How do maternal emotional regulation difficulties modulate the mother–infant behavioral synchrony?

Karyn Doba, Laurent Pezard, Jean-Louis Nandrino

How do maternal emotional regulation difficulties modulate the mother-infant behavioral synchrony?

A short running title: Maternal emotional regulation and behavioral synchrony

Karyn Doba, Laurent Pezard, Jean-Louis Nandrino

Research Highlights

- Mothers touched their 6-month-old infant more often in the reunion condition after a stressful situation than in the initial condition.
- The synchrony between mothers' motor behaviors and infant global behavioral involvement was higher during the reunion episode following a stressful separation than during the initial play episode.
- Maternal anxiety mediates the relationships between mothers' emotion regulation difficulties and gaze, vocal and motor synchrony between mothers and infants in both the initial and reunion conditions.
- Findings emphasize the importance of the dynamic quantification of mother-infant interactions as a complement to static description.

Abstract

Mother-infant synchrony is one of the most important processes in the development of socio-affective competencies in children. While maternal abilities and psychopathology are related to maladaptive mother-infant synchrony, it is as yet unclear how maternal emotion regulation difficulties contribute to it. Based on a panel of behavioral indicators (i.e. gaze, vocal and motor), the present study examined mother-infant synchrony at 6 months of age in a modified version of Ainsworth's Strange Situation (n=72 dyads). Mother-infant interaction sequences were characterized by indicators of complexity (LZ complexity of joint behavioral sequences) and of synchronization quality (cross-recurrence plot quantification). Results showed that mothers' touch was greater in the reunion condition than in the initial condition. Mothers' motor behaviors were associated with the global levels of infants' behavioral involvement in the reunion condition, unlike the symmetrical influence observed between mothers and infants in the initial condition. Results show that maternal anxiety mediates the relationships between mothers' emotion regulation difficulties and gaze, vocal and motor synchrony between mothers and infants in the initial and reunion conditions. This study emphasizes the central role of maternal emotion regulation difficulties in the establishment of maladaptive synchrony and in the adjustments of maternal physical contacts with infants.

Keywords: Mother-child interaction, synchrony, emotion regulation difficulties, maternal anxiety, maternal depression

Introduction

In both humans and other mammals, mothers' postpartum behaviors and their coordination with infant states are important for early developmental processes, such as the regulation of distress states in stressful situations (Bowlby 1969; Feldman, Gordon, & Zagoory-Sharon 2011; Kim et al., 2010; Mikulincer, Shaver, & Pereg, 2003). Human infants' extreme immaturity at birth leads them to depend on mothers' behaviors for relatively long periods. This provides specific environmental inputs for the regulation of infants' internal states (Feldman, 2007; Kim et al., 2010). Maternal behavioral cues, such as vocalizations, facial expressions, proximity position, movements, and gaze and affective display, are coordinated with specific neurodevelopmental sensitivities in infants (Abney, Warlaumont, Kimbrough, Wallot, & Kello, 2017; Messinger, Mahoor, Chow, & Cohn, 2009). These maternal and interactive behaviors serve to regulate the organization of neurobiological, sensory, perceptual, emotional, physical, and relational systems in infants (Jaffe et al., 2001; Kochanska, 2002).

From a dynamic systems theory perspective, co-regulation between mothers and infants constitutes a dynamically interactive system organized by the behavioral inputs of both partners (Beebe et al., 2016; Fogel, 2011; Pezard, Doba, Lesne, & Nandrino, 2017; Provenzi et al., 2015; Smith & Thelen, 2003; Sravish, Tronick, Hollenstein, & Beeghly, 2013). This dynamic reciprocal adaptation of the temporal structure of behaviors between mothers and infants involves repetitive cycles of behaviors (Beebe et al., 2016; Coburn, Crnic, & Ross 2015; Sravish et al., 2013). Different types of mothers' behaviors tend to co-occur with some infants' behaviors, and mother-infant interactions tend to cycle between behaviors in a relatively predictable way (Provenzi et al., 2015; Van der Giessen, Branje, Frijns, & Meeus, 2012; Weinberg, Tronick, Cohn, & Olson, 1999).

The temporal concordance between simultaneous or sequential behaviors across a wide range of physiological or behavioral indicators including eye gaze, facial expressions, prosody, movement and emotional states of partners are usually referred to as synchrony phenomena (Feldman, 2007; Harrist & Waugh, 2002; Leclère et al., 2014). A well-organized and flexible mother-infant interaction is driven by a moderate degree of synchrony between mothers and infants during social interactions (Feldman, 2007; Feldman, Magori-Cohen, Galibi, Singer, & Louzoun, 2011). Several studies have shown that a high level of mother-infant synchrony interferes with infants' developing abilities to self-regulate and to explore (Leclère et al., 2014; Lotzin, Schiborr, Barkmann, Romer, & Ramsauer, 2015). Indeed, a high level of mother-infant synchrony may reduce the adjustment to both internal and external changes of situation and promote inflexible and invariant affective experiences in infants. Recent empirical research has indicated that co-regulated patterns of interactions show significant developmental shifts at around 6 months of age, with mother-infant interactions becoming increasingly more symmetrical and bidirectional (Cortney & Porter, 2009; Kochanska, 2002).

Despite empirical evidence of the impact of interactive influences on mother-infant synchrony, little is known about the relative importance of each partner in creating these processes or about the identification of behavioral indicators (i.e. gaze, vocal and motor) of mother-infant synchrony that change after a stressful situation induced by maternal separation. Mothers are generally rather efficient in reading their infants' emotional displays, and sensitive mothers tend to regulate their own affective responses to modulate their infants' emotional states (Beebe & Steele, 2013; Montague & Walkers-Andrews, 2002). In a developmental perspective, these maternal emotional abilities may depend on the quality of mothers' attachment experiences (Eisenberg, Cumberland, & Spinrad, 1998; Morris, Silk, Steinberg, Myers, & Robinson, 2007) and could be associated with the development of mother-infant synchrony. Studies have shown that maladaptive mother-infant synchrony may depend upon maternal insensitivity, unresponsiveness to the infant and maternal emotional disorders, such as maternal anxiety and depression (Beebe et al., 2011; Lotzin, Schiborr et al., 2015; Lundy, 2002; Sravish et al., 2013).

Even though anxiety and depression are often comorbid, several studies also suggest that they are partially distinct, e.g. due to their different symptom time course (Der Wee et al., 2011). Furthermore, empirical evidence suggests that each may have specific effects on child development and mother-infant interaction, and it is important to differentiate their effects on outcomes (Hakanen, et al., 2019; Nolvi, et al., 2016). Anxious mothers are more controlling and intrusive (Feldman, Greenbaum, Mayes, & Erlich, 1997; Stein et al., 2012), exhibit more fearful responses than those without anxiety symptoms (Murray et al., 2008), and display fewer positive emotions (Nicol-Harper, Harvey, & Stein, 2007). Anxiety symptoms in mothers predict higher synchrony in the touch modality, greater frequencies of gaze to infant, and lower affect synchrony in face-to-face play (Beebe et al., 2011; Granat, Gadassi, Gilboa-Schechtman, & Feldman, 2017). Several studies have shown that mothers with depressive symptoms display less gaze, facial affect, vocal and touch behaviors than mothers without depressive symptoms (Field, 2010; Granat et al., 2017; Righetti-Veltema, Conne-Perreard, Bousquet, & Manzano, 2002). Maladaptive mother-infant synchrony in the context of maternal depression is expressed in various forms including fewer episodes of mutual gaze (Beebe et al., 2008; Feldman & Eidelman, 2007) and a less predictable duration of vocal switch-pauses (Zlochower & Cohn, 1996). Although this research suggests that maternal anxiety and maternal depression are expressed in two specific styles, few studies to date have evaluated their associations with maternal relational behaviors and mother-infant synchrony. Some recent studies also shown that mothers with depressive symptoms are more withdrawn and less intrusive with their infants than those with anxiety symptoms (Feldman et al., 2009; Hakanen, et al., 2019). In both gaze and touch, synchrony was higher in mothers with anxiety than in those with depression (Granat et al., 2017).

Maternal anxiety and depression have been associated with emotion regulation (ER) difficulties corresponding to processes that modulate emotions for appropriately responding to environmental demands. They have also been associated with difficulties in monitoring, evaluating, and modulating or accepting emotional experiences, given the demands of a specific goal or set of goals (Gratz & Roemer, 2004; Gross, 1998). As such, ER difficulties involve several domains, including a lack of awareness of emotion, a poor clarity of emotion (emotional understanding), a non-acceptance of emotion, and a poor ability to access effective emotion regulation strategies. Greater maternal ER difficulties were significantly associated with high levels of facial and gaze synchrony between infants and depressed mothers before and after a stressful situation induced by the still-face paradigm (Lotzin, Romer, et al., 2015; Lotzin, Schiborr, et al., 2015). These paradigms show that the effect of maternal ER difficulties on mother-infant synchrony constitutes a key process for the development of synchrony between infants and depressed mothers in clinical populations. While ER difficulties are core features of maternal anxiety and maternal depression, their associations with mother-infant synchrony have not yet been systematically investigated in a non-clinical population (Stein et al., 2012). Therefore, it is important to evaluate the impact of maternal ER difficulties, anxiety, and depressive symptoms in the development mother-infant synchrony in a non-clinical population.

The present study examined mother-infant synchrony patterns at 6 months of age based on a modified version of Ainsworth's Strange Situation (Field, Vega-Lahr, Scafidi, & Goldstein, 1986). This version generates typical stress reactions in infants at 6 months of age in a natural condition (Hill-Soderlund et al., 2008; Laurent, Ablow, & Measelle, 2012). Using video microanalysis, the first aim of the study using a panel of behavioral indicators (i.e. gaze, vocal and motor) was to determine the levels of mother-infant synchrony before and after a stressful situation induced by maternal separation (initial condition and reunion condition, respectively). We also sought to determine the degree to which maternal behaviors drive infant behaviors, and vice-versa, in mother-infant synchrony in an initial condition and a reunion condition.

Based on evidence that mothers' ER difficulties might be one pathway by which maternal depression and anxiety are transmitted to higher levels of mother-infant synchrony (Lotzin, Romer, et al., 2015; Lotzin, Schiborr, et al., 2015), the second aim of the study was to examine the relationships between maternal ER difficulties, maternal anxiety, depressive symptoms and gaze, vocal and motor synchrony in mother-infant interactions. We hypothesized that mothers' ER difficulties are associated with higher levels of mother-infant synchrony indirectly through higher levels of maternal anxiety and depression. In addition, as a growing body of research supports the idea that the quality of security of attachment experienced by parents in their own childhood may affect the quality of the affective experiences and the acquisition of emotional recognition and expression with their children (Eisenberg et al., 1998; Morris et al., 2007), we expected that poor parental bonding experienced in mothers' childhood would be related to maternal ER difficulties.

Because mother-infant interactions are not static, an interactional model for the measurement of synchrony needs to capture the dynamic of mother-infant interactions over time. Recent mathematical methods derived from nonlinear dynamics make it possible to study complex time-varying phenomena (Doba, Nandrini, Lesne, Humez, & Pezard, 2008; Hollenstein, 2013; Pezard et al., 2017; Tschacher, Rees, & Ramseyer, 2014) and their application to behavioral sciences to complement time-series analysis such as frequency and cross correlations (Coburn et al., 2015; Van der Giessen et al., 2012). We used several indicators, including dynamic indicators that allow the mutual and bidirectional co-regulation in mother-infant synchrony to be assessed. We quantified the dynamics of mother-infant interactions using the Lempel-Ziv complexity of joint behavioral sequences and a cross-recurrence plot across a wide range of synchrony indicators including gaze, motor, and vocal behaviors.

Materials and methods

Participants

The participants were 72 mothers, aged from 22 to 42 years old (M = 30.72, SD = 4.35), and their 6-month-old infants (M = 6.57, SD = 0.45). All the infants (52.8 % male and 47.2 % female) included in the study were born at full term after a normal pregnancy and delivery. Infants' birth weight ranged from 2.18 to 4.12 kg (M = 3.23 kg, SD = 0.45 kg).

At the time of the assessment, their current weight ranged from 6.3 to 8.02 kg (M = 8.02, SD = 0.98). DSM-IV was used as a diagnostic instrument to assess the exclusion criteria only (Andreas, Theisen, Mestel, Koch, & Schulz, 2009). Exclusion criteria for mothers were: mothers with an intellectual impairment, a psychotic disorder, and/or present substance abuse (DSM-IV). Exclusion criteria for infants included the following: intrauterine growth retardation, perinatal asphyxia, genetic or metabolic diseases, deafness, congenital defects, and/or twins. Most of the mothers were married or lived with their partner (94.4 % married, and 5.6 % no partner). All mothers were fluent French speakers of French and none were immigrants to France. Social class was measured by the mother's own occupational class categorized into: professional and managerial occupations (30.1%), intermediate occupations (employees, self-employees) (27.7%), lower occupations (lower technical occupations, semi-routine and routine occupations) (25.3), and no job (16.9). The education levels of mothers were as follows: 27.8% high school incomplete, 14% high school and 58.2% university degree. The number of pregnancies ranged from 1 to 5 (M = 1.67, SD = 0.95).

Procedure

The present study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the independent ethics committee (2010-1-S1) at the University of Lille. Mothers were recruited from the maternity ward of the University Hospital. The second day after birth, research assistants visited the ward and invited women who were physically healthy and had delivered a healthy, full-term infant to participate in the study.

When the infant was approximately 6 months old, mothers were contacted by phone and invited to participate in the behavioral observation (i.e. modified version of Ainsworth's Strange Situation). They were visited at home by the child psychologist at the infants' age of 6 months. Each mother received a study information sheet and written informed parental consent was obtained before the start of the behavioral observation. During the home visit, mothers and infants were videotaped for 23 minutes in the modified version of Ainsworth's strange paradigm, and mothers completed self-report measures.

Measures

Maternal characteristics

Maternal emotion regulation difficulties were scored using the Difficulties in Emotion Regulation Scale (DERS). This self-report questionnaire includes 36 items rated from 1 (i.e. almost never) to 5 (i.e. almost always) according to the relationship between the item and subject experience (Dan-Glauser & Scherer, 2013; Gratz & Roemer, 2004). The DERS measures nonacceptance of negative emotional responses (Cronbach's $\alpha = 0.87$) (i.e. When I'm upset, I become irritated with myself), difficulties in engaging in goal-directed behavior (Cronbach's $\alpha = 0.90$) (i.e. When I'm upset, I have difficulty focusing on other things), difficulties in controlling impulsive behaviors (Cronbach's $\alpha = 0.87$) (i.e. When I'm upset, I become out of control), lack of emotional awareness (Cronbach's $\alpha = 0.80$) (i.e. I don't pay attention to or care how I feel), limited access to emotion regulation strategies (Cronbach's $\alpha = 0.80$) (i.e. When I'm upset, it takes me a long time to feel better), and lack of emotional clarity (Cronbach's $\alpha = 0.74$) (i.e. I have difficulty making sense out of my feelings). Higher scores indicate greater ER difficulties.

Maternal postpartum depression was scored using the Edinburgh Postnatal Depression Scale (EPDS). This self-report questionnaire is designed to detect depression among women in the postpartum period (Cox, Chapman, Murray, & Jones, 1996; Guedeney & Fermanian, 1998). The scale addresses the intensity of depressive symptoms. In the EPDS, the mothers are asked to choose from a set of given options those that best describe their feelings. The scale consists of 10 items scored on a 4-point scale from 0 to 3. The sum score of items ranges from 0 to 30 and higher scores indicate greater maternal postpartum depression. The EPDS showed good internal consistency (Cronbach's $\alpha = 0.76$). Prior research has suggested a cut-off score of 12 for the identification of depressive symptoms (Cox, Holden, & Saaovskv, 1987).

Maternal anxiety was scored using the State Anxiety Inventory (STAI-State). This $20 - item$ scale is designed to measure state anxiety (Spielberger, 1983). The state anxiety scale evaluates current feelings of tension and anxiety. The STAI-State has demonstrated reliability and validity and has been used widely in pregnancy and postpartum studies. Scores range from 20 to 80 and higher scores indicate a higher level of anxiety. The STAI showed good internal consistency (Cronbach's $\alpha = 0.73$). A cut-off score of 46 is suggested for detecting anxiety symptoms (Granta, McMahonb, & Austina, 2008).

Parental bonding was scored using the Parental Bonding Inventory (PBI), which comprises two self-report questionnaires that measure parenting attitudes and behaviors (i.e. care and overprotection) that respondents remember from their first 16 years of life (Mohr, Preising, Fenton, & Ferrero, 1999; Parker, Tupling, & Brown, 1979). The first questionnaire assesses maternal bonding and the second (which is otherwise identical to the first) assesses paternal bonding. Participants rate each parent on a care subscale (comprising 12 items) and on an overprotection subscale (comprising 13 items). The care subscale evaluates affection, emotional warmth, empathy and closeness (Cronbach's $\alpha = 0.89$). The overprotection subscale measures intrusion, control, and prevention of independence (Cronbach's $\alpha = 0.81$). Each of the 50 items is rated on a $4 - point$ scale with "very" or "moderately" like or unlike being among the choices. Higher scores on the care scales represent more positive parental behavior (i.e. higher levels of perceived care), while higher scores on the overprotection scales represent less positive parental behavior (i.e. higher levels of perceived parental intrusiveness and overcontrol).

Observation of mother-infant interaction

In most observational studies, a Strange Situation procedure is used to classify child attachment behavior at 12 months of age (Ainsworth, Blehar, Waters, & Wall, 1978). In this study, a modified version of Ainsworth's Strange Situation (Field et al., 1986) was used to assess the synchrony between mothers and infants at 6 months of age in a natural condition (Guo, Leu, Barnard, Thompson, & Spieker, 2015; Russel, Belsky, & Von Eye, 1989). The mother places her infant in a chair and directly faces him/her. A camera was placed on a stand $1.2m$ away and focused on the mother and child, consistent with prior work on synchrony measured in a home setting (Atzil, Hendler, & Feldman, 2011; Feldman & Eidelman, 2004).

The procedure consisted in three episodes:

1. An initial condition of spontaneous interaction between the mother and the infant (10 min);

2. A period during which the infant was separated from his/her mother (3 min) (i.e. mothers left the room) and remained alone with the female stranger (child psychologist);
3. A reunion condition in which the mother and infant reengage in a spontaneous interaction (10 min).

Mothers were instructed to play normally with their children during the initial and reunion conditions. Instructions were: “play with your child as you normally do.’’ No toys were provided. Mothers used their own toys during both conditions, which they presented to their infants. The restrictions imposed on the stranger’s behavior during the separation episode were to stay in the room and not to play with the child. The female stranger was visible to the infant during the initial and reunion conditions. The female stranger did not interact with anyone during any of the conditions. We quantified the mother-infant interactions during both conditions. The maternal separation condition evokes typical stress reactions in infants (Hill-Soderlund et al., 2008; Laurent et al., 2012).

Behavioral coding

Coding of the videotapes was conducted in a university laboratory by six graduate students in psychology. For each $3 - second$ interval of video recording, the maternal and infant behaviors within a dyad were coded by the same rater but initial and reunion conditions were coded by independent raters (Feldman, 2007; Pezard et al., 2017; Tronick, Als, & Brazelton, 1980).

Maternal behaviors were encoded according to three categories:

- Verbal behaviors. Mothers’ verbal behavior was divided into three categories (Fonagy, 2011; Gros-Louis, West, Goldstein, & King, 2006; Stacks et al., 2014): silence, reflective verbalization, and vocalizations/verbalizations. Mothers’ reflective verbalization corresponded to verbal expressions regarding their representations regarding their children, and/or their relationship with them and curiosity about their experience, e.g. by asking open questions about their feelings, beliefs, intentions and desires. Mothers’ reflective verbalization corresponded to mothers' ability to infer or mentalize about infants' mental and emotional states. For example, mothers commented on their infants’ mental or emotional states, e.g. "I think you are angry? " or Which toy do you prefer? ". Maternal vocalization/verbalization corresponded to an approximation of their infants’ vocalization, or attributing some characteristic or value to an object, or making playful vocalizations, such as making sounds and singing.
- Motor behaviors. Mothers’ motor behavior was divided into three categories (Granat et al., 2017; Mantis, Stack, Ng, Serbin, & Schwartzman, 2014): no movement, touch, and movement without physical contact. Mother touch corresponded to affectionate touch (i.e. touch that serves no functional purpose and is intended only to express affection, such as stroking, kissing, light touching), moving extremities (i.e. touching infant’s arms or legs), touching infant with object (i.e. touching with soft doll). Movement without physical contact referred to voluntary movements (i.e. gestures consisting primarily of hand, arm, and finger movements towards the infant).
- Gaze behaviors. Mothers’ gaze behavior referred to direction of gaze and was divided in two categories (Kim, Fonagy, Koss, Dorsett, & Strathearn, 2014; Lotzin, Schiborr,

et al., 2015): gaze toward infant and gaze away (i.e. when the mother gazed away from the infant's face and did not gaze toward him/her).

For the infants, vocal behaviors were divided into three categories (Feldman, 2003): silence, vocalizations and negative vocal behaviors. Vocalizations category corresponded to positive and neutral vocalizations. Negative vocal behaviors category corresponded to crying, screaming and fussing. Vegetative sounds (i.e. burp, hiccup, cough, yawn, heavy breathing) were excluded. Motor behaviors (i.e. movement and no movement) and direction of gaze (i.e. gaze toward mother and gaze away) were also coded. Vocal behaviors, motor behaviors and direction of gaze were taken into account to describe a global state of behavioral involvement (see Table 1) divided into three levels of global behavioral involvement (i.e. low, moderate and high) on a continuum from disengagement to engagement in the interaction (Feldman, Greenbaum, & Yirmiya, 1999; Tronick et al., 1980). The principle for choosing the involvement level was the following: for all combinations, no or one behavioral involvement was rated low, two behavioral involvements were rated moderate and three involvements were rated high. Infants' distress levels were encoded according to the intensity of crying during the three minutes of separation. Crying intensity was divided into four categories: no crying, low (i.e. infant cried a few seconds during the separation episode), moderate (i.e., infant cried for half the time of the separation episode) and high (i.e. infant cried during the three minutes of separation). To test the reliability of the coding procedure, 20% of the video recordings were coded independently by two researchers. The κ-coefficients of inter-rater agreement for the mothers' behaviors (verbal $\kappa = 0.77$; motor $\kappa = 0.83$; gaze $\kappa = 0.99$) and the infants' behaviors (vocal $\kappa = 0.69$; motor $\kappa = 0.78$; gaze $\kappa = 0.80$) were considered satisfactory (Fliess, 1981).

As a result, infants' and mothers' behaviors were associated with a symbolic sequence encoded according to the respective categories of behavior. For each maternal behavior i.e. verbal behavior, motor behavior and gaze, we thus considered two symbolic sequences x_t and y_t for mother X and infant Y encoded according to alphabets $A = \{\alpha_0, \cdots, \alpha_{k-1}\}$ and $B = \{\beta_0, \beta_1, \beta_2\}$ respectively, where each symbol represents a category of behavior for the mother i.e. {silence, reflective verbalization, verbalization} for mothers' verbal behavior, {no movement, touch, movement without physical contact} for mothers' motor behavior and {toward infant, away} for mothers' gaze behavior and a level of behavioral involvement for the infant i.e. {low, moderate, high} for infants' global behavioral involvement.

Dynamic quantification

Four encoded behavioral sequences (one for the infant, i.e. the **level** of global behavioral involvement, and three for the mother, i.e. verbal, motor and gaze) were obtained for each condition and each mother-infant pair. They were used to compute the dynamic indices which characterize the mother-infant interaction. The dynamics of three types of interactions (verbal, motor, and gaze) were quantified using the same procedure for each pair and each condition (initial and reunion).

First, the complexity of the interaction was quantified using Lempel-Ziv complexity (Lempel & Ziv, 1976; Lesne, Blanc, & Pezard, 2009) computed on the joint sequence between infants' global level **of behavioral involvement** and one of the mother's behavioral sequence (verbal, motor or gaze). The joint sequences correspond to the single sequence obtained after recoding of the pair of sequences (infant and mother) according to the cross product of the alphabets of each sequence. Second, interaction was also characterized using recurrence plots (RP) quantification analysis (Marwan & Webber, 2015) of the joint recurrence matrix which allows one to quantify synchrony (Romano, Thiel, Kurths, & von Bloh, 2004; Stam & Dijk, 2002) using the percent of determinism and the Shannon entropy of the frequency distribution of the diagonal line lengths. Synchronization likelihood (Stam & Dijk, 2002) was also computed as the recurrence rate of joint recurrence plot. Finally, the direction of coupling between mothers and infants was obtained using the mean conditional probabilities of recurrence between two sequences (Zou, Romano, Thiel, & Kurths, 2015) where the sign of the difference of mean conditional recurrence is an index of the direction of the coupling. Mathematical definitions of these indices are given in the technical appendix.

Statistical analysis

First, we conducted a series of multivariate analyses of variance (MANOVA) and t-tests to examine the differences between both conditions for maternal behaviors, infant behaviors and dynamic indices of mother-infant interactions. Cohen's d was used to illustrate the magnitude of significant effects. The analysis was divided into two levels: frequency analysis and dynamic analysis. For the frequency analysis, the distribution of the frequency of the occurrence of symbols for each behavior was analyzed using MANOVA and paired t tests. In the dynamic analysis, the set of dynamic indices (LZ complexity, Shannon entropy, percent of determinism, synchronization likelihood and mean conditional probability of recurrence i.e. direction of coupling) were first studied using a principal component analysis to reveal the main factors for quantifying the interaction and possibly reducing the number of dimensions for this description. For the main factors, t tests were used to assess the difference between the two conditions.

Second, we performed Partial Least Squares Path Modeling (PLS-PM) to evaluate the associations between maternal characteristics and dynamic indices of mother-infant interactions (Vinci, Trinchera, & Amato, 2010). PLS-PM is a method for studying complex multivariate relationships between manifest variables (MVs) and latent variables (LVs). It is a variance-based structural equation modeling technique that does not rely on distributional assumptions and can deal with small sample sizes (Fornell & Bookstein, 1982; Ringle, Wende, & Will, 2010). A full path model is comprised of two submodels: the inner model describes associations between the LVs and the outer model describes associations between each LV and respective MV. The overall quality of the model was assessed by examining R^2 and the goodness of fit index (GOF) (Hair, Hult, Ringle, & Sarstedt, 2013). The results are shown as path coefficients (β) and their bootstrap (1000 resamples) 95% confidence interval (CI). For analysis, we used R and constructed a PLS-PM model according to the procedure described in Sanchez (2013).

Results

Table 2 shows the descriptive statistics for ER difficulties (DERS), depression (EPDS), anxiety (STAI), and parental care and overprotection (PBI) in mothers. Scores on the EPDS ranged from 0 to 20 (mean score, 5.97 ± 5.38) with 18.06% of the mothers rated above the cut-off score (≥12) for depressive symptoms. Scores on the STAI traits ranged from 20 to 57 (mean score, 36.61 ± 9.92) with 23.6% of the mothers rated above the cut-off score

(≥46) for anxiety symptoms. Results revealed that 12.5% of the mothers reported above the cut-off score for maternal depression and anxiety.

Difference between initial condition and reunion condition

Frequency analysis. The frequencies for infants' level of behavioral involvement and maternal behaviors are shown in Table 3. The distributions of infants' levels of behavioral involvement (Pillai $V = 0.02$; $F[2,70] = 1.02$, $p = 0.36$), mothers' verbal behaviors (Pillai $\lambda = 0.01$; $F[2,70] = 0.68$, $p = 0.51$) and mothers' gaze behaviors ($t = 0.72$, $p = 0.47$) did not differ significantly between initial and reunion conditions. The frequencies of infants' crying intensity were as follows: no crying: 85.2%, low: 5.6, moderate: 1.9% and high: 7.4%. Whereas the distributions of mothers' motor behaviors differed significantly between the two conditions (Pillai $\lambda = 0.25$; $F[2,70] = 11.8$, $p < 0.01$). Pairwise t-tests revealed that mothers' touch increased from the initial to the reunion condition ($t_{71} = -4.861, p = 0$, Cohen's $d = 0.62$), whereas movement without physical contact ($t_{71} = 2.757, p = 0.007$, Cohen's $d = 0.28$) and the absence of movement ($t_{71} = 3.741, p = 0$, Cohen's $d = 0.44$) decreased from the initial condition to the reunion condition (Table 3).

Dynamic analysis. An example of a dynamic sequence of interaction between mothers and infants is given in Figure 1 for both initial and reunion conditions using grid representation (Hollenstein, 2013). The qualitative changes in dynamic organization were characterized by using both a complexity measure (Lempel-Ziv complexity) and recurrence plots. The recurrence plots and joint recurrence plots for the same sequences are depicted in Figure 2.

The dynamic indices were computed for three categories of mother behavior: motor, verbal and gaze behavior related to the global level of the infant's behavioral involvement. For each mothers' behavior category, a principal component analysis was performed for the set of dynamic characteristics. Figure 3 shows that, for each behavior, there is the same relationship between variables, thus revealing two main factors:

1. a synchronization / desynchronization factor related to LZ and RP indices;
2. a factor related to the direction of the dynamic influence (mother towards infant vs. infant towards mother).

This allowed the mother-infant interaction to be quantified by two factors: the *synchrony* factor (first dimension) and the *driver* factor (second dimension). The synchrony factor quantifies the level of synchronization between mothers and infants from low synchrony for negative values to high synchrony for positive values. The driver factor quantifies the direction of dynamic coupling between mothers and infants: for negative values, the mother drives the infant, whereas the infant drives the mother for positive values and a zero value characterizes a symmetrical interaction. These factors represented more than 90% of the total variance for all three conditions (verbal: synchrony 74.15%, driver

19.08%, total 93.23%; motor: synchrony 73.75%, driver 18.55%, total 92.30%; gaze: synchrony 76.04%, driver 19.16%, total 95.20%).

A summary of statistical results for the synchrony and driver factors for the initial and the reunion conditions is given in Table 4. No significant difference between initial and reunion conditions was observed for gaze (synchrony: $t_{71} = 0.829, p = 0.41$, driver: $t_{71} = -0.237, p = 0.813$) and verbal behavior (synchrony: $t_{71} = 0.898, p = 0.372$, driver: $t_{71} = 0.103, p = 0.918$). For motor behavior, synchrony increased between the initial and reunion condition ($t_{71} = -2.2, p = 0.031$, Cohen's $d = 0.28$) and the driver index decreased ($t_{71} = 2.236, p = 0.028$, Cohen's $d = 0.27$). Since the driver index tended to negative values, it means that, for the reunion condition, the mother drives the infant, whereas a more symmetrical relationship between mothers and infants is apparent in the initial condition. Changes on the Synchronization axis and Driver axis for motor behavior are represented in Figure 4.

Measurement models with PLS-PM

The relationships between maternal characteristics and dynamic indices of mother-infant interactions were studied by building a PLS-PM model. The theoretical model involved 24 MVs (outer model) loaded on 6 LVs (inner model). The inner model was represented using the following theoretical entities: (1) parental care, (2) parental overprotection, (3) mothers' ER difficulties (4) maternal depression, (5) maternal anxiety and (6) mother-infant synchrony as LVs. LV parental care corresponds to the factors of PBI (i.e. maternal and paternal care), LV parental overprotection refers to the factor of PBI (i.e. maternal and paternal overprotection), mothers' ER difficulties correspond to the factors of DERS, and maternal depression and anxiety refer to the factors of EPDS and STAI, respectively. Finally, mother-infant synchrony corresponds to the dynamic indices of mother-infant interactions in the initial and reunion conditions (i.e. motor, verbal and gaze synchrony and interaction-driver). In addition, the control variables (infant gender and mothers' age) were entered into the model because evidence exists that these variables may impact mother-infant synchrony (Leclère et al., 2014). To test whether these variables were associated with mother-infant synchrony, we examined the moderating effects of mothers' age and maternal education on the relationships between maternal anxiety, maternal depression and mother-infant synchrony, and conducted a nonparametric multi-group analysis between female and male infant.

Outer Model

The first steps consisted of selecting MVs to obtain acceptable unidimensionality of LVs ($DG - rho > 0.7$) and significant loadings of MVs on each LV ($loading > 0.7$). Unidimensionality for parental overprotection was not acceptable (DG-rho < 0.7). Small and non-significant loadings between MVs (maternal overprotection and paternal overprotection) and LV parental overprotection were observed. According to the unidimensional and loadings results, LV parental overprotection was removed. In addition, interaction-driver (gaze, verbal and motor) in the initial and reunion conditions was removed (small and non-significant loading) for mother-infant synchrony. As the distribution of infants’ crying was low, this variable could not be included in the PLS-PM model.

The resulting model comprised 16 MVs loaded on 5 LVs (Figure 5) corresponding to the factors of PBI (i.e. maternal and paternal care), DERS, EPDS, STAI and dynamic indices of mother-infant interactions (i.e. motor, verbal and gaze synchrony in the initial and reunion conditions). The quality of this outer model was acceptable regarding the unidimensionality of all LVs (all DG-rho > 0.70) and cross-loadings. MVs were always more correlated with their respective LVs. Although correlation between maternal anxiety and maternal depression was 0.66, the quality of the model was acceptable regarding multicollinearity (VIF < 0.5) between these variables. Because each causal subsystem sequence of paths is estimated separately in the PLS-PM approach, the standard practice for PLS-PM estimations is that the sample size should be equal to the larger of the following (Tenenhaus et al., 2005): 10 times the number of indicators of the scale with the largest number of manifest indicators. As such, the sample size should be larger than 60 mothers in the current study, suggesting that the PLS-PM analyses were feasible with the present sample. Construct reliability was also calculated using the average variance extracted for each construct (Tenenhaus et al., 2005). Average Variance Extracted for the LVs of parental care (AVE = 0.66, 95% bootstrap CI [0.49,0.76]), mothers' ER difficulties (AVE = 0.59, 95% bootstrap CI [0.53,0.66]), and mother-infant synchrony (AVE = 0.54, 95% bootstrap CI [0.44,0.62]) were relatively large (Chin 1998).

Inner Model

The final PLS-PM model is depicted in Figure 5. It comprised 16 MVs (outer model) loaded on 5 LVs (inner model). The final inner model included parental care, mothers' ER difficulties, depression, maternal anxiety and mother-infant synchrony as LVs. The analysis of the PLS-PM model showed that mother-infant synchrony was mostly measured by motor synchronization, verbal synchronization, and gaze synchronization in the initial and reunion conditions. Results revealed that the path between parental care and mother-infant synchrony was not significant ($\beta = 0.10$, 95% bootstrap CI $[-0.15, 0.35]$). The path results showed that parental care was significantly negatively associated with mothers' ER difficulties ($\beta = -0.28$, 95% bootstrap CI $[-0.49, -0.06]$). The direct path between mothers' ER difficulties and mother-infant synchrony ($\beta = 0.13$, 95% bootstrap CI $[-0.24, 0.49]$) was not significant.

Results show that mothers' ER difficulties were significantly positively associated with maternal depression ($\beta = 0.67$, 95% bootstrap CI $[0.51, 0.80]$) and maternal anxiety ($\beta = 0.72$, 95% bootstrap CI $[0.60, 0.81]$). There was a significant direct effect between maternal anxiety and mother-infant synchrony ($\beta = 0.58$, 95% bootstrap CI $[0.20, 0.94]$) and no significant direct effect between maternal depression and mother-infant synchrony ($\beta = -0.27$, 95% bootstrap CI $[-0.61, 0.06]$). To examine the mediating effects of maternal anxiety and depression between mothers' ER difficulties and mother-infant synchrony, we tested the indirect effects between these LVs (Chin, 2010). The bootstrap method for testing indirect effects indicated that the indirect effect from mothers' ER difficulties through maternal anxiety to mother-infant synchrony was significant ($\beta = 0.42$, 95% bootstrap CI $[0.15, 0.72]$). These results indicated that mothers' ER difficulties affected maternal anxiety, which in turn modulated the motor, verbal and gaze synchrony between mothers and infants in the initial and reunion conditions. The indirect effect from mothers' ER difficulties through maternal depression to mother-infant synchrony was not significant ($\beta = -0.19$, 95% bootstrap CI $[-0.44, 0.04]$).

The moderating effect of mothers' age on the relationships between maternal anxiety, maternal depression and mother-infant synchrony was tested with the product indicator approach (Chin, Marcolin, & Newsted, 2003) for the interaction effects between these latent variables. Moderating effects of mothers’ age were not significant between maternal anxiety and synchrony ($\beta = -0.10, 95\%$ bootstrap CI $[-0.16, 0.36]$), or between maternal depression and mother-infant synchrony ($\beta = -0.16, 95\%$ bootstrap CI $[-0.08, 0.36]$). Moderating effects of maternal education were not significant between maternal anxiety and synchrony ($\beta = -0.06, 95\%$ bootstrap CI $[-0.30, 0.24]$), or between maternal depression and mother-infant synchrony ($\beta = 0.07, 95\%$ bootstrap CI $[-0.26, 0.27]$). A nonparametric multi-group analysis was conducted to test for possible differences between female and male infants using the PLS-MGA method (Hair et al., 2013). Direct path comparisons showed that the effect from maternal anxiety to mother-infant synchrony ($\beta = 0.13, 95\%$ bootstrap CI $[-0.06, 0.98]$) and the effect from maternal depression to mother-infant synchrony ($\beta = 0.53, 95\%$ bootstrap CI $[-0.77, -0.04]$) were not significantly different between female and male infants.

R^2 for the LVs of mothers’ ER difficulties (0.10), mother-infant synchrony (0.31), maternal depression (0.46) and maternal anxiety (0.52), indicating moderate-to-large values (Vinci, Trinchera, & Amato, 2010), and model quality (GoF = 0.51) were satisfactory (Tenenhaus et al., 2005).

Discussion

In the present study, frequential analysis revealed that mothers touched their infants more often in the reunion condition than in the initial condition. Several studies previously reported that maternal touch attenuates infants' physiological stress responses, such as cardiac vagal tone and cortisol reactivity (Feldman, Singer, & Zagoory-Sharon, 2010). Touch behaviors during periods of early maternal deprivation are known to buffer the disruptions to the HPA-axis stress regulating system and the negative effects of stress on infants' physiological reactivity (Weller & Feldman, 2003). Moreover, touching during the maternal still-face paradigm reduced infants' distress, such as crying, self-soothing behaviors and gaze aversion (Jean, Stack, & Fogel, 2009; Stack & Muir, 1992). Several studies reported that high maternal touch in early infant development (5 and 9 weeks) reduced the associations between maternal antenatal anxiety or depression and emotional problems in children at 2.5 years of age (Sharp, Hill, Hellier & Pickles, 2015; Sharp et al., 2012). Parental touch is a central mode of parent-infant interactions, particularly in infants younger than 6 months old (Feber, Feldman, & Makhoul, 2007; Feldman, Gordon, & Zagoory-Sharon, 2011; Mantis et al., 2014), and it facilitates infants' cognitive and neurobehavioral development (Feldman & Eidelman, 2007).

Another main finding of the current study is that motor synchrony between mothers and infants was greater in the reunion condition than in the initial condition. This result reflects the simultaneous synchrony between the levels of activation of mothers' motor behaviors and those of infants' global states (Feldman, 2007; Leclère et al., 2014). Importantly, it confirms and extends previous data (Feldman, Magori-Cohen, et al., 2011; Leclère et al., 2014; Moore & Calkins, 2004) by demonstrating how mothers adapt their motor responses to infants' states of behavioral involvement after a stressful situation induced by maternal separation around the age of 6 months. Motor interaction has been shown to be an influential channel through which mothers and their infants convey emotion and affection, and establish a strong connection (Moszkowski, Stack, & Chiarella, 2009; Stack, 2010; Waters, West, Karnilowicz, Mendes, 2017). Feldman, Gordon, and Zagoory-Sharon (2010) underscored the central role of early experiences of parent-infant synchrony in organizing the structural and functional features of the oxytocinergic system. They showed that parents' and infants' salivary oxytocin levels were correlated when parent-child interaction was characterized by a higher level of touch synchrony in 6-month-old infants. In line with this putative biobehavioral synchrony model (Feldman, 2012; Pratt, Singer, Kanat-Mayon, & Feldman, 2015), the experiences of touch and motor synchrony between mothers and infants during the first months of life could be an example of the critical environmental input required for the affective development of infants. In addition to affectionate touch and physical contact, mother-infant synchrony has been observed very early in the development in the form of vocalizations and gaze orientations (Feldman, 2007; Harrist & Waugh, 2002; Leclère et al., 2014). The present findings show that the simultaneous synchrony between mothers' vocal and visual behaviors and levels of infants' global behavioral involvement did not differ between the initial and reunion conditions. They suggest that mothers' behaviors take place predominantly through tactile and motor modes rather than through visual and vocal ones to regulate the behavioral involvement of infants after a stressful situation during the first 6 months of life. Since several interactive configurations change in frequency between the ages of 3 and 9 months (Feldman, 2007), it is possible that mothers' vocal and visual behaviors may become central modalities for the regulation of infants' behavioral involvement after stressful situations during the second 6 months.

Developmental theorists have long postulated that infants show an ongoing tendency to adapt to the behavioral and emotional patterns of their parents (Ainsworth et al., 1978; Morris et al., 2007; Tronick et al., 1980). Nevertheless, it is not clear from previous studies whether infants' responses lead mothers to behave in a certain way or whether mothers' behaviors lead infants to respond in a particular manner. A key contribution of the present study is the quantification of the influence of mothers' and infants' behaviors in the development of mother-infant synchrony. Based on methods derived from non-linear dynamics, the present findings show that it is particularly mothers' motor behaviors that influence the global levels of infants' behavioral involvement in the reunion condition, and that the opposite is the case in the initial condition. This evidence of the direction of effects between mothers and infants sheds new light on the processes underpinning mother-infant synchrony after a stressful situation. Taken together, these findings reinforce attachment theory by demonstrating the central role played by mothers when they adjust their physical contact with their infants according to the states of behavioral involvement of the latter during the first 6 months of life.

The second aim of the study was to examine how the indicators of the quality of parental care, maternal ER difficulties, maternal anxiety, and depression impact mother-infant synchrony. Our results reveal that the incidence of anxiety symptoms and/or depressive symptoms was not different from that of the general population (Dennis, Falah-Hassani, & Shiri, 2017; Wang, Wu, Anderson, & Florence, 2011). The results show that maternal anxiety mediates the relationships between mothers' ER difficulties and mother-infant synchrony in both the initial and reunion conditions. Thus, if mothers are less able to regulate their emotions, it is likely that they will experience anxiety symptoms and exhibit heightened levels of gaze synchrony, verbal synchrony and motor synchrony in both conditions. Therefore, it seems that high levels of ER difficulties and anxiety symptoms in mothers are associated with a greater synchrony between the levels of infants' global states and the levels of activation of gaze, motor and verbal behaviors in mothers. Previous studies reported that maternal anxiety symptoms predicted higher mother-infant synchrony in the motor modality, greater frequencies of gaze to infant, and lower affect synchrony in face-to-face play between mothers and infants during the first year of life (Beebe et al., 2011; Granat et al., 2017). Our findings expand on those studies by showing the crucial role of mothers' ER difficulties in the development of maternal anxiety and high levels of mother-infant synchrony in various situations (i.e. initial and reunion conditions) and modalities (i.e. gaze, vocal and motor behaviors). These high levels of mother-infant synchrony may reduce the adjustment to both internal and external changes of situation and promote inflexible and invariant affective experiences in infants (Jaffe et al., 2001). High levels of mother-infant synchrony may reflect interpersonal difficulties in mother-infant interactions and appear to be related to intrusive and hypervigilance behaviors in mothers (Beebe et al., 2008; Kaitz & Maytal, 2005).

Importantly, the results also reveal a direct association between a high level of maternal ER difficulties and a high level of maternal depression. Nevertheless, the indirect path indicates that maternal depression does not contribute to greater mother-infant synchrony in the gaze, motor, and vocal modalities. These findings contradict the results of previous studies indicating that depressed mothers show greater synchrony in facial expressions (Lotzin, Schiborr, et al., 2015), less synchrony in the touch modalities (Granat et al., 2017), and either lowered or heightened synchrony in the gaze modalities (Beebe et al., 2008; Lotzin, Romer, et al., 2015). These discrepancies in results could be explained by the severity of mothers' depressive symptoms (Beebe et al., 2012). Our data, along with the results of previous studies, support the idea that high levels of maternal depression and anxiety affect mother-infant synchrony in the gaze, motor and vocal modalities in different ways (Feldman et al., 2009; Granat et al., 2017; Hakanen, et al., 2019). They suggest that maternal depression and maternal anxiety have two separate effects on the development of the mother-infant synchrony during the first months of life.

Another finding is that parental care was not associated with mother-infant synchrony. Nevertheless, a low level of parental care may lead to an increase in mothers' ER difficulties, which might in turn contribute to the emergence of maternal anxiety and depression. These results suggest that the quality of parental care that mothers experience in childhood and adolescence might modulate their ability to monitor, evaluate, and modulate their emotional experiences according to the demands of a specific context or set of goals, but that it might not affect mother-infant synchrony.

The present findings emphasize the importance of the dynamic quantification of mother-infant synchrony as a complement to static descriptions. The methodology proposed herein is based on the encoding of behavior into symbolic sequences and the computation of dynamic indices, as in the field of complex systems. These indices may then be used to investigate the nature and directionality of mother-infant synchrony. Our data suggest that the precursors of mother-infant synchrony may be observed during the first 6 months of life, and that touch behaviors between mothers and infants should be offered in psychoeducation programs. In addition, clinical or psychoeducational interventions for mothers might target not only maternal anxiety but also ER difficulties.

Video feedback (Bakermans-Kranenburg, Van Ijzendoorn, & Juffer, 2003) could also be used to focus on maternal ER difficulties.

The current study has some limitations. First, the results are based on self-report measures for the evaluation of ER difficulties. Replication with other methods of data collection (e.g. observer ratings or physiological and neurobiological indicators of ER) would be useful in future research. From a demographic point of view, the higher percentages of managerial occupations (managerial occupations :30.1% vs 16% in French women) and university degrees (58.2% university degree vs 49% in French women) (INSEE; 2020) in our sample limit the generalizability of our results. Second, the cross-sectional design of this study precludes any causal interpretations. Longitudinal studies employing measures of synchrony at multiple time-points might help to clarify how maternal ER difficulties shape the pathways to maternal anxiety and mother-infant synchrony at different ages. Another shortcoming is the simplification of infants' behavior to a global behavioral involvement and the lack of specific measurements of the stress response, i.e. physiological responses. Further research should be designed specifically to cover the variety of infant behaviors and emotional reactions more thoroughly. A future expansion of this research would be to explore affective synchrony (e.g. vocal affect, facial affect) between mothers and their 6-month-old infants. Indeed, the ability of a mother-infant dyad to go from non-matching to matching affective states may be one of the mechanisms through which dyadic synchrony affects the development of self-regulation in infants. Longitudinal studies using measures of infants’ crying at multiple time-points might help clarify how individual differences in separation distress are associated with maternal and infant reunion behaviors. Finally, fathers should also be studied to examine whether high levels of paternal ER difficulties reinforce the relationships between maternal anxiety and mother-infant synchrony.

TECHNICAL APPENDIX

The recurrence matrix $R(x)$ of x_t (resp. $R(y)$ of y_t) is the matrix with elements:

$$R_{i,j}(x) = \delta_{i,j}$$

where $\delta_{i,j}$ is based on Kronecker delta with $\delta_{i,j} = 1$ if $x_i = x_j$ (resp. $y_i = y_j$) and $\delta_{i,j} = 0$ otherwise. This matrix makes it possible to define a recurrence plot (RP) where the recurrence matrix is represented with black dots for elements equal to 1.

The joint recurrence matrix $J(x, y)$ of x_t and y_t is the matrix with elements:

$$J_{i,j}(x, y) = R_{i,j}(x)R_{i,j}(y) = \delta_{i,j}^{x}\delta_{i,j}^{y}$$

The joint recurrence plot (JRP) is the representation of this matrix with black dots for elements equal to 1.

First, the histogram of the lengths of the diagonal structure of the JRP,

$$H_D(l) = \sum_{i,j=1}^{N} \left(1 - J_{i-1,j-1}\right)\left(1 - J_{i+1,j+1}\right) \prod_{k=0}^{l-1} J_{i+k,j+k}$$

was computed to define the *percent of determinism* D:

$$D = \frac{\sum_{l=2}^{N} l\, H_D(l)}{\sum_{i,j=1}^{N} J_{i,j}}$$

and the *Shannon entropy of the frequency distribution of the diagonal line lengths* S:

$$S = -\sum_{l=2}^{N} p\,(l) ln\big(p(l)\big) \textbf{ with} p(l) = \frac{H_D(l)}{\sum_{l=2}^{N} H_D(l)}$$

The *recurrence rate* RR of joint recurrence plot is defined as:

$$RR = \frac{1}{N^2 - N} \sum_{i,j=1;i\neq j}^{N} J_{i,j}$$

The *mean conditional probabilities of recurrence* M between two sequences x and y is defined as:

$$M(Y \vee X) = \frac{1}{N}\sum_{i=1}^{N} p\,(y_i \vee x_i) = \frac{1}{N}\sum_{i=1}^{N} \frac{\sum_{j=1}^{N} J_{i,j}\,(x,y)}{\sum_{j=1}^{N} R_{i,j}\,(x)}$$

and

$$M(X \vee Y) = \frac{1}{N}\sum_{i=1}^{N} p\,(x_i \vee y_i) = \frac{1}{N}\sum_{i=1}^{N} \frac{\sum_{j=1}^{N} J_{i,j}\,(x,y)}{\sum_{j=1}^{N} R_{i,j}\,(y)}$$

The criterion that detects the asymmetry of the coupling is the following:

- If X drives Y, $M(Y \vee X) < M(X \vee Y)$
- If Y drives X, $M(X \vee Y) < M(Y \vee X)$
- Symmetrical coupling, $M(Y \vee X) = M(X \vee Y)$

References

Abney, D., Warlaumont, A., Kimbrough, O., Wallot, S., & Kello, C. (2017). Multiple coordination patterns in infant and adult vocalizations. *Infancy, 22*(4), 514–539.

Ainsworth, M. S., Blehar, M., Waters, E., & Wall, S. (1978). *The strange situation: Observing patterns of attachment*. Erlbaum: Hillsdale.

Andreas, S., Theisen, P., Mestel, R., Koch, U., & Schulz, H. (2009). Validity of routine clinical DSM-IV diagnoses (axis i/ii) in inpatients with mental disorders. *Psychiatry Research, 170*, 252–255.

Atzil, S., Hendler, T., & Feldman, R. (2011). Specifying the neurobiological basis of human attachment: Brain, hormones, and behavior in synchronous and intrusive mothers. *Neuropsychopharmacology, 36*(13), 2603– 2615.

Bakermans-Kranenburg, M.,VanIjzendoorn,M., & Juffer,F. (2003). Less is more: Meta-analyses of sensitivity and attachment interventions in early childhood. *Psychological Bulletin, 129*(2), 195–215.

Beebe, B., Jaffe, J., Buck, K., Chen, H., Cohen, P., & Feldstein, S. (2008). Six-week postpartum maternal depressive symptoms and 4-month mother-infant self and interactive contingency. *Infant Behavior and Development, 29*, 442–471.

Beebe, B., Lachmann, F., Jaffe, J., Markese, S., Buck, K., Chen, H., ... Feldstein, S. (2012). Maternal postpartum depressive symptoms and 4-month mother–infant interaction. *Psychoanalytic Psychology, 29*(4), 383– 407.

Beebe, B., Messinger, D., Bahrick, L., Margol, Buck, K., & Chen, H. (2016). A systems view of mother-infant face-to-face communication. *Developmental Psychology, 52*(4), 556–571.

Beebe, B., & Steele, M. (2013). How does microanalysis of mother-infant communication inform maternal sensitivity and infant attachment. *Attachment and Human Development, 15*, 583–602.

Beebe, B., Steele, M., Jaffe, J., Buck, K., Chen, H., Cohen, P., ... Feldstein, S. (2011). Maternal anxiety symptoms and mother-infant self and interactive contingency. *Infant Mental Health Journal, 32*(2), 174–206.

Bowlby, J. (1969). *Attachment and loss.* London: Hogarth Press.

Chin, W. (1998). The partial least squares approach to structural equation modeling. *In Modern methods for business research* (pp. 295–358). Mahwah: Erlbaum.

Chin, W. (2010). How to write up and report pls analyses. In E. Vinci, W. Chin, J. Henseler, & H. Wang (Eds.), *Handbook of partial least squares: Concepts, methods and applications in marketing and related fiels* (pp. 655–690). New York: Springer.

Chin, W., Marcolin, B.L., Newsted, P.R. (2003). A partial least squares latent variable modeling approach for measuring interaction effects. Results from a Monte Carlo simulation study and an electronic-mail emotion/adoption study. *Information Systems Research, 14*(2), 189–217.

Coburn, S., Crnic, K., & Ross, E. (2015). Mother-infant dyadic state behavior: Dynamic systems in the context of risk. *Infant and Child Development, 24*, 274–297.

Cortney, A., & Porter, C. (2009). The emergence of mother-infant co-regulation during the first year: Links to infants' developmental status and attachment. *Infant Behavior and Development, 32*, 147–158.

Cox, J., 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.

Cox, I., Holden, J., & Saaovskv, R. (1987). Detection of postnatal depression. Development of the 10-item Edinburgh Postnatal Depression Scale. *British Journal of Psychiatry*, *150*, 782–786.

Dan-Glauser, E., & Scherer, K. (2013). The difficulties in emotion regulation scale: Factors structure and consistency of a french translation. *Swiss Journal of Psychology*, *72*, 5–11.

Dennis, C.L., Falah-Hassani, K., & Shiri, R. (2017). Prevalence of antenatal and postnatal anxiety: Systematic review and meta-analysis. *The British Journal of Psychiatry*, *20*(5), 315–323.

Der Wee, N., van, Beekman, A.T.F., Lamers, F., Cuijpers, P., der Meer, K., van, Ormel, J.,…Smit, J.H. (2011). Two-year course of depressive and anxiety disorders: Results from the Netherlands study of depression and anxiety (NESDA). *Journal Affective Disorders* *133*(1–2), 76–85.

Doba, K., Nandrino, J.L., Lesne, A., Humez, C., & Pezard, L. (2008). Organization of the narrative components in autobiographical speech of anorexic adolescents: A statistical and nonlinear dynamical analysis. *New Ideas in Psychology*, *26*(2), 295–308.

Eisenberg, N., Cumberland, A., & Spinrad, T. (1998). Parental socialization of emotion. *Psychological Inquiry*, *9*(4), 241–273.

Feber, S., Feldman, R., & Makhoul, I. (2007). The development of maternal touch across the first year of life. *Early Human Development*, *84*, 363–370.

Feldman, R. (2003). Infant-mother and infant-father synchrony: The coregulation of positive arousal. *Infant Mental Health Journal, 24*(1), 1–23.

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.

Feldman, R. (2012). Parent-infant synchrony: A biobehavioral model of mutual influences in the formation of affiliative bond. *Monographs of the Society for Research in Child Development, 77,* 42–51.

Feldman, R., & Eidelman, A. (2004). Parent-infant synchrony and the social-emotional development of triplets. *Developmental Psychology, 40*(6), 1133– 1147.

Feldman, R., & Eidelman, A. (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,* 290–302.

Feldman, R., Gordon, I., & Zagoory-Sharon, O. (2010). The cross-generation transmission of oxytocin in humans. *Hormones and behavior, 58,* 669–676.

Feldman, R., Gordon, I., & Zagoory-Sharon, O. (2011). Maternal and paternal plasma, salivary, and urinary oxytoxin and parent-infant synchrony: Considering stress and affiliation components of human bonding. *Psychological Science, 14*(4), 752–761.

Feldman, R., Greenbaum, C., Mayes, L., & Erlich, S. (1997). Change in mother-infant interactive behavior: Relations to change in the mother, the infant and the social context. *Infant Behavior and Development, 20,* 151– 163.

Feldman, R., Greenbaum, C., & Yirmiya, N. (1999). Mother infant affect synchrony as an antecedent of the emergence of self-control. *Developmental Psychology, 35*(5), 223–231.

Feldman, R., Granat, A., Pariente, C., Kanety, H., Kuint, J., & Gilboa-Schechtman, E. (2009). Maternal Depression and Anxiety Across the Postpartum Year and Infant Social Engagement, Fear Regulation, and Stress Reactivity. *Journal of the American Academy of Child & Adolescent Psychiatry*, *48*(9), 919-927.

Feldman, R., Magori-Cohen, R., Galibi, 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.

Feldman, R., Singer, M., & Zagoory-Sharon, O. (2010). Touch attenuates infants' physiological reactivity to stress. *Developmental Science, 13*(2), 271–278.

Field, T. (2010). Postpartum depression effects on early interactions, parenting, and safety practices: A Review. *Infant Behavior and Development, 33*(1), 1–6.

Field, T., Vega-Lahr, N., Scafidi, F., & Goldstein, S. (1986). Effects of maternal unavailability on mother-infant interactions. *Infant Behavior and Development, 9*, 473–478.

Fliess, J. (1981). *Statistical methods for rates and proportions*. New York: Wiley.

Fogel, A. (2011). Theoretical and applied dynamic system research in developmental science. *Child Development Perspectives, 5*(4), 267–272.

Fonagy, P. (2011). The mentalization-focused approach to social development. In F. Bush (Ed.), *Mentalization. theoretical considerations, research findings and clinical implications* (pp. 3–55). New York: Routledge.

Fornell, C., & Bookstein, F. (1982). Two structural equation models: Lisrel and pls applied to consumer exit-voice theory. *Journal of Marketing Research, 19*, 440–452.

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.

Granta, K.A., McMahonb, C., & Austina, M. (2008). Maternal anxiety during the transition to parenthood: A prospective study. *Journal of Affective Disorders, 108,* 101–111.

Gratz, K., & Roemer, L. (2004). Multidimensional assessment of emotion regulation and dysregulation: Development factor structure, and initial validation of the difficulties in emotion regulation scale. *Journal of Psychopathology and Behavioral Assessment, 26*, 41–54.

Gros-Louis, J., West, M., Goldstein, M., & King, A. (2006). Mothers provide differential feedback to infants' prelinguistic sounds. *International Journal of Behavioral Development, 30*(6), 509–516.

Gross, J. (1998). The emerging field of emotion regulation: An integrative review. *Review of General Psychology, 2*, 271–299.

Guedeney, N., & Fermanian, J. (1998). Validation study of the french version of the edinburgh postnatal depression scale (epds): New results about use and psychometric properties. *European Psychiatry, 13*(2), 83–89.

Guo, Y., Leu, S., Barnard, K., Thompson, E., & Spieker, S. (2015). An examination of changes in emotion coregulation among mother and child dyads during the strange situation. *Infant and Child Development, 24*, 256–273.

Hair, J., Hult, G., Ringle, C., & Sarstedt, M. (2013). *A primer on partial least squares structural equation modeling (pls-sem).* Thousand Oaks: Sage.

Hakanen, H., Flykt, M., Sinervä, E., Nolvi, S., Kataja, E. L., Pelto, J., et al (2019). How maternal pre-and postnatal symptoms of depression and anxiety affect early mother-infant interaction? *Journal of Affective Disorders*, 257, 83–90.

Harrist, A., & Waugh, R. (2002). Dyadic synchrony: Its structure and function in children's development. *Developmental Review*, *22*(4), 555–592.

Hill-Soderlund, A., Mills-Koonce, W., Propper, C., Calkins, S., Granger, D., Moore, G., ... Cox, M. (2008). Parasympathetic and sympathetic responses to the strange situation in infants and mothers from avoidant and securely attached dyads. *Developmental Psychobiology*, *50*(4), 361–376

Hollenstein, T. (2007). State space grids: Analyzing dynamics across development. *International Journal of Behavioral Development*, *31*, 384–396.

Hollenstein, T. (2013). *State space grids. detecting dynamics across development*. New York: Springer.

INSEE (2020). *Tableaux de l'économie française*. INSEE reference.

Jaffe, J., Beebe, B., Feldstein, S., Crown, C., & Jasnow, M. (2001). Rhythms of dialogue in infancy. *Monographs of the Society for Research in Child Development*, *66*(2), 1–149.

Jean, A., Stack, D., & Fogel, A. (2009). A longitudinal investigation of maternal touching across the first 6 months of life: Age and context effects. *Infant Behavior and Development*, *32*, 344–349.

Kaitz, M., & Maytal, H. (2005). Interactions between anxious mothers and their infants: An integration of theory and research findings. *Infant Mental Health Journal*, *26*(6), 570–597.

Kim, P., Leckman, J., Mayes, L., Feldman, R., Wang, S., & Swain, J. (2010). The plasiticity of human maternal brain: Longitudinal changes in brain anatomy during the early postpartum period. *Behavioral Neuroscience, 124*(5), 695–700.

Kim, S., Fonagy, P., Koos, O., Dorsett, K., & Strathearn, L. (2014). Maternal oxytocin response predicts mother-to-infant gaze. *Brain Research, 11*(1580), 132–142.

Kochanska, G. (2002). Mutually responsive orientation between mothers and their young children: A context for the early development of conscience. *Current Directions in Psychological Science, 11*(6), 191–195.

Laurent, H., Ablow, J., & Measelle, J. (2012). Taking stress response out of the box: Stability, discontinuity, and temperament effects on HPA and SNS across social stressors in mother-infant dyads. *Developmental Psychology, 48*(1), 35–45.

Leclère, C., Viaux, S., Avril, M., Achard, C., Chetouani, S., Missonnier, S., & Cohen, P. (2014). Why synchrony matters during mother-child interactions: A systematic review. *PLoS One, 9*(12), e113571. https//doi.org/10.1371/journal.pone.0113571.

Lempel, A., & Ziv, J. (1976). On the complexity of finite sequences. *IEEE Transactions on Information Theory, 22*(1), 75–81.

Lesne, A., Blanc, J.-L., & Pezard, L. (2009). Entropy estimation of very short symbolic sequences. *Physical Review E*, 79, 046208. doi:10.1103/PhysRevE.79.046208.

Lotzin, A., Romer, G., Schiborr, J., Noga, B., Schulte-Markwort, M., & Ramsauer, B. (2015). Gaze synchrony between mothers with mood disorders and their infants: Maternal emotion dysregulation matters. PLos One, 10 (12), e0144417.doi:10.1371/journal.pone. 0144417

Lotzin, A., Schiborr, J., Barkmann, C., Romer, G., & Ramsauer, B. (2015). Maternal emotion dysregulation isrelated to heightened mother-infant synchrony of facial affect. *Development and Psychopathology*, *28*(2), 327–339.

Lundy, B. (2002). Paternal socio-psychological factors and infant attachment: The mediating role of synchrony in father-infant interactions. *Infant Mental Health Journal*, *25*(2), 221–236.

Mantis, I., Stack, D., Ng, L., Serbin, L., & Schwartzman, A. (2014). Mutual touch during mother-infant face-to-face interactions: Influences of interaction period and infant birth status. *Infant Behavior and Development, 37*(3), 258–267.

Marwan, N., & Webber, C. L. (2015). Mathematical and computational foundations of recurrence quantification. In C. L. Webber & N. Marwan (Eds.), *Recurrence quantification analysis. theory and best practices.* (pp. 33–44). New York: Springer.

Messinger, D., Mahoor, M., Chow, S., & Cohn, J. (2009). Automoted measurement of facial expression in infant-mother interaction: A pilot study. *Infancy*, *14*(3), 285–305.

Mikulincer, M., Shaver, P., & Pereg, D. (2003). Attachment theory and affect regulation: The dynamics, development, and cognitive consequences of attachment related strategies. *Motivation and Emotion*, *27*(2), 77– 102.

Mohr, S., Preisig, M., Fenton, B., & Ferrero, F. (1999). Validation of the french version of the parental bonding instrument in adults. *Personality and Individual Differences*, *26*(6), 1065–1074.

Montague, D., & Walkers-Andrews, A. (2002). Mothers, fathers, and infants: The role of person familiarity and parental involvement in infants' perception of emotion expressions. *Child Development*, *73*(5), 1339–1352.

Moore, G., & Calkins, S. (2004). Infants' vagal regulation in the still-face paradigm is related to dyadic coordination of mother-infant interaction. *Developmental Psychology*, *40*, 1068–1080.

Morris, A., Silk, J., Steinberg, L., Myers, S., & Robinson, L. (2007). The role of the family context in the development of emotion regulation. *Social Development*, *16*(2), 361–388.

Moszkowski, R., Stack, D., & Chiarella, S. (2009). Infant touch with gaze and affective behaviors during mother-infant still-face interactions: Co-occurence and function of touch. *Infant Behavior and Development*, *32*, 392–403.

Murray, L., De Rosnay, M., Pearson, J., Bergeron, C., Schofield, E., Royal-Lawson, M., & Cooper, P. (2008). Intergenerational transmission of social anxiety: The role of social referencing processes in infancy. *Child and Development, 79*, 1049–1064.

Nicol-Harper, R., Harvey, A., & Stein, A. (2007). Interactions between mothers and infants: Impact of maternal anxiety. *Infant Behavior and Development, 30*, 161– 167.

Parker, G., Tupling, H., & Brown, L. (1979). A parental bonding instrument. *British Journal of Medical Psychology, 52*(1-10).

Pezard, L., Doba, K., Lesne, A., & Nandrino, J. (2017). Quantifying the dynamics of emotional expressions in family therapy of patients with anorexia nervosa. *Psychiatry Research, 253*, 49–57.

Pratt, M., Singer, M., Kanat-Maymon, Y., & Feldman, R. (2015). Infant negative reactivity defines the effects of parent–child synchrony on physiological and behavioural regulation of social stress. *Development and Psychopathology, 27*, 1191–1204.

Provenzi, L., Casini, E., DeSimone, P., Reni, G., Borgatti, R., & Montirosso, R. (2015). Mother-infant dyadic reparation and individual differences in vagal tone affect 4-month-old infants' social stress regulation. *Journal of Experimental Child Psychology, 140*, 158–170.

Righetti-Veltema, M., Conne-Perreard, E., Bousquet, A., & Manzano, J. (2002). Postpartum depression and the mother–infant relationship at 3 months old. *Journal of Affective Disorders, 70*, 291–306.

Ringle, C., Wende, S., & Will, A. (2010). Finite mixture partial least squares analysis: Methodology and numerical examples. In E. Vinci, W. Chin, J. Henseler, & H. Wang (Eds.), *Handbook of partial least squares: Concepts, methods and applications in marketing and related fiels* (Vol. 2, pp. 195–218). New York: Springer.

Romano, M., Thiel, M., Kurths, J., & von Bloh, W. (2004). Multivariate recurrence plots. *Physical Letters A, 330*, 214– 223.

Russel, I., Belsky, J., & Von Eye, A. (1989). Origins of infant-mother attachment: An examination of interactional synchrony during the infant's first year. *Development and Psychopathology, 25*(1), 12–21.

Sanchez, G. (2013). *Pls path modeling with r*. Berkeley: Trowchez.

Sharp, H., Hill, J., Hellier, J., & Pickles, A. (2015). Maternal antenatal anxiety, postnatal stroking and emotional problems in children: outcomes predicted from pre- and postnatal programming hypotheses. *Psychological Medicine, 45*, 269–283.

Sharp H, Pickles A, Meaney M, Marshall K, Tibu F, Hill J (2012). Frequency of infant stroking reported by mothers moderates the effect of prenatal depression on infant behavioural and physiological outcomes. *PLOS ONE, 7*, e45446.

Smith, L., & Thelen, E. (2003). Development as a dynamic system. *Trends in Cognitive Sciences, 7*(8), 343–348.

Spielberger, C. (1983). *Manual for the state-trait anxiety inventory (STAI)*. Palo Alto: Consulting Psychologists Press.

Sravish, A., Tronick, E., Hollenstein, T., & Beeghly, M. (2013). Dyadic flexibility during the face-to-face still face paradigm: A dynamic systems analysis of its temporal organization. *Infant Behavior and Development*, *36*, 432–437.

Stack, D. (2010). Touch and physical contact during infancy: Discovering the richness of the forgotten sens. In G. Bremner & T. Wachs (Eds.), *The wileyblack well handbook of infant* (Vol. 1, pp. 532–567). Blackwell Publishing Ltd.

Stack, D., & Muir, D. (1992). Adult tactile stimulation during face-to-face interactions modulates five-month olds' affect and attention. *Child and Development, 63*, 1509–1525.

Stacks, A., Muzik, M., Wong, K., Beeghly, M., Huth-Bocks, A., Irwin, J., & Rosenblum, K. (2014). Maternal reflective functioning among mothers with childhood maltreatment histories: Links to sensitive parenting and infant attachment security. *Attachment and Human Development, 16*(5), 515–533.

Stam, C. & van Dijk, B. (2002). Synchronization likelihood: An unbiased measure of generalized synchronization in multivariate data sets. *Physica D, 163*, 236–251.

Stein, A., Craske, M., Lehtonen, A., Harvey, A., Savage McGlynn, E., Davies, B.,... Counsell, N.(2012). Maternal cognitions and mother-infant interaction in postnatal depression and generalized anxiety disorders. *Journal of Abnormal Psychology, 121*(4), 795–809.

Tenenhaus, M., Vinci, E., Chatelin, Y., & Lauro, C. (2005). Pls path modeling. *Computational Statistics and Data Analysis, 48*(1), 159–205.

Tronick, E., Als, H., & Brazelton, B. (1980). Monodic phases: A structural descriptive analysis of infantmother face to face interaction. *Merrill-Palmer Quarterly of Behavior and Development, 26*(1), 3–24.

Tschacher, W., Rees, G., & Ramseyer, F. (2014). Nonverbal synchrony and affect in dyadic interactions. *Frontiers in Psychology, 5*, 1323.

Van der Giessen, D., Branje, S., Frijns, T., & Meeus, W. (2012). Dyadic variability in mother-adolescent interactions Developmental trajectories and associations with psychosocial functioning. *Journal of Youth Adolescence*, *42*, 96–108.

Vinci, E., Trinchera, L., & Amato, S. (2010). Pls path modeling: From foundations to recent developments and open issues for model assessment and improvement. In E. Vinci, W. Chin, J. Henseler, & H. Wang (Eds.), *Handbook of partial least squares: Concepts, methods and applications in marketing and related fiels* (pp. 47–82). Springer.

Wang, L., Wu, T., Anderson, J., & Florence, J. (2011). Prevalence and risk factors of maternal depression during the first three years of child rearing. *Journal of Women's Health*, *20*(5):711–8.

Waters, S., West, T., Karnilowicz, H., & Mendes, W. (2017). Affect contagion between mothers and infants: Examining valence and touch. *Journal of Experimental Psychology: General*, *146*(7), 1043–1051.

Weinberg, M., Tronick, E., Cohn, J., & Olson, K. (1999). Gender differences in emotional expressivity and self-regulation during early infancy. *Developmental Psychology, 35*, 175–188.

Weller, A., & Feldman, R. (2003). Emotion regulation and touch in infants: The role of cholecystokinin and opoids. *Peptides*, *24*, 779–780.

Zlochower, A., & Cohn, J. (1996). Vocal timing in faceto-face interaction of clinically depressed and nondepressed mothers and their 4-month-old infants. *Infant Behavior and Development, 19,* 371–374.

Zou, Y., Romano, M.C., Thiel,M., & Kurths, J. (2015).Identifying coupling directions by recurrences. In C. L. Webber & N. Marwan (Eds.), *Recurrence quantification analysis. theory and best practices.* (pp. 65–100). New York: Springer.

Table 1. Recoding of infant behavior to account for global behavioral involvement

Motor behaviors	Vocal behaviors	Gaze behaviors	Global behavioral involvement
No movement	Silence	Gaze away	Low
No movement	Silence	Gaze toward mother	Low
No movement	Vocalization	Gaze away	Low
No movement	Vocalization	Gaze toward mother	Moderate
No movement	Negative	Gaze away	Low
No movement	Negative	Gaze toward mother	Moderate
Movement	Silence	Gaze away	Low
Movement	Silence	Gaze toward mother	Moderate
Movement	Vocalization	Gaze away	Moderate
Movement	Vocalization	Gaze toward mother	High
Movement	Negative	Gaze away	Moderate
Movement	Negative	Gaze toward mother	High

Table 2. Descriptive statistics of maternal characteristics

Maternal Characteristics		Mean	SD	Min.	Max.
DERS	Nonacceptance	8.43	3.57	3	18
	Goals	9.08	3.32	3	16
	Impulsivity	6.14	3	3	15
	Awareness	7.72	3.53	3	18
	Strategies	7.26	3.18	3	18
	Clarity	7.08	2.99	3	15
EPDS	Depression	5.97	5.39	0	21
STAI	Anxiety	36.6	9.92	20	57
PBI	Maternal Care	27.65	7.37	7	36
	Paternal Care	23.81	8.87	3	36
	Maternal Overprotection	12.4	6.74	2	32
	Paternal Overprotection	10.96	6.45	0	31

Note. DERS: Difficulties of Emotion Regulation Scale; EPDS: Edinburgh Postnatal Depression Scale; STAI: State-Trait Anxiety Inventory; PBI: Parental Bonding Inventory.

Table 3. Infant's level of behavioral involvement and maternal behaviors in initial and reunion conditions scored by modified version of Ainsworth's Strange Situation

	Initial condition				Reunion Condition			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Infant								
Low level	0.59	0.19	0.12	0.94	0.56	0.19	0.03	0.94
Moderate level	0.31	0.12	0.06	0.57	0.33	0.12	0.05	0.61
High level	0.09	0.09	0	0.42	0.10	0.11	0	0.54
Mothers' verbal behaviors								
Silence	0.30	0.20	0.02	0.99	0.31	0.20	0.02	0.99
Reflective verbalization	0.14	0.17	0	0.77	0.13	0.16	0	0.82
Vocalization/verbalization	0.54	0.24	0	0.95	0.54	0.23	0	0.93
Mothers' motor behaviors								
No movement	0.37	0.24	0.01	0.95	0.30	0.24	0	0.93
Touch	0.44	0.25	0.01	0.95	0.55	0.27	0.02	0.99
Movement without physical contact	0.17	0.14	0	0.68	0.14	0.13	0	0.49
Mothers' gaze behaviors								
Gaze away	0.12	0.09	0	0.47	0.13	0.11	0	0.55
Gaze toward infant	0.87	0.09	0.53	1	0.86	0.11	0.44	1

Table 4. Values of two main factors obtained using Principal Component Analysis of dynamical indices

	Initial Condition				Reunion Condition			
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.
Verbal								
Synchrony	0.10	2.15	-2.94	6.28	-0.10	2.09	-3.26	5.97
Driver	0.005	1.1	-2.9	2.19	-0.005	1.06	-2.6	2.19
Motor								
Synchrony	-0.26	2.02	-3.42	5.41	0.26	2.18	-3.35	6.02
Driver	0.15	1.06	-2.32	2.65	-0.15	1.04	-2.21	2.69
Gaze								
Synchrony	0.09	2.24	-3.26	6.84	-0.09	2.05	-3.78	5.99
Driver	0.01	1.09	-1.94	3.44	-0.01	1.06	-2.0	3.08