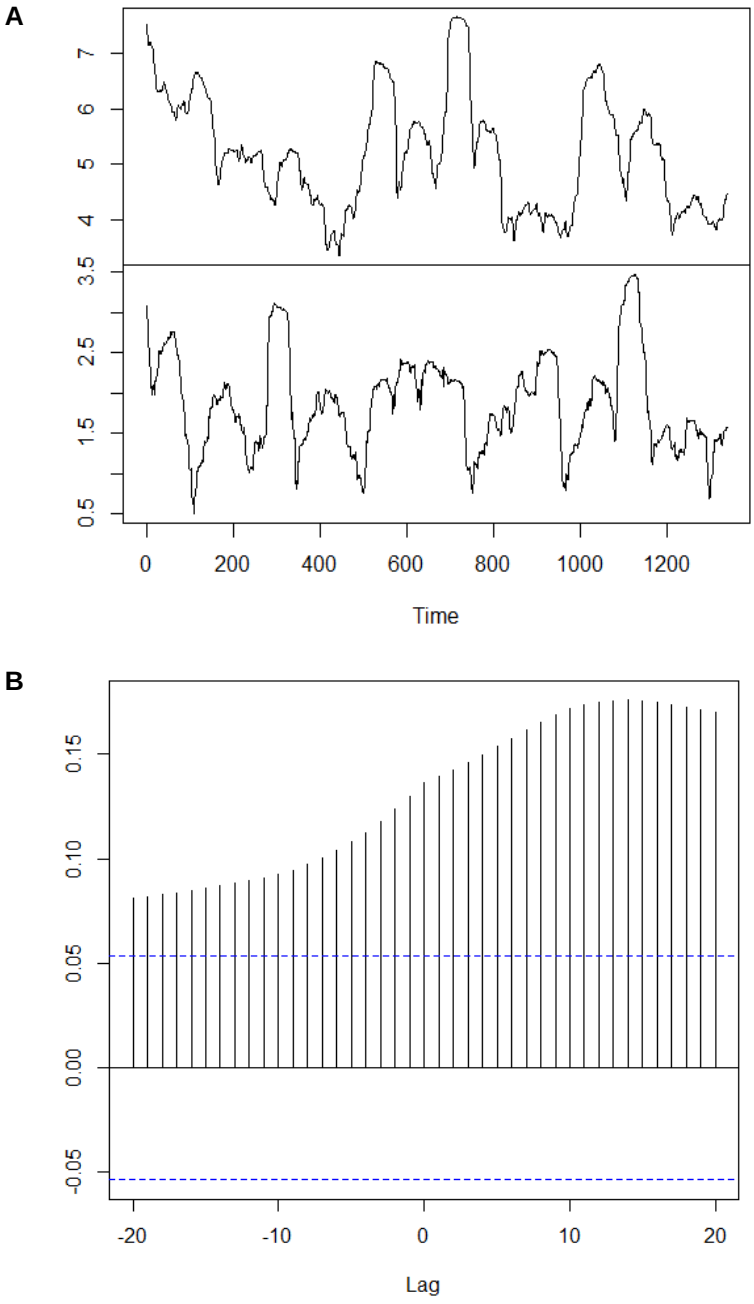

Figure 1. A): Exemplary plot of time lines of mother's (above) and infant's RSA (below) during free-play. B): Cross-Correlation function of the two RSA time lines. For analyses of concurrent synchrony, we extracted the value at lag = 0, which indicates a weak positive association of mother's and infant's RSA in this dyad.

Average synchrony across all dyads, accordingly, was near zero (*M* = -.02, *SD* = .24). Eleven dyads displayed negative synchrony, 16 displayed positive synchrony. Concurrent synchrony was not correlated with age or sex of the infant, or other demographic variables (all *p*s > .05).

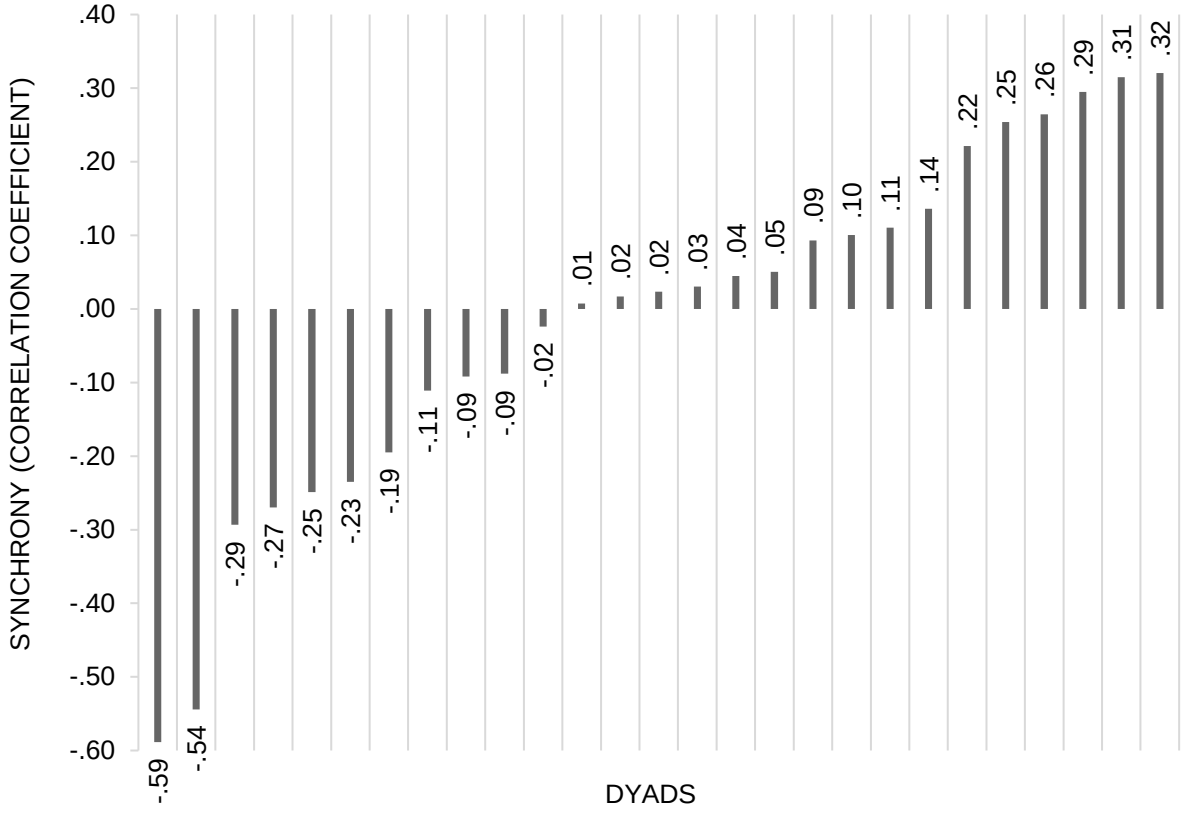

Figure 2. Correlational coefficients for concurrent physiological synchrony of all dyads, ranked from negative to positive.

Analyses of main hypotheses

Based on previous research, we expected maternal PPD to be associated to lower total levels of maternal touch (H1) and to higher rates of active touch (H2). Due to the facts that we tested a non-clinical sample and that our sample was rather small, we used PPD as continuous variable instead of testing for group differences between non-depressed and depressed mothers. PPD scores were not significantly correlated with total touch scores (r = .12, p = .55). To test whether mothers with higher PPD scores used higher rates active touch, we correlated PPD score and active touch, which was also not statistically significant (r = .33, p = .10). This association also did not change significantly when controlling for total touch score, (r = .31, p = .12).

To analyze the effects of PPD and maternal touch on physiological synchrony (H3-5),

a multiple regression analysis was conducted. The data did not meet all required assumptions for parametric tests (regarding normal distribution, linearity, homoscedasticity). We decided to employ a regression analyses anyways, because of lack of non-parametric alternatives. Therefore, results should be interpreted with caution. PPD and total touch score were entered as predictors into a linear regression model. Other touch forms were excluded from the model because of multicollinearity between the different types of touch. Both PPD and total touch did not significantly predict physiological synchrony (β for PPD = .05, p = .80; β for total touch = .16, p = .43). The overall model fit was R^2 = .03. The lack of significant associations between PPD, touch and physiological synchrony also ruled out a fit for a model including touch as a mediator for the relation of PPD and physiological synchrony (H5).

We additionally tested H3 and H4 by checking for differences respective the direction of synchrony, i.e. splitting the sample based on concurrent synchrony into positive and negative synchrony. We then employed a Mann-Whitney-U-Test to examine whether touch and PPD scores would differ in dyads displaying positive (n = 16) vs. negative synchrony (n = 11). Results indicated that there were no significant differences in dyads displaying positive vs. negative synchrony regarding PPD or total, active and passive touch scores (all ps > .05).

Discussion

Physiological synchrony between infants and mothers has been frequently suggested to be an important mechanism for infants' development of physiological regulation, yet its determinants, mechanisms and adaptive functions have not been clarified satisfyingly. More specifically, empirical findings on the role of maternal factors and behaviors for physiological coupling have been rather heterogeneous. While it is well established that maternal touch is a key component in early mother-infant interactions and critical for the development of infants' physiology and self-regulatory capacities, empirical studies are yet to investigate the impact of maternal touch on physiological synchrony in context of parental risk factors at infant age. This study aimed at contributing evidence to these questions, by assessing the co-occurrence of maternal and infant RSA in a naturalistic face-to-face free-play session between mothers and their 4-5-month-old infants, while including two crucial maternal factors in early mother-child interactions, namely maternal PPD and touching behaviors.

Following previous studies that found handholding to increase physiological coupling between romantic partners (Chatel-Goldman et al., 2014; Goldstein et al., 2017) or close bodily contact to support heart rhythm attunement in mothers and young infants (Van

Puyvelde et al., 2015), we expected physiological synchrony to be predicted by higher rates of maternal touch (H3). Moreover, we expected PPD to attenuate physiological attunement (H4), as some previous studies connected maternal depression to lower, or negative physiological coupling (Amole et al., 2017; Suveg et al., 2018). We further hypothesized that potential lower levels of physiological synchrony in cases of higher PPD might be mediated through lower levels of maternal touch (H5), which have been frequently linked to PPD in previous studies.

Against our expectations, physiological synchrony was not significantly predicted by either PPD or maternal touch. Our results thereby fall in line with a series of studies offering mixed evidence on risk factors and predictors of physiological synchrony in mother-children dyads, contributing to the complex current state of research in this field.

We could not provide significant evidence that touch between mother and infant facilitated physiological coupling. While touch was not identified as a significant predictor of synchrony, our data on maternal touching behavior yielded some notable results. We found that touch between mother and infant was present in the interactions in our sample for averagely 94% of the 5-minute free-play. Correspondingly, only during 6% of the time, mothers and infants were not in any form of physical contact with each other. The lack of significant findings on total touch in regard to PPD or physiological synchrony can be at least partly explained by this low variance in total touch and a resulting ceiling effect. However, the high percentage of time spent in tactile contact is in line with prior research finding equally high amounts of maternal touch during mother-infant interactions (e.g. Jean & Stack, 2009) and underlines the importance of touch as a mode of communicating in early interactions, especially at an age at which other forms of communication, such as speech, are not accessible for infants yet. The high amount of touch in our study could also be partly attributed to the setting specifics of the study. During the face-to-face free-play, mothers were seated relatively closely to the infants and were instructed not to use toys, so that many mothers made use of touch to engage their child in playful activities. Using touch for play could also partly explain why mothers in our sample used high amounts of active touch (average of 67% of total free-play time), which often served stimulating and playful functions, as compared to passive touch (25%), which instead often served calming functions. Our findings empathize that active touch, or similar touch categorizations, such as stimulating or playful touch, represent a valuable means for caregivers to engage their infants in interactions and playful activities through tactile stimulation.

As opposed to what previous research has suggested (Beebe et al., 2008; Feldman,

2011; Ferber et al., 2008), the quantity and quality of maternal touch was not associated to maternal depression in our study (H1 and H2). According to our data, mothers with higher self-reported depressive symptoms did not touch their infants significantly less than mothers with lower depressive symptoms, nor was PPD significantly linked to different rates of used type of touch. Note however, that our participants were recruited from a normal population and represent a low-risk sample. Therefore, while there was some variance regarding PPD scores in our sample, the major part of mothers (85.20%) fell within the scope of low risk for PPD. Because of this asymmetric distribution in non-depressed and depressed mothers, we used PPD as a continuous variable. We can therefore not draw conclusions as to how touching behavior is affected by clinically relevant depression. With a larger sample size and higher variance of PPD scores, differences in touching quality regarding depressed and non-depressed mothers could be investigated on a group-level. Nevertheless, not finding significant associations between PPD and maternal touch or physiological synchrony provides important insights regarding the impact of sub-clinical depression on mother-infant interactions. It is likely that in a low-risk sample, disadvantageous parenting behaviors that are typically linked to depression, do not manifest as strongly in interactions with the infant as they would in cases of full-blown PPD. This might explain the lack of significant associations of PPD with maternal touching behavior in the present study or why PPD did not moderate the direction of physiological synchrony, as was found in other studies that investigated PPD on a group-level based on previous depression diagnoses (e.g. Amole et al., 2017; McKillop & Connell, 2018; Woody et al., 2016) or on cut-off scores for higher risk of depression (Beebe et al., 2008).

A lot of the studies investigating patterns of physiological coupling and maternal risk factors focused on stressful context or interactions (e.g. Still-face, Moore et al., 2009; Ostlund, Measelle, Laurent, Conradt, & Ablow, 2017; conflict discussion, Suveg et al., 2018). Apart from the present study, only few studies have investigated physiological synchrony between mother and infant in naturalistic settings. In a similar setting to the present study, Field and colleagues (1989) investigated depressed and non-depressed mothers with their 3-month old infants during a face-to-face free-play session and also did not find differences regarding heart rate synchrony between the groups (both groups exhibited high physiological synchrony in this study). Possibly, the impact of PPD on mother-infant cardiac synchrony is most prominently evident in situations or contexts that elicit a specific emotional or physiological state. An example could be stressful situations, in which maternal dysregulated stress responses and potential disruptions in vagal functioning, often associated with

depression, would affect infants' physiological regulation and stress responses through physiological synchronization processes particularly negatively. Wass and colleagues (2019) investigated concurrent arousal synchrony during a whole day in naturalistic settings and found evidence for physiological synchrony between infant and mother in peak arousal moments, but not across the whole observation period or across intermediate levels of arousal. A similar approach could be used in further analyses of our data or in other studies. It is possible that PPD in our sample had different impacts on RSA coupling depending on specific phases of interaction, e.g. in phases of infant's negative affect, as indexed by crying or fussiness, or in phases of positive affect and playful engagement. As alternate approach to analyzing concurrent synchrony across the whole free-play episode, subdividing analyses according to specific phases of the interaction could allow to pinpoint distinctive instances of patterns of physiological synchrony.

Taken together, the lack of significant findings on PPD in our study could be attributed to our sample specifics, which mostly included mothers with a low risk for depression, as well as analysis specifics, which focused on assessing concurrent synchrony across the whole free-play episode but did not include sub-analyses of specific interactional phases or emotional contexts. As previous literature has suggested, depending on situational context and dyadic factors, physiological synchrony might then inherent different functions (Ostlund et al., 2017). To achieve better understanding of these functions, more studies in naturalistic interactions and real-life context are necessary.

Although not part of the investigated hypotheses in the present study and only to be interpreted very carefully due to our small sample size, an interesting side observation was that mothers with male infants reported significantly higher PPD symptoms. A possible explanation for this finding can be derived from literature examining gender differences in behavior in infants of depressed mothers. Some of these studies suggest that male infants are more emotionally reactive in early mother-child interactions than female infants, and depend more strongly on the maternal input to regulate their affect (Weinberg & Tronick, 1998). Mothers of male infants might therefore perceive a higher demand of their caregiving resources and feeling overwhelmed or fatigued, which could reflect, or facilitate the development of depression.

Limitations and implications for future research

As mentioned above, the small sample size in the present study did not allow to test for differences in dyads with depressed vs. non-depressed mothers on a group-level. Larger scale analyses could also include coding and analyses of other behaviors and parameters such

as infant affect and vocalizations, as well as physical proximity or type of activity of the interacting dyad. This would allow to examine physiological synchrony in certain phases, e.g. according to negative vs. positive infant affect, thereby enabling a more thorough insight to physiological synchrony as compared to using a single concurrent synchrony value. Furthermore, additional coding of infant affect or vocalization would enable a more in-depth analysis of touching behavior. In the present paper, we did not distinguish between different functions or contexts of maternal touch, e.g. whether touch was used in a playful context or in order to calm down the infant when he or she was crying or upset. Implementing coding for affect could allow to control for these contexts.

Our study focused on maternal behavior and characteristics as predictors for synchrony. Future studies or analyses could address infant aspects, such as infant touching behavior or gaze, or infant temperament, which is closely intertwined with physiological arousal and reactivity (Calkins, 1997; Stifter & Corey, 2001) and might therefore provide particularly valuable insights on physiological synchrony. Especially during the first years of life, when mother-infant interactional dynamics undergo many important developments and become gradually more coordinated and bi-directional (Feldman, 2007), it is important to investigate how infants' behaviors and characteristics contribute to caregiver-child coordination on a physiological level. Moreover, it would be interesting to focus on these infant parameters in the context of parental psychopathology, since previous studies found that infants of depressed mothers exhibited difficulties in cognitive functioning and engaging in social interactions (Tronick & Reck, 2009), which may also impair the transfer of physiological signals and the onset of physiological synchrony through touch. Often underrepresented in empirical studies, future research should also include the father's role in regard to maternal depression and physiological synchrony, as previous studies have shown that father's sensitive caregiving can have a buffering effect on negative influences of maternal depression on infants' development (Vakrat et al., 2018).

To the best of our knowledge, our study was the first to use the categorization of active vs. passive touch as a basis for analyzing the role of touch in physiological synchrony. Further studies could use these touch categorizations in other settings and for example instruct mothers to use the specific touch types for other approaches of analyzing their effect on physiological coupling. Regarding the analysis of touch, one small limitation in our study was that we were not always able to fully control the physical distance between mother's and infant's seat because some mothers adjusted or moved their seat during the experiment which could lead for example to mothers sitting very closely and in constant physical contact (i.e.

touch) with the child. Therefore, the minor variations of distance between mother's and infant's chair (i.e. physical proximity) might account for some of the variance in touching scores. Examining touch in the context of physiological synchrony is crucial, as tactile contact has previously been suggested to be a gateway to transmitting physiological rhythmicity and coupling processes, as well as a tool for caregivers to display affection and care in context of depression or other risk contexts, in which other forms of affective communication might be blocked or unavailable (Feldman et al., 2010).

Conclusions

All in all, our study added to the complexity of current research on facilitating factors and risk factors of physiological synchrony in caregiver-infant dyads. Only very few previous studies investigated physiological synchrony and its risk factors in the context of naturalistic free-play between mother and infant. Regarding PPD as a risk factor, the lack of significant associations of maternal depression to both touch and physiological synchrony implies that maternal depressive symptoms are not necessarily reflected in maternal behavior or physiological attunement, at least in a low-risk sample and across a free-play session not tied to a specific emotional context. This offers an optimistic outlook on the effects of depressive symptoms on early mother-infant interactions.

The present study aimed at providing more insight on the determinants of physiological synchrony in mother-infant interactions. The high variance in both direction and strength of physiological synchrony in the present study could not be explained by maternal touch or maternal depression, but it could encourage new studies to keep investigating other factors that might account for such inter-dyadic differences in physiological synchrony, such as infant touch or temperament, or other maternal behaviors like gaze, or touch categorizations other than passive or active touch. Identifying determinants of physiological synchrony is important to eventually gain a deeper understanding of how and when physiological synchrony can support interactional coordination and developmental outcomes for infants, and how parental behavior can facilitate these processes.

References

Aguirre, M., Couderc, A., Epinat-Duclos, J., & Mascaro, O. (2019). Infants discriminate the source of social touch at stroking speeds eliciting maximal firing rates in CT-fibers. *Developmental Cognitive Neuroscience*, *36*, 100639. https://doi.org/10.1016/j.dcn.2019.100639

Amole, M. C., Cyranowski, J. M., Wright, A. G. C., & Swartz, H. A. (2017). Depression impacts the physiological responsiveness of mother–daughter dyads during social interaction. *Depression and Anxiety*, *34*(2), 118–126. https://doi.org/10.1002/da.22595

Beebe, B., Jaffe, J., Buck, K., Chen, H., Cohen, P., Feldstein, S., & Andrews, H. (2008). Six-week postpartum maternal depressive symptoms and 4-month mother–infant self- and interactive contingency. *Infant Mental Health Journal*, *29*(5), 442–471. https://doi.org/10.1002/imhj.20191

Bergant, A. M., Nguyen, T., Heim, K., Ulmer, H., & Dapunt, O. (1998). Deutschsprachige Fassung und Validierung der »Edinburgh postnatal depression scale«. *DMW - Deutsche Medizinische Wochenschrift*, *123*(03), 35–40. https://doi.org/10.1055/s-2007-1023895

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1993). Respiratory sinus arrhythmia: Autonomic origins, physiological mechanisms, and psychophysiological implications. *Psychophysiology*, *30*(2), 183–196. https://doi.org/10.1111/j.1469-8986.1993.tb01731.x

Brauer, J., Xiao, Y., Poulain, T., Friederici, A. D., & Schirmer, A. (2016). Frequency of Maternal Touch Predicts Resting Activity and Connectivity of the Developing Social Brain. *Cerebral Cortex*, *26*(8), 3544–3552. https://doi.org/10.1093/cercor/bhw137

Calkins, S. D. (1997). Cardiac vagal tone indices of temperamental reactivity and behavioral regulation in young children. *Developmental Psychobiology*, *31*(2), 125–135. https://doi.org/10.1002/(SICI)1098-2302(199709)31:2<125::AID-DEV5>3.0.CO;2-M

Champagne, F. A. (2008). Epigenetic Mechanisms and the Transgenerational Effects of Maternal Care. *Frontiers in Neuroendocrinology*, *29*(3), 386–397. https://doi.org/10.1016/j.yfrne.2008.03.003

Chatel-Goldman, J., Congedo, M., Jutten, C., & Schwartz, J.-L. (2014). Touch increases autonomic coupling between romantic partners. *Frontiers in Behavioral Neuroscience*, *8*. https://doi.org/10.3389/fnbeh.2014.00095

Cirelli, L. K., Einarson, K. M., & Trainor, L. J. (2014). Interpersonal synchrony increases prosocial behavior in infants. *Developmental Science*, *17*(6), 1003–1011. https://doi.org/10.1111/desc.12193

Cohen, J. (1960). A Coefficient of Agreement for Nominal Scales. *Educational and Psychological Measurement*, *20*(1), 37–46. https://doi.org/10.1177/001316446002000104

Cox, J. L., Chapman, G., Murray, D., & Jones, P. (1996). Validation of the Edinburgh postnatal depression scale (EPDS) in non-postnatal women. *Journal of Affective Disorders*, *39*(3), 185–189. https://doi.org/10.1016/0165-0327(96)00008-0

Creavy, K. L., Gatzke-Kopp, L. M., Zhang, X., Fishbein, D., & Kiser, L. J. (2019). When you go low, I go high: Negative coordination of physiological synchrony among parents and children. *Developmental Psychobiology*. https://doi.org/10.1002/dev.21905

Crucianelli, L., Wheatley, L., Filippetti, M. L., Jenkinson, P. M., Kirk, E., & Fotopoulou, A. (Katerina). (2018). The mindedness of maternal touch: An investigation of maternal mind-mindedness and mother-infant touch interactions. *Developmental Cognitive Neuroscience*. https://doi.org/10.1016/j.dcn.2018.01.010

Fairhurst, M. T., Löken, L., & Grossmann, T. (2014). Physiological and Behavioral Responses Reveal 9-Month-Old Infants' Sensitivity to Pleasant Touch. *Psychological Science*, *25*(5), 1124–1131. https://doi.org/10.1177/0956797614527114

Feldman, R. (2007). Parent–infant synchrony and the construction of shared timing; physiological precursors, developmental outcomes, and risk conditions. *Journal of Child Psychology and Psychiatry*, *48*(3–4), 329–354. https://doi.org/10.1111/j.1469-7610.2006.01701.x

Feldman, R. (2011). Maternal touch and the developing infant. In *The handbook of touch: Neuroscience, behavioral, and health perspectives* (pp. 373–407). Springer Publishing Co.

Feldman, R., & Eidelman, A. I. (2007). Maternal postpartum behavior and the emergence of infant–mother and infant–father synchrony in preterm and full-term infants: The role of neonatal vagal tone. *Developmental Psychobiology*, *49*(3), 290–302. https://doi.org/10.1002/dev.20220

Feldman, R., Magori-Cohen, R., Galili, G., Singer, M., & Louzoun, Y. (2011). Mother and infant coordinate heart rhythms through episodes of interaction synchrony. *Infant Behavior and Development*, *34*(4), 569–577. https://doi.org/10.1016/j.infbeh.2011.06.008

Feldman, R., Singer, M., & Zagoory, O. (2010). Touch attenuates infants' physiological reactivity to stress. *Developmental Science*, *13*(2), 271–278. https://doi.org/10.1111/j.1467-7687.2009.00890.x

Ferber, S. G., Feldman, R., & Makhoul, I. R. (2008). The development of maternal touch across the first year of life. *Early Human Development*, *84*(6), 363–370. https://doi.org/10.1016/j.earlhumdev.2007.09.019

Fergus, E. L., Pickens, J., & Schmidt, J. (1998). Touch during mother-infant interactions. *Infant Behavior and Development*, *21*, 405. https://doi.org/10.1016/S0163-6383(98)91618-6

Field, T., Healy, B., & LeBlanc, W. G. (1989). Sharing and synchrony of behavior states and heart rate in nondepressed versus depressed mother-infant interactions. *Infant Behavior and Development*, *12*(3), 357–376. https://doi.org/10.1016/0163-6383(89)90044-1

Fleming, A. S., O'Day, D. H., & Kraemer, G. W. (1999). Neurobiology of mother–infant interactions: Experience and central nervous system plasticity across development and generations. *Neuroscience & Biobehavioral Reviews*, *23*(5), 673–685. https://doi.org/10.1016/S0149-7634(99)00011-1

Goldstein, P., Weissman-Fogel, I., & Shamay-Tsoory, S. G. (2017). The role of touch in regulating inter-partner physiological coupling during empathy for pain. *Scientific Reports*, *7*(1), 3252. https://doi.org/10.1038/s41598-017-03627-7

Granat, A., Gadassi, R., Gilboa-Schechtman, E., & Feldman, R. (2017). Maternal depression and anxiety, social synchrony, and infant regulation of negative and positive emotions. *Emotion*, *17*(1), 11–27. https://doi.org/10.1037/emo0000204

Han, Z. R., Gao, M. M., Yan, J., Hu, X., Zhou, W., & Li, X. (2019). Correlates of Parent-Child Physiological Synchrony and Emotional Parenting: Differential Associations in Varying Interactive Contexts. *Journal of Child and Family Studies*, *28*(4), 1116–1123. https://doi.org/10.1007/s10826-019-01337-4

Harrison, L. L., Williams, A. K., Berbaum, M. L., Stem, J. T., & Leeper, J. (2000). Physiologic and behavioral effects of gentle human touch on preterm infants. *Research in Nursing & Health*, *23*(6), 435–446. https://doi.org/10.1002/1098-240X(200012)23:6<435::AID-NUR3>3.0.CO;2-P

Helm, J. L., Miller, J. G., Kahle, S., Troxel, N. R., & Hastings, P. D. (2018). On Measuring and Modeling Physiological Synchrony in Dyads. *Multivariate Behavioral Research*, *53*(4), 521–543. https://doi.org/10.1080/00273171.2018.1459292

Henning, R. A., Boucsein, W., & Claudia Gil, M. (2001). Social–physiological compliance as a determinant of team performance. *International Journal of Psychophysiology*, *40*(3), 221–232. https://doi.org/10.1016/S0167-8760(00)00190-2

Hertenstein, M. J. (2002). Touch: Its Communicative Functions in Infancy. *Human Development*, *45*(2), 70–94. https://doi.org/10.1159/000048154

Hoehl, S., & Markova, G. (2018). Moving developmental social neuroscience toward a second-person approach. *PLOS Biology*, *16*(12), e3000055. https://doi.org/10.1371/journal.pbio.3000055

Hofer, M. A. (1995). Hidden regulators: Implications for a new understanding of attachment, separation, and loss. In *Attachment theory: Social, developmental, and clinical perspectives* (pp. 203–230). Analytic Press, Inc.

Jean, A. D. L., & Stack, D. M. (2009). Functions of maternal touch and infants' affect during face-to-face interactions: New directions for the still-face. *Infant Behavior and Development*, *32*(1), 123–128. https://doi.org/10.1016/j.infbeh.2008.09.008

Kaufmann, T., Sütterlin, S., Schulz, S. M., & Vögele, C. (2011). ARTiiFACT: A tool for heart rate artifact processing and heart rate variability analysis. *Behavior Research Methods*, *43*(4), 1161–1170. https://doi.org/10.3758/s13428-011-0107-7

Korner, A. F., & Thoman, E. B. (1972). The Relative Efficacy of Contact and Vestibular-Proprioceptive Stimulation in Soothing Neonates. *Child Development*, *43*(2), 443–453. JSTOR. https://doi.org/10.2307/1127547

Leclère, C., Viaux, S., Avril, M., Achard, C., Chetouani, M., Missonnier, S., & Cohen, D. (2014). Why Synchrony Matters during Mother-Child Interactions: A Systematic Review. *PLOS ONE*, *9*(12), e113571. https://doi.org/10.1371/journal.pone.0113571

Lewis, G. F., Furman, S. A., McCool, M. F., & Porges, S. W. (2012). Statistical strategies to quantify respiratory sinus arrhythmia: Are commonly used metrics equivalent? *Biological Psychology*, *89*(2), 349–364. https://doi.org/10.1016/j.biopsycho.2011.11.009

Lunkenheimer, E., Busuito, A., Brown, K. M., & Skowron, E. A. (2018). Mother–Child Coregulation of Parasympathetic Processes Differs by Child Maltreatment Severity and Subtype. *Child Maltreatment*, *23*(3), 211–220. https://doi.org/10.1177/1077559517751672

Markova, G., Nguyen, T., & Hoehl, S. (2019). Neurobehavioral Interpersonal Synchrony in Early Development: The Role of Interactional Rhythms. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.02078

McKillop, H. N., & Connell, A. M. (2018). Physiological linkage and affective dynamics in dyadic interactions between adolescents and their mothers. *Developmental Psychobiology*, *60*(5), 582–594. https://doi.org/10.1002/dev.21630

Moore, G. A., Hill-Soderlund, A. L., Propper, C. B., Calkins, S. D., Mills-Koonce, W. Roger., & Cox, M. J. (2009). Mother-Infant Vagal Regulation in the Face-To-Face Still-Face Paradigm Is Moderated by Maternal Sensitivity. *Child Development*, *80*(1), 209–223. https://doi.org/10.1111/j.1467-8624.2008.01255.x

Moszkowski, R. J., & Stack, D. M. (2007). Infant touching behaviour during mother–infant face-to-face interactions. *Infant and Child Development*, *16*(3), 307–319. https://doi.org/10.1002/icd.510

Ostlund, B. D., Measelle, J. R., Laurent, H. K., Conradt, E., & Ablow, J. C. (2017). Shaping emotion regulation: Attunement, symptomatology, and stress recovery within mother–infant dyads. *Developmental Psychobiology*, *59*(1), 15–25. https://doi.org/10.1002/dev.21448

Palumbo, R. V., Marraccini, M. E., Weyandt, L. L., Wilder-Smith, O., McGee, H. A., Liu, S., & Goodwin, M. S. (2017). Interpersonal Autonomic Physiology: A Systematic Review of the Literature. *Personality and Social Psychology Review*, *21*(2), 99–141. https://doi.org/10.1177/1088868316628405

Porges, S. W. (1986). Respiratory Sinus Arrhythmia: Physiological Basis, Quantitative Methods, and Clinical Implications. In P. Grossman, K. H. L. Janssen, & D. Vaitl (Eds.), *Cardiorespiratory and Cardiosomatic Psychophysiology* (pp. 101–115). Springer US. https://doi.org/10.1007/978-1-4757-0360-3_7

Priel, A., Djalovski, A., Zagoory-Sharon, O., & Feldman, R. (2019). Maternal depression impacts child psychopathology across the first decade of life: Oxytocin and synchrony as markers of resilience. *Journal of Child Psychology and Psychiatry*, *60*(1), 30–42. https://doi.org/10.1111/jcpp.12880

Provasi, J., Anderson, D. I., & Barbu-Roth, M. (2014). Rhythm perception, production, and synchronization during the perinatal period. *Frontiers in Psychology*, *5*. https://doi.org/10.3389/fpsyg.2014.01048

Reck, C., Hunt, A., Fuchs, T., Weiss, R., Noon, A., Moehler, E., Downing, G., Tronick, E. Z., & Mundt, C. (2004). Interactive Regulation of Affect in Postpartum Depressed Mothers and Their Infants: An Overview. *Psychopathology*, *37*(6), 272–280. https://doi.org/10.1159/000081983

Smith, C., Jones, E. J. H., Charman, T., Clackson, K., Mirza, F., & Wass, S. (2019). *Anxious parents show higher physiological synchrony with their infants* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/m2rsg

Smith, J. D., Woodhouse, S. S., Clark, C. A. C., & Skowron, E. A. (2016). Attachment status and mother–preschooler parasympathetic response to the strange situation procedure. *Biological Psychology*, *114*, 39–48. https://doi.org/10.1016/j.biopsycho.2015.12.008

Stack, D. M. (2004). Touching during mother-infant interactions. In T. M. Field & J. Fredman (Eds.), *Advances in touch research* (pp. 49–81). Johnson & Johnson.

Stack, D. M., LePage, D. E., Hains, S., & Muir, D. W. (1996). Qualitatitive changes in maternal touch as a function of instructional condition during face-to-face social interactions. *Infant Behavior and Development*, *19*, 761. https://doi.org/10.1016/S0163-6383(96)90815-2

Stifter, C. A., & Corey, J. M. (2001). Vagal Regulation and Observed Social Behavior in Infancy. *Social Development*, *10*(2), 189–201. https://doi.org/10.1111/1467-9507.00158

Suveg, C., Braunstein, K. W., Davis, M., Caughy, M., Smith, E. P., & Oshri, A. (2018). Symptoms and synchrony: Mother and child internalizing problems moderate respiratory sinus arrhythmia concordance in mother-preadolescent dyads. *Developmental Psychology*. https://doi.org/10.1037/dev0000648

Suveg, Cynthia, Shaffer, A., & Davis, M. (2016). Family stress moderates relations between physiological and behavioral synchrony and child self-regulation in mother-preschooler dyads: Physiological Synchrony in Mother-Child Dyads. *Developmental Psychobiology*, *58*(1), 83–97. https://doi.org/10.1002/dev.21358

Tronick, E., & Reck, C. (2009). Infants of Depressed Mothers: *Harvard Review of Psychiatry*, *17*(2), 147–156. https://doi.org/10.1080/10673220902899714

Vakrat, A., Apter-Levy, Y., & Feldman, R. (2018). Sensitive Fathering Buffers the Effects of Chronic Maternal Depression on Child Psychopathology. *Child Psychiatry & Human Development*, *49*(5), 779–785. https://doi.org/10.1007/s10578-018-0795-7

Van Puyvelde, M., Loots, G., Meys, J., Neyt, X., Mairesse, O., Simcock, D., & Pattyn, N. (2015). Whose clock makes yours tick? How maternal cardiorespiratory physiology influences newborns' heart rate variability. *Biological Psychology*, *108*, 132–141. https://doi.org/10.1016/j.biopsycho.2015.04.001

Wass, S. V., Smith, C. G., Clackson, K., Gibb, C., Eitzenberger, J., & Mirza, F. U. (2019). Parents Mimic and Influence Their Infant's Autonomic State through Dynamic

Affective State Matching. *Current Biology*, *29*(14), 2415-2422.e4. https://doi.org/10.1016/j.cub.2019.06.016

Waters, S. F., West, T. V., Karnilowicz, H. R., & Mendes, W. B. (2017). Affect contagion between mothers and infants: Examining valence and touch. *Journal of Experimental Psychology: General*, *146*(7), 1043–1051. https://doi.org/10.1037/xge0000322

Weinberg, M. K., & Tronick, E. Z. (1998). The Impact of Maternal Psychiatric Illness on Infant Development. *The Journal of Clinical Psychiatry*, *59*(suppl 2), 53–61.

Woody, M. L., Feurer, C., Sosoo, E. E., Hastings, P. D., & Gibb, B. E. (2016). Synchrony of physiological activity during mother–child interaction: Moderation by maternal history of major depressive disorder. *Journal of Child Psychology and Psychiatry*, *57*(7), 843–850. https://doi.org/10.1111/jcpp.12562

Zelenko, M., Kraemer, H., Huffman, L., Gschwendt, M., Pageler, N., & Steiner, H. (2005). Heart Rate Correlates of Attachment Status in Young Mothers and Their Infants. *Journal of the American Academy of Child & Adolescent Psychiatry*, *44*(5), 470–476. https://doi.org/10.1097/01.chi.0000157325.10232.b1

Appendices

A. Abstract

Physiological synchrony in mother-infant interactions describes the coupling of mother's and infant's physiological signals and plays an important role in infants' development of physiological systems and self-regulatory processes. However, it is still poorly understood how specific maternal behaviors and risk factors affect the coupling of heart rhythms in mother-infant interactions. This study investigated if and how physiological synchrony is impacted by maternal touch and postpartum depression (PPD), two maternal aspects of particular relevance in early mother-infant interactions. For this, we examined the concordance of respiratory sinus arrythmia (RSA) in 27 mothers and their 4-5-month-old infants during a 5-minute free-play session. Concurrent physiological synchrony was obtained by calculating cross-correlation functions of mother's and infant's RSA. Durations of maternal touch and different types of touch were micro-coded. Mothers self-reported their depressive symptoms via a questionnaire. According to our results, neither maternal touch nor depression symptomology significantly predicted physiological synchrony between mother and infant. Maternal PPD was not associated to different rates or quality of touch. The results contribute to the current complex state of research regarding physiological synchrony and raise possible directions for future research on determinants and functions of physiological coupling.

B. Zusammenfassung

Physiologische Synchronizität in Mutter-Kind-Interaktionen beschreibt die Verknüpfung physiologischer Abläufe von Mutter und Kind und spielt eine wichtige Rolle in der kindlichen Entwicklung von physiologischen Systemen und Selbstregulierungsprozessen. Es ist jedoch noch weitestgehend unklar, wie sich spezifische mütterliche Verhalten und Risikofaktoren auf die Synchronisierung mütterlicher und kindlicher Herzrhythmen auswirken. Die vorliegende Arbeit fokussiert sich auf mütterliches Berührungsverhalten und mütterliche postpartale Depression (PPD) und untersucht, ob und inwiefern sich diese beiden in frühen Mutter-Kind-Interkationen besonders relevanten Aspekte auf physiologische Synchronizität auswirken. Dazu wurde respiratorische Sinusarryhtmie (RSA) von 27 Müttern und ihren 4-5-Monate alten Kindern während einer 5-minütigen freien Interaktion erfasst und durch Kreuzkorrelationsanalysen in Verbindung gesetzt. Dauer und Art mütterlicher Berührungen wurde mikrocodiert. Mütterliche PPD wurde durch einen selbstberichtenden Fragebogen erfasst. Die vorliegenden Ergebnisse zeigen, dass physiologische Synchronizität weder durch mütterliche Berührung, noch PPD signifikant vorhergesagt wurde. PPD war nicht mit Quantität oder Qualität mütterlicher Berührung assoziiert. Diese Ergebnisse fügen sich in den derzeitigen komplexen Forschungsstand zu physiologischer Synchronizität in Mutter-Kind-Dyaden ein, und eröffnen mögliche Ansatzpunkte für weitere Forschung, um Determinanten und Funktionen physiologischer Synchronizität genauer zu ermitteln.

C. List of Figures

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E. List of Abbrevations

CCF Cross-Correlation function

ECG Electrocardiogram

EPDS Edinburgh Postnatal Depression Scale

IRR Inter-rater reliability

PPD Postpartum depression

RSA Respiratory sinus arrythmia