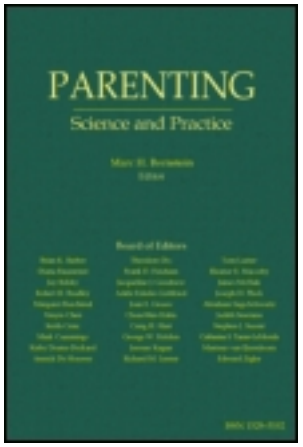

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Bio-behavioral Synchrony: A Model for Integrating Biological and Microsocial Behavioral Processes in the Study of Parenting

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Bio-behavioral Synchrony: A Model for Integrating Biological and Microsocial Behavioral Processes in the Study of Parenting

Ruth Feldman

SYNOPSIS

A behavior-based neurobiological approach to the study of normative and high-risk parenting is presented and suggests that human affiliations are formed on the basis of *bio-behavioral synchrony* between the online physiological and behavioral processes of attachment partners. Theoretical foundations for the model ranging from neuroscience to phenomenology are discussed, and the unique expressions of micro-level synchrony are detailed across development. Specific disruptions to parameters of synchrony in various high-risk conditions and examples for time-locked processes of biology and behavior are described. Finally, implications of the findings to the implementation of specific interventions to mothers, fathers, and families are highlighted.

INTRODUCTION

In searching for the most useful "tricks of the trade" of parenting research, the first step, as suggested by William James (1956), is a good theory. And a good theory, according to James' brilliant metaphor of "alive electrical wires" versus "dead electrical wires" (p. 2), is one which connects and resonates. It connects multiple dimensions into a unified model, lights-up a unique viewpoint, and resonates meaning in the mind of the reader.

In this review, I present our theory of *bio-behavior synchrony* as one meaningful viewpoint for the study of affiliative bonds in general and parenting in particular (Feldman, 2007a, 2012). Affiliative bonds, defined as *selective* and *enduring* attachments, are formed on the basis of multiple genetic, horomonal, brain, autonomic, epigenetic, behavioral, and—in humans—mental processes that coordinate to establish the parent–infant bond, which serves as the central vehicle for evolutionary adaptation and has been the focus of inquiry in fields ranging from neuroscience to epistemology. I describe the conceptual frameworks that contributed to its definition, address its utility in integrating multiple biological and psychological components into unified model, and argue that such perspective may provide a useful angle to study typical and high-risk parenting. Following, I bring examples for bio-behavioral synchrony between the physiology and behavior of attachment partners in three physiological systems: autonomic reactivity, affiliative hormones, and brain activations. The central feature of the model, the temporal component

through which discrete biological and behavioral events synchronize into a unified experience, is highlighted. Through the lens of this theory, I try to address three important issues in the study of parenting: what is optimal parenting, what is culture specific, and what are the potential avenues for intervention.

A THEORY OF BIO-BEHAVIOR SYNCHRONY BASED ON THREE MAIN APPROACHES

The first approach is the writings of the early Ethologists (Lorenz, 1950; Timbergen, 1963), which provided the basis for Bowlby's (1969) seminal formulations on the attachment system, and for more recent evolutionary-based approaches to bond-formation. Such evolutionary-based research, mostly in animal models, has demonstrated that during periods of bond formation a major bio-behavioral reorganization occurs in the parents' physiology and behavior that leads to heightened sensitivity to infant cues, prepares parents to the difficult task of infant care, and gives rise to the expression of the species-specific behaviors critical for infant growth and adaptation to the eco-social niche. Over time and repeated experience, parent and child become sensitized to the physiological and behavioral cues of the partner, particularly to its intensity, rhythms, and temporal qualities, leading to the formation of the selective and enduring attachment bond (Fleming, O'Day, & Kraemer, 1999). Such coordination between parent and infant social behavior, parent and infant ongoing physiology, and the physiology of one and the behavior of the other, charts the four-channel matrix of *parent–infant bio-behavioral synchrony*. Infants must experience such synchrony during the critical postpartum period and this experience supports neurobehavioral maturation, shapes the ability to handle stress, and organizes the child's lifetime capacity for social affiliation and the ultimate ability to provide adequate parenting in the next generation (Meaney, 2010).

According to ethological notions, the study of affiliative bonds should begin with meticulous documentation of behaviors that emerge or intensify during bond formation. Adapting this viewpoint, Bowlby shifted from the broad theoretical outlook of his psychoanalytic training to the concrete assessment of maternal and infant behavior in their natural ecology during daily routines, moments of high arousal, and episodes of maternal separation. By doing so, Bowlby advocated a bottom-up approach that is based on micro-level observations of maternal behavior, thereby revolutionizing thinking in the study of human relatedness. According to this ethological-based model, behavior is not just central to the study of parenting but that parenting is behavior—or repeatedly executed sets of specific behaviors of varying goals, rhythms, intensities, frequencies, and durations. Although parental behavior is certainly shaped by the parent's physiology and mental state, the parent's actual behavior is the only phenomenon directly available to the infant. For this reason, it is only through the interface of synchronous behavioral exchanges that the parent's physiological systems and mental internalizations can impact the infant's biological organization and emerging consciousness. Our approach, therefore, is behavior-based and emphasizes how discrete micro-level behaviors organize to form the dyad-specific bond.

From an evolutionary perspective, the origins of reciprocity have been controversial since Darwin first published his seminal work, as reciprocity seems to contradict the biological drive to control environmental resources and prefer one's progeny. Reciprocity

was theorized to evolve in ecological niches that included large groups of non-kin members who needed to form collaborative societies, and thus, reciprocity is considered the cornerstone of adaptive social life (Hauser, McAuliffe, & Blake, 2009). It has been long postulated that the evolution of mammals implied that mammalian young receive their training for social reciprocity not within the large group—as is the case, for instance, with the social insects—but in the context of the nursing dyad (Rosenblatt, 1965; Schneirla, 1946; Wheeler, 1928). The experience of parent–infant reciprocity, therefore, is the central context in which human infants can learn to become collaborative members of society, develop empathy, and practice intimacy.

The second perspective supporting our approach is Edelman's (2004) theory of neural Darwinism. According to this model, which shaped current thought in neuroscience, synchrony is the mechanism that underlies consciousness and enables the brain to form unitary events out of simultaneous activity in discrete brain regions without postulating a "central organizer" or resorting to the Cartesian rift between body and mind. Our conscious experiences are unitary events assembled of discrete components that synchronize in time, are "situated" within the present moment, and are "in relationship" with parameters of the context. The centrality of time and synchrony for the organization of brain activity is echoed in Llineas' words (2001, p. 120): "timeness is consciousness" and complements the bottom-up ethological approach to bonding.

The third perspective draws from phenomenological philosophy, particularly the work of Husserl (1977), which suggested that any "objective" perception of reality is composed of the relations between observer and phenomenon, thus highlighting the inherently relational nature of the human mind; the writing of Bergson (1907), which address the "present moment" and its experiential attributes; and the formulations of Merleau-Ponty (1945), emphasizing the embededness of the human mind in concrete time-locked sensory experiences. Overall, these theories highlight the need for a behavioral, time-based focus in the study of parenting as central to the formation of affiliative bonds, through which children grow, adapt, create, and become collaborative members of society.

POST-PARTUM PARENTAL BEHAVIOR AND THE DEVELOPMENT OF SYNCHRONY ACROSS THE LIFESPAN

Maternal behavior appears immediately after birth and is triggered by complex hormonal priming and brain activations. In humans, the maternal behavioral repertoire includes gaze at infant face and body, "motherese" vocalizations, the expression of positive affect, and affectionate touch, the human parallel to "licking-and-grooming" in other mammals. Furthermore, as soon as the infant is born human mothers begin to coordinate their social behaviors with the infant's state. Newborn can maintain alert-scanning states for about 7% of the time; yet mothers provide nearly 70% of their maternal behavior during these few alert episodes (Feldman & Eidelman, 2007). These maternal behaviors facilitate the development of parent–infant synchrony at three months and predict children's cognitive and social-emotional competencies across early childhood (Feldman & Eidelman, 2009a). Maternal behaviors are also associated with the activation of brain networks, affiliative hormones, and autonomic response, connecting mother and newborn's physiology and behavior.

During the third month of life, infants become active participants in the social world and synchrony between the personal patterns of mother and infant's gaze, affect, vocal, and touch cohere into repetitive-rhythmic matched patterns (Feldman, 2007a). At this age, mothers and fathers co-create distinct types of synchrony with the infant; maternal synchrony is more cyclic and social oriented while paternal synchrony orients toward the environment and encourages exploration (Feldman, 2003). Each form of synchrony bears important implications for the development of children's social competence and dialogical skills across childhood and up to adolescence.

Between three and nine months the experience of affective matching is critical for infant growth and predicts children's prosocial and moral orientation, self-regulation, attachment security, and social competence in research spanning from infancy to adolescence (Feldman, 2007a). During the second six months, with the emergence of intentionality, infants also begin to follow the mother's affective patterns and interactions become more truly reciprocal (Feldman, Greenbaum, & Yirmiya, 1999). Finally, with the development of symbolic thought and language, interactions between parents and children develop along two parallel lines; one nonverbal underlying line maintains the dyad-specific patterns of affect synchrony, and the second involves verbal coordination between the child's symbolic expression and the parent's reciprocal expansion and both are guided by the same temporal pattern (Feldman, 2007b). From that stage onward, interactions between attachment partners maintain both the nonverbal synchrony of gaze, vocal quality, and facial expressions and the verbal synchrony between levels of empathy and self-disclosure. We found affect synchrony in the interactions of parents and adolescents, close friends, and romantic partners, and the experience of synchrony in each relationship was similarly supported by autonomic reactivity, affiliative hormones, and brain activation, indicating that the biological basis of synchrony continues throughout life (Feldman, 2012). Furthermore, longitudinal studies suggest a transfer from synchronous experiences within the parent–child relationship and synchronous relationship in other affiliative bonds throughout life (Feldman, 2012).

The developmental line of synchrony is sensitive to both cultural differences and high-risk conditions. Matched interactions that resonate with the infant's social behavior and internal state, do not over-stimulate, and provide children the experience of containment are universally more optimal. However, research showed that, whereas parents in industrialized societies provide more active parenting behavior, present objects, and use active forms of touch, parents in traditional societies maintain closer physical proximity and engage in less active behavior. We found that higher levels of physical proximity among Palestinian parents and affect synchrony among Israeli parents at five months each predicted preschoolers' self-regulation in kindergarten in the respective culture, yet levels of self regulation were comparable, suggesting that culture-typical patterns of synchrony chart unique pathways to the attainment of developmental milestones (Feldman, Masalha, & Alony, 2006).

High-risk parenting is related to either excessive maternal behavior, which overrides the infant's signals, or the deprivation of maternal behavior, which minimizes the opportunity for a synchronous exchange. Excessive maternal behavior is typically associated with maternal anxiety, whereas minimal mothering with depression, and both alter the temporal pattern of early interactions (Feldman et al., 2009). Clinically depressed mothers take five times longer than controls to reach the first episode of gaze synchrony and the intervals between episodes of joint engagement are seven times longer, charting

a temporal pattern of inactivity, flat affect, minimal contact, and few social episodes. By contrast, maternal anxiety is associated with a pace that is three and a half times quicker than the typical one and with increased mys-synchrony—moments when infant signals need for rest and mothers provides high-arousal parenting. Following a group of postnatally depressed mothers and their infants from birth to six years, we found that such patterns tended to persist over time. Children of depressed mothers showed less social behavior, expressed withdrawal, declined physical proximity, and engaged in minimal coordination of nonverbal and verbal behavior. These children also showed reduced symbolic complexity and their play was marked by repetitive functional activities. Finally, although children of postnatally depressed mothers were at significantly greater risk for developing psychiatric disorder upon school entry, fathering served as resilience factor. Consistent with family system perspectives and our research in infancy (Feldman, 2007c), more involved and synchronous fathering at six years moderated the effects of maternal depression on child psychopathology.

Infant-related risk conditions, such as prematurity, are also associated disruptions to synchrony and with over-stimulatory parenting. Premature infants send unclear social messages, making interactions more anxiety-provoking for mothers who turn to intrusive tactics, particularly when infants suffer intrauterine growth retardation in addition to prematurity (Feldman & Eidelman, 2006). Our research on the development of premature infants spanned from birth to 10 years and long-term consistencies were found in the mother's micro-level behavior and her adaptation to the child's developmental level and social cues. Infants were observed at birth, prior to discharge, at 3, 6, 12, and 24 months corrected age, and at 5 and 10 years. At each age, measures of mother–infant relatedness and of child self-regulation were collected. We found that at each age mother–child synchrony predicted children's self-regulation at the next stage, indicating that age-appropriate matched interactions promote the next stage of growth, particularly in the domain of emotion regulation.

Research assessing infant–mother and infant–father synchrony in triplets found that, overall, parents provided similar amounts of parenting behavior compared to singletons and twins, but such behaviors were not synchronous with the infant's communications. Synchrony depends on the *exclusivity* component of attachment and requires familiarity with the partner's signals. The immense burden of raising three infants simultaneously taxes the parents' capacity to adapt to moment-by-moment signals of each child (Feldman & Eidelman, 2004). Yet, unlike maternal depression, the reduced synchrony, which was linked to delayed cognitive and social-emotional development across the first two years, improved by five years and most triplets showed a developmental catch-up. These findings highlight the utility of the micro-level approach for defining early indices of growth trajectories that can serve as early markers of developmental risk.

Children with autism spectrum disorders (ASD) are another group of children at high-risk for social development. Infant siblings of autistic children, who are genetically more susceptible, exhibited less mother–infant synchrony already at four months (Yirmiya et al., 2006). Currently, we are studying parent–child synchrony among high-functioning autistic preschoolers in relation to physiological and emotion regulatory capacity. We found lower levels of reciprocal interactions between ASD children and both parents, but differences were mainly related to the child's minimal social engagement, which impaired the dyadic co-regulation. The degree of parent–infant synchrony was linked with more adequate emotion regulation strategies during the elicitation of both positive and negative emotions, indicating that even among children with marked

disturbances in social relatedness, synchronous experiences, albeit limited, promote more optimal regulatory skills.

Finally, a large cohort of Israeli and Palestinian children aged one and a half to five who live in war zones and are exposed to repeated war-related trauma were observed to assess the effects of contextual risk on the development of synchrony. We found that among war-exposed children who developed post traumatic stress disorder, mother–child reciprocity was significantly lower than among those exposed to the same wartime experiences who did not develop the disorder (Feldman & Vengrober, 2011).

SYNCHRONY IN BIOLOGICAL PROCESSES IN RELATION TO INTERACTIVE SYNCHRONY

The coordination between ongoing physiological processes and moment-by-moment behavioral concordance is the hallmark of the bio-behavioral synchrony process and may provide one avenue to address the major controversy in the neuroscience of consciousness—the formation of a "brain-based epistemology" that links the subjective world with objective markers of neural activity (Edelman, 2004). The following sections, which describe the time-locked interrelatedness between the ongoing physiological and behavioral response of attachment partners, demonstrate that in humans, as in other mammals, infants' affiliation-related physiological systems are open to social influences and their organized functioning consolidates by means of synchronous interactions within attachment relationships.

Autonomic Reactivity and the Synchrony of Heart Rhythms

The autonomic nervous system, with its sympathetic and parasympathetic branches, provides online support for ongoing social processes (Porges, 2003). Cardiac vagal tone is an index of parasympathetic regulatory activity that quantifies the respiratory cycle in heart rhythms and serves as a marker of emotion regulation. Overall, we and others found that mother and child's vagal tone is interrelated (Feldman, Singer, & Zagoory, 2010), suggesting that the degree of parasympathetic control during social engagement is shaped by co-regulatory processes. Mothers' and fathers' sympathetic reactivity is similarly impacted by attachment processes. First-time mothers and fathers engaged in a conflict discussion while cardiac output was collected online from both parents. The appearance of own-infant picture on a screen half-way into the interaction (compared to neutral picture) altered sympathetic reactivity in gender-specific ways. Infant cues decreased maternal sympathetic reactivity while increasing fathers' sympathetic arousal consistent with notions on the co-evolution of mothering and fathering and their neurobiological underpinnings (Mosek-Eilon, Hirschberger, Kanat-Maymon, & Feldman, 2012).

One mechanism by which the social context regulates the infant's online physiology is maternal behavior. In mammals, both the mother's physical proximity exerts a regulatory impact on the infant's physiological systems (Hofer, 1995), and active maternal behavior, such as licking-and-grooming, shapes Oxytocin-dependent affiliation networks and stress management systems (Meaney, 2010). Both mechanisms, however, rely on tactile contact. Human synchrony, which includes the modalities of gaze, affect, and

vocalizations, is thought to be sufficient to induce tangible changes in the infant's ongoing physiological response. To test the coordination between biological synchrony—synchrony between mother and infant's heart rhythms—and interactive synchrony, mothers and their three-month-old infants were videotaped during face-to-face interactions while cardiac output was measured from mother and child. Using mathematical modeling, we demonstrated that during social interactions mother and infant's heart rhythms synchronize within lags of less than one second. Moreover, during episodes of vocal or affective synchrony, and particularly during the rare moments when mothers and infants engaged in gaze, vocal, and affect synchrony simultaneously, the level of heart-rate coupling was significantly tighter compared to moments of non-synchrony, suggesting that biological synchrony shows online sensitivity to the partners' ongoing behavior (Feldman, Magori-Cohen, Galili, Singer, & Louzoun, 2011). These findings provide a prototypical example for the process of bio-behavioral synchrony. Through moments of interactive synchrony mothers increase the degree of biological fittedness, facilitating bond formation but also providing "external regulation" to the infant's immature systems. Thus, while the findings demonstrate consistency between humans and other mammals, they also point to the uniqueness of the human synchronous process that relies on nonverbal coordination of affective cues. Consistent with our recent findings that autonomic reactivity is altered during other periods of bond formation, such as falling in love (Schneiderman, Zilberstain-Kra, Leckman, & Feldman, 2011), it appears that the human autonomic nervous system remains open to influences by affiliation processes throughout life. Possibly, the well-known positive effects of attachment bonds on the individual's well-being and health may relate to the positive impact of close social contacts on organizing the individual's affiliation-related physiology (Taylor et al., 2000).

Endocrine Synchrony between Parent and Child and Among Couples

Processes of "endocrine fit" between hormonal levels of mother and child indicate that the partners' hormonal reactivity undergo processes of attunement through the interplay of genetic dispositions, prenatal programming, and postnatal care. Fit in hormonal levels has been typically observed in cortisol reactivity, in both baseline and reactivity assessment. For instance, we found that cortisol levels in depressed and anxious mothers and their infants were interrelated and were higher than controls (Feldman et al., 2009). Following the still-face paradigm, concordance was found between mothers and six-month olds' cortisol at baseline and reactivity, which correlated with greater interactive mys-synchrony (Feldman, Gordon, & Zagoory-Sharon, 2010).

In addition to stress hormones, we were interested in assessing "endocrine fit" in affiliation hormones, particularly Oxytocin. Oxytocin (OT), a nonapeptide involved in uterine contraction during labor and milk let down, has been implicated in a range of social related processes, including parenting, trust, empathy, social cognition, and sexual behavior. Disruptions to the OT system were described in conditions involving disordered social functioning, including autism, depression, social anxiety, and schizophrenia.

In multiple studies, we examined the involvement of peripheral and central OT in affiliative processes throughout life. In each study, we found evidence for bio-behavioral synchrony. In the first study, assessing plasma OT longitudinally in women during the first trimester of pregnancy, third trimester, and first postpartum month, high degree of

individual stability in OT was found and levels at first trimester predicted the expression of maternal behavior and its coordination with infant state (Feldman, Weller, Zagoory-Sharon, & Levine, 2007). In the next experiment, we examined whether plasma OT levels in fathers differ from those observed in mothers. Among 160 first-time mothers and fathers (80 couples) correlations were found between maternal and paternal OT at both the first postpartum month and at 6 months postpartum. Possibly, through long-term affiliative processes, including falling in love, marriage, pregnancy, and child-drearing, levels of OT between partners become synchronized, again attesting to the process of bio-behavioral synchrony between romantic partners. Furthermore, OT levels in mother and fathers were related to the parent-specific behavioral repertoire: to the affectionate-type parenting in mothers, but to the stimulatory-type parenting in fathers, including stimulatory touch, encouragement of exploration, and high positive arousal (Gordon, Zagoory-Sharon, Leckman, & Feldman, 2010a). Triadic synchrony between mother, father, and child during social interactions at 6 months was similarly predicted by maternal and paternal OT, pointing to the links between biological synchrony in the parents' hormones and their behavioral synchrony during family interactions (Gordon, Zagoory-Sharon, Leckman, & Feldman, 2010b). Finally, we examined the cross-generation transmission of OT from parents to infants. Mothers and fathers (not couples) and their 4- to 6-month-old infants participated in a 15-min play-and-touch interaction. Salivary OT was collected from parent and child before and after interactions and sessions were coded for synchrony. Correlations were found between the OT levels of parent and child at both the baseline and reactivity assessments, suggesting cross-generation transmission in the neurobiology of affiliation. Moreover, the hormonal concordance was moderated by interactive synchrony. Similar to the high licking-and-grooming of rat mothers whose high OT receptor densities passed to their children through mechanisms of maternal behavior, high levels of affect synchrony were related to higher parental and infant OT and such hormonal concordance was moderated by the close match in their social behavior (Feldman et al., 2010).

Synchrony and Brain Activations

Animal studies and human imaging research has described a neural network that is central to the expression of parenting and supports the development of parenting behavior. In two studies we examined links between synchrony and the parental brain by observing parents' brain response to video vignettes of their infant.

In the first, mother–infant interactions were videotaped at home and micro-coded for synchrony and intrusiveness. We selected 14 synchronous and 14 intrusive mothers who underwent brain scanning while observing their infants. Consistent with the animal literature, whole brain analysis revealed two limbic areas that were activated to own-infant stimuli; the left nucleus accumans (NAcc), part of the dopamine pathway implicated in reward, and the right amygdala, which is associated with vigilance to the affective features of a stimulus, particularly to its threat components. As expected, NAcc activations were higher among synchronous mothers, whereas amygdala activations were higher in the intrusive mothers. Functional connectivity analysis with left NAcc and right amygdala as seed regions revealed an interesting pattern. Cortical activations in the social brain, including the superior temporal sulcus (STS), inferior frontal gyrus, insula, pre supplementary motor areas, parietal cortices, and the medial prefrontal

cortex (mPFC) emotional modulation areas, which are implicated in empathy, theory-of-mind, and mirror functions and are central to the mother's capacity to read her infant cues and plan adequate caregiving actions, were co-activated with the NAcc in the synchronous group but with the amygdala in the intrusive group. These findings suggest that for synchronous mothers, the underlying nonconscious emotional valance of maternal care relates to the reward component of attachment, but for the highly-anxious intrusive mothers it is colored by fear and worries. Furthermore, NAcc and amygdala activations showed cross-time organization and correlated with mothers' plasma OT levels only in the synchronous group, pointing to coherence in brain, behavior, and hormones in the context of parent–infant interactive synchrony (Atzil, Hendler, & Feldman, 2011).

In the second study, we scanned mothers' and fathers' brain while during exposure to their infant's solitary play video. We found that mothers and fathers synchronize online their brain activations in social-cognitive networks including STS, mPFC, insula, and TPJ, which are implicated in empathy and mirror functions, but not in limbic areas, which showed greater activations in mothers. These findings may suggest that the co-evolution of mothering and fathering and the formation of family units were based on the higher mammals' capacity to represent others' states in one's physiology and may suggest that human attachment evolved within the matrix of biological attunement of brain reactivity within close relationships (Atzil et al., in press).

IMPLICATIONS FOR INTERVENTIONS

Detailing the moment-by-moment process associated with bond formation, its transformations across infancy, and its specific expressions across psychopathological conditions may provide a scientific basis for developing more concrete interventions. In our infant clinic, we use video feedback and micro-analytic approach to sensitize parents to the non-verbal components of social behavior, help them understand their child's non-verbal signals, and teach parents to identify moments of synchrony, mys-synchrony, and avoidance in their response. Programs for fathers of postnatally depressed mothers are guided by the findings on the father's buffering role, and we teach fathers skills for engaging in reciprocal interactions with their children. Finally, we conduct triadic family interactions in light of the findings on family synchrony and the micro-level coordination between the marital and parenting sub-systems. The emphasis on bottom-up, clearly observable, and temporally organized patterns often grounds the interactive context for parents and models concrete behaviors without invoking guilt. We find that with growing parental attention to micro-level social signals, an arc of bio-behavioral regulatory process is opened: interactive synchrony is formed, biological synchrony begins to emerge along the behavioral coordination, the child's negative emotionality decreases and self-regulation increases, and moments of joy and reward—which likely activate reward pathways in the parental brain—may be experienced for the first time. We focus on the importance of parental touch, consistent with the associations between parental touch and OT release (Feldman et al., 2010b). As the neurobiology of affiliation is highly sensitive to social influences, such interventions at key developmental nodes may go a long way and establish what neuroscientists term as "brain-based epistemology"—the associations between the subjective experience of being contained within attachment relationships and the objective assessment of positive parenting.

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