Relational psychophysiology: Lessons from mother-infant physiology research on dyadically expanded states of consciousness
Jacob Ham; Ed Tronick

* Beth Israel Medical Center, New York, & Albert Einstein College of Medicine, New York
b University of Massachusetts at Boston, & Children’s Hospital Boston, Harvard Medical School, Boston

To cite this Article Ham, Jacob and Tronick, Ed(2009) 'Relational psychophysiology: Lessons from mother-infant physiology research on dyadically expanded states of consciousness', Psychotherapy Research, 19: 6, 619 — 632
To link to this Article DOI: 10.1080/10503300802609672
URL: http://dx.doi.org/10.1080/10503300802609672

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf
This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.
Relational psychophysiology: Lessons from mother–infant physiology research on dyadically expanded states of consciousness

JACOB HAM & ED TRONICK

1Beth Isreal Medical Center, New York, & Albert Einstein College of Medicine, New York; 2University of Massachusetts at Boston, & Children’s Hospital Boston, Harvard Medical School, Boston

(Received 10 December 2007; revised 22 October 2008; accepted 3 November 2008)

Abstract

The authors illustrate how their work on mother–infant “relational psychophysiology” might inform psychotherapy research. They examined psychophysiology in 18 mother–infant dyads (infants’ age: 5 months) during normal interaction and a still-face perturbation. They measured respiratory sinus arrhythmia (RSA) as an index of emotion regulation and explored whether skin conductance (SC) concordance, previously linked to therapist empathy, occurs in mothers and infants. During the still-face episode, SC concordance correlated to infant negative engagement. Upon reengagement, when mothers often soothe their infants, concordance instead correlated to behavioral synchrony, an index of maternal sensitivity. Furthermore, maternal RSA became correlated to infant negative engagement. These findings suggest that a mother trying to calm her infant calms herself physiologically and her sensitivity on a behavioral level becomes coherent physiologically. Implications for psychotherapy research are discussed.

Keywords: philosophical/theoretical issues in therapy research; technology in psychotherapy research and training

The purpose of this invited article is to present our nascent work on relational psychophysiology in mother–infant research and offer some ways in which this approach might apply to and inform psychotherapy research and clinical practice. We first briefly review our theories of infant emotional development that were derived from our empirical research. These theories include the mutual regulation model and, more recently, dyadically expanded states of consciousness, which integrates a nonlinear dynamic systems framework into the mutual regulation model. The core of the article is an introduction to our latest efforts to add physiological measures and perspectives to our mother–infant work. Throughout this article, we discuss applications to psychotherapy research.

The Mutual Regulation Model

For the past three decades, we have studied mutual regulatory processes between mothers and infants during face-to-face interactions using measures of behavior and affect (see Tronick, 2007, for a collection of this work over the past 30 years). We have found that mothers and infants engage in self-directed and other-directed actions during face-to-face interaction in efforts to maintain optimal levels of self and dyadic arousal and engagement. In the mutual regulation model (Gianino & Tronick, 1988; Tronick, 1989), infants play a major agentic role in regulating the interaction. They invite fitted, regulatory scaffolding, with meanings conveyed through eye contact, facial expressions, and emotive expressions such as crying or laughing. They modulate the intensity of
interaction and their internal state, again with mean-
ings conveyed through gaze aversion, self-soothing, and expressions of protest. Caregivers vary in the degree to which they apprehend and learn their infant’s messages and thus vary in how much they help (or hinder) the infant’s regulation. Caregivers smile when infants smile, wait when infants turn away, and soothe infants when they are distressed. In this way, temporal features of the interaction reveal con-
tingencies of signaling, synchrony, and attunement, and both caregivers and infants use nonverbal forms of communication that convey meaning.

However, the ideal interaction is not of absolute synchrony and coordination. Rather, the interaction is “messy.” It involves mismatches of affective states, miscoordination of responses, and misapprehensions of relational intentions (Tronick, 2007). The actual interaction involves reparation of mismatch and the rejoicing of shared relational meaning. In our model, reparation is a central driving force for change and has consequences beyond developing shared mean-
ings. Through reparation, the infant and the care-
giver come to implicitly know that the negative experience of mismatch can be transformed into a positive affective match, that the partner can conse-
quently be trusted, and that the infant (and care-
giver) can act effectively in the world. Also, out of the reparation of messiness, new implicit ways of being together are cocreated and come to be implicitly known (Tronick, 2004).

Our research using the face-to-face still-face (FFSF) paradigm (Tronick, Als, Adamson, Wise, & Brazelton, 1978) has shown the dramatic impact on the infant when the mother’s regulatory input is experimentally halted. The typical paradigm consists of three interaction segments, each lasting 2 to 3 min. In the first episode (face to face), mothers are instructed to play with their infant as they normally do. In the next episode (still face), mothers are instructed to face their infant but to no longer respond to their infant in any way. The effect on the infant is dramatic. Infants quickly detect the change and use a variety of strategies to reengage their mothers (smiling, cooing, fussing). This solicita-
tion cycle may be repeated many times. However, when the attempts fail, infants can withdraw, avert their gaze, and lose postural control and self-
comfort. Some, but not many, infants cry. In the third episode (reunion), mothers are asked to resume normal interactions with their infants. Mothers often end up having to exert effort to soothe their infants, and infants display a mix of positive and negative affects. Over time, with the regulatory engagement of the mother and the fulfillment of infants’ intention to relicit interaction, the interaction resumes its typical messy state. Decades of research have shown that infants’ response to the still-face predicts indices of emotional and behavioral health later in development, such as infant attachment classification at 1 year (Braungart-Rieker, Garwood, Powers, & Wang, 2001; Cohn, Campbell, & Ross, 1991; Kiser, Bates, Maslin, & Bayles, 1986) and behavior prob-
lems in early childhood (Bates, Maslin, & Frankel, 1985; Moore, Cohn, & Campbell, 2001). We have also documented the impact of maternal illnesses, particularly depression, on infant interaction behav-
iors, leading to more infant hostility, withdrawal, and negative affect that even generalize to other adult–infant interactions (Tronick, 2007).

Our work and that of many other developmental researchers (e.g., Beebe & Lachmann, 2002; Fon-
ag, 2002; Stern, 2004) have had a profound impact on the conceptualization of therapeutic processes. It is not an overstatement to say that the early work on mutual regulation was constitutive and foundational to nearly all forms of relational psychotherapies. For example, Safran and Muran’s (2000) relational approach to psychotherapy sug-
gests that the type of reparations in relating identi-
fied in mother–infant relationships might reflect parallel processes in adult psychotherapy, such that reparations of the patient–therapist relationship fa-
cilitate a restructuring of the patient’s relational schemas into more healthy relational patterns of expectation.

Dyadically Expanded States of Consciousness

More recently, we have been integrating principles of nonlinear dynamic systems theory (Kiel & Elliot, 1996; M. D. Lewis, 2000; Thelen & Smith, 1994) into the mutual regulation model and have coined the term “dyadically expanded states of conscious-
ness” to loosely capture our thinking (Tronick, 2007). Although we may use the term “conscious-
ness,” it is less than ideal because we use it quite differently from neurologists and philosophers and do not believe that all states of consciousness are necessarily in awareness. Nonetheless, we feel that it best captures our belief that the totality of human function is involved in the meaning-making process—from cells to physiological function, from action to awareness. We believe that the human being is an open, nonlinear dynamic system consisting of many interrelated domains of functioning (physiological, emotional, cognitive-symbolic, and social/behavioral). This system is thought to move toward more complex and coherent states of self-
organization as it interfaces with itself and the outer environment. We refer to this self-organization as a “state of consciousness.” This state expresses the entire system of meanings, intentions, and purposes
through which one operates and experiences the self in the world. As in all complex systems, there are multilayered, hierarchically organized domains of functioning, and each domain is related to and affects the other. A more coherent state of consciousness occurs when “all” domains are organized into greater (but never complete) harmony with other levels. Coherence is a function of organization, complexity, and flexibility in adapting to different environmental conditions.

It is crucial to note that in establishing self-organization, others are necessarily involved. We agree with T. Lewis, Armini, and Lannon (2001) in positing that human beings are open systems that receive direct input from the external environment, most importantly other organisms, and that human beings hunger for “limbic resonance” with other organisms. We believe that others shape the human system at every level of function. The impact of others on rudimentary functions is most apparent in infants, who require regulatory input from others to sustain even basic homeostatic and physiological processes such as body temperature, sleep cycle, digestion, and motor stability. Infancy is also the stage in which humans are most open to the influence of others (T. Lewis et al., 2001). They have less capacity to self-regulate and self-organize, and their organization dissipates most quickly without sustained external support. The necessity of others’ input has been dramatically demonstrated in the early studies of institutionalized infants who failed to thrive and even died without routine human touch despite receiving basic sustenance and medical care (Provence & Lipton, 1962; Spitz, 1945). From animal studies, the vital importance of maternal input for basic physiological functioning has been elegantly demonstrated in studies that deprive newborn rat pups of a particular piece of maternal input (Hofer, 1996). These studies have shown that various aspects of maternal input (heat, grooming, nursing, pheromones) discretely maintain the various aspects of the pups’ physiological state, alter neurochemical function, and even cause an epigenetically driven increase in the production of cortisol receptors in the hippocampus (Liu et al., 1997).

As the human infant develops and other domains of function emerge, caregivers remain vital inputs to increasing the coherence of self-organization. For instance, social referencing is a means for infants to use the meaning expressed by the emotional states of others to help them determine their own emotional experience and thus the meaning of a given situation. In classic visual cliff studies, a mother’s facial expression (such as fear or interest) determined whether an infant drops and slowly backs away from the visual cliff or approaches it boldly (Sorce, Emde, Campos, & Klinnert, 1985). As the domain of language emerges, the toddler learns the name of things and enters the sociocultural matrix of meaning with every new word learned (Bruner, 1990). The toddler also learns to name his or her own experience and through this reflective capacity, which Fonagy (2002) calls mentalization, adds another layer of function to his or her self-organizing system.

For us, meaning making permeates every level of functioning in domain-specific ways and becomes more and more complex with development. Freeman (2001) saw this meaning as a form of biological purposiveness, in which all subsystems operate to fulfill a goal with the means available at that level.

**Dyadically Expanded States of Consciousness in Psychotherapy**

We propose that psychotherapy involves a process of increasing the coherence and complexity of the patient’s self-organization (state of consciousness). Here we use coherence to refer to a state in which all domains of functioning resonate with each other and operate harmoniously with each other, like an orchestra playing on point with individual musical streams merging into a sonata that is greater and more beautiful than the sum of its parts.

We suggest that some patients enter therapy because they experience some type of incoherence. They may complain of having a false self, of living a lie, or of not knowing who they are, what they feel, or what they want (e.g., Masterson, 1990). They may lack insight or self-awareness (i.e., coherence of identity and meaning with behavior, affect, and physiology). Alternatively, they may lack greater control over their behaviors or emotions (coherence of will and action or feeling). From an adult attachment perspective (George, Kaplan, & Main, 1996), these patients may be identified as dismissive in attachment style and display a poverty of content or report a lack of feeling when discussing attachment issues.

Other patients may present with problems in complexity. Complexity, from a nonlinear dynamic systems perspective, refers to both a stability in system organization and a flexibility to respond and adapt to changing environmental demands (Siegel, 1999). Low-complexity patients are those who, as the saying goes, find themselves stuck in a hole but keep on digging because they only have a shovel. These patients cannot help but repeatedly make meaning of situations in the same dysfunctional ways or react to situations in the same way (i.e., automatic thoughts, from a cognitive perspective). They may be described as rigid, intolerant, angry, or
afraid and are likely to be diagnosed with a personality disorder. Other patients may have disorganized complexity, tending toward randomness. They may become incoherent when anxious, vague, flighty, distracted, and fearful. In the literature on adult attachments, these patients may be categorized as preoccupied and display linguistic and semantic incoherence when discussing anxiety-provoking attachment issues. More seriously, they may present as disorganized, which represents the ultimate level of disruption in self-organization and is often associated with the most severe experiences of trauma or loss.

We believe that therapeutic action lies in dyadically expanding the coherence of patients’ self-organization. Any domain of function (physiological processes, behaviors, emotions, conscious awareness, reflective awareness, identity, intentions, and social relationships) can be an effective target for intervention because increasing the coherence in one domain will likely impact the entire system. We highlight the importance of the emotional domain because we believe that it serves as a foundational building block for coherence, is the “product” of domains of function, and thus is a critical target for therapeutic intervention and growth. Somewhat like the responsive mother with her child, the therapist must attend to the immediate, moment-to-moment emotional meaning state occurring in the patient, in the therapist, and between patient and therapist. The purpose of this apprehending is to facilitate two overlapping and synergistic processes important in the development of coherence: regulation of affect and awareness of affect. This is not to say that we privilege the emotional domain in therapy, because cognitive therapists have certainly highlighted how alterations in semantic levels of meaning (such as changing cognitive distortions or attributional biases) can have resounding effects on emotions as well. We also acknowledge the interesting work of body psychotherapists (e.g., Ogden, Minton, & Pain, 2006), who focus more directly on the nonverbal, sensorimotor domain of function, and believe that this work too can impact self-organization at higher levels.

We cannot overemphasize the centrality of others in the development of coherence and complexity. From our clinical experience, one of the greatest sources of malaise in patients is a deep sense of isolation, and many patients report that one of the things that feels best and is most helpful about therapy is the chance to feel heard and understood by another and to have their views on the world validated, their meanings shared. Something magical happens when the patient’s most private and shame-inducing vulnerabilities are shared with the therapist, particularly one who is nonjudgmental, empathic, and accurate in his or her perception (Rogers, 1992). The therapist resonates with the patient on an affective, visceral level. Sometimes, on a nonverbal level, vocal rhythms converge (Beebe & Lachmann, 2002) and gestures become mirrored (Bernieri & Rosenthal, 1991). However, this alone would be sympathy. The therapist must also accurately convey through language and other forms of communicating meaning that he or she grasps the patient’s meaning. Then the multiple layers of the patient’s self-organization becomes resonant with the therapist’s and they cocreate a new and greater coherence, a dyadically expanded, harmonically amplified state of consciousness shared between them. This then becomes empathy (Greenberg, 1997). We believe that this experience facilitates reconstruction of implicit relational schemas (Tronick, 2007) that exist in the body and mind in all organizational levels of the self.

Introduction to Relational Psychophysiology

In the spirit of studying physiological and behavioral states as they might relate to dyadically driven relational processes that enhance self-organization and emotion regulation capacities, we have begun to measure psychophysiological variables during mother–infant interactions. Psychophysiology is the study of the physical substrates underlying or associated with mental processes such as cognition, emotion, and behavior (Cacioppo, Tassinary, & Bernston, 2000). Examples of commonly studied psychophysiological signals are cardiac, particularly respiratory sinus arrhythmia (RSA) as an index of parasympathetic tone and emotion regulation (Porges, 2003), and salivary cortisol as an index of the stress response mediated through the hypothalamic-pituitary-adrenal axis system (Stansbury & Gunnar, 1994). However, the problem with these measures, particularly salivary cortisol, is that they are not very temporally discrete. RSA is ideally calculated in at least a 5-min window of time1 (Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996) and salivary cortisol typically peaks 20 to 30 min after a moderate stressor (Lovallo & Thomas, 2000). We thus decided to measure skin conductance (SC), a measure of sympathetic activity that is much more temporally sensitive. We also included measurement of RSA because of its widely accepted use as an index of emotion regulation.
Respiratory Sinus Arrhythmia

In developmental research, studies abound examining cardiac measures, particularly vagal tone or RSA as an index of emotion regulation capacities (Porges, 2003). RSA is an indirect measure of parasympathetic influence on heart rate variability (Brownley, Hurwitz, & Schneiderman, 2000). The parasympathetic system is generally considered to modulate arousal and activate positive states of rest and digestion. RSA is reflected in heart rate fluctuations that naturally occur with respiration (i.e., increases in heart rate during inspiration and decreases during expiration). RSA can be calculated through spectral analysis of cardiac frequencies and is equivalent to the power density of the high-frequency band typically associated with respiration (Brownley et al., 2000; Task Force of the European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). RSA has been shown to be positively related to emotional and behavioral regulation and attentional control (Porges, 2003) and is thought to index the “efficiency of central-peripheral neural feedback mechanisms” that control those processes (Thayer & Lane, 2000, p. 204). Dysregulated RSA has also been associated with preterm birth status and greater cost to behavioral self-regulation and attentional control (Lester, Boukydis, & LaGasse, 1996).

A few studies have examined the association between infant RSA and the mother–infant relationship. Two studies have examined RSA during the classic FFSF paradigm (Moore & Calkins, 2004; Weinberg & Tronick, 1996). Both found that RSA decreases during the still-face episode and increases again to prior levels during the reunion episode. Moore and Calkins (2004) further found that infants who did not decrease RSA during the still-face episode showed less positive affect, higher reactivity, and less synchrony with their mothers during normal play. Feldman and Eidelman (2007) measured neonatal RSA during sleep and found it to predict mother–infant and father–infant synchrony at 3 months of infant age. Porter (2003) also found that higher baseline RSA in 6-month-old infants predicted more positive, symmetrical coactivated communication patterns between mothers and infants.

Findings from research on adult psychopathology suggest that RSA amplitude is lower in adults with anorexia (Bar et al., 2007), borderline personality disorder (Austin, Riniolo, & Porges, 2007), depression (Rottenberg, Wilhelm, Gross, & Gotlib, 2002), panic disorder (Friedman & Thayer, 1998), and generalized anxiety disorder (Thayer, Friedman, & Borkovec, 1996). RSA has also been used as an outcome measure in a clinical trial of paroxetine and venlafaxine XR for depression (Davidson et al., 2005) and electroconvulsive therapy (Schultz, Anderson, & van de Borne, 1997). Biofeedback using RSA has also been studied as a promising treatment for depression (Rottenberg, 2007) and posttraumatic stress disorder (Fourie, 2006). Finally, new but controversial techniques in vagal nerve stimulation for severe, intractable depression also suggest that alterations in RSA might improve depression (Rush et al., 2005).

Skin Conductance

Although almost never done in psychophysiological research with infants, we have also included measurement of SC, which indexes the electrical conductivity of the skin (electrodermal activity) as regulated by activity of the eccrine sweat glands. These sweat glands are primarily located on the palms of the hands, soles of the feet, and forehead. SC is a useful complement to RSA because it is a noninvasive peripheral measure of sympathetic nervous system activity, the complementary, though not strictly reciprocal (Berntson, Cacioppo, & Quigley, 1991), part of the autonomic nervous system that is responsible for the “fight-or-flight” response (Cannon, 1929) but is currently considered to more generally instantiate action (Bradley, 2000). Furthermore, unlike most other physiological measures, electrodermal activity is not dually innervated by the parasympathetic system as well. It is important to add a measure of sympathetic activity in general and not just study the parasympathetic system because these two systems, although generally reciprocal, can also function separately and even coactively (Berntson et al., 1991). SC also has the benefit of being temporarily discrete and immediately measurable, as discussed previously. SC can signify a wide variety of neurophysiological processes (e.g., thermoregulation, deep breathing, general affective processes, orienting, attention, increased muscle tone) but, of particular significance for relational psychophysiological studies, it is related to emotional arousal and anxiety (Dawson, Schell, & Filion, 2000).

In developmental research, very few studies have used SC in psychophysiological research on infant emotion and none have studied mother–infant interaction. In fact, some current infant researchers doubt that it can even be used with infants because of the significant challenge of movement artifact (R. Keen, personal communication, 2006). The studies that have been done have primarily focused on evaluating whether or not infants produce typical SC responses and elevations to various stimuli. These studies have confirmed that from birth infant SC levels vary with sleep-wake and arousal states.
and infant SC responses can be produced by normal handling, heel pricks, and loud noises (Gladman & Chiswick, 1990; Storm, 2000, 2001). In addition, Hernes et al. (2002) tracked the development of SC and documented that in full-term healthy infants the profile of SC responses to loud noises becomes similar to adults after 10 weeks of life. Finally, we have documented that 5-month-old infants produce unconditioned and conditioned SC responses to sudden claps and the amplitude of SC response is related to a physical startle reaction (Ham & Tronick, 2008). Although no studies have measured SC in mothers and infants simultaneously, some have measured SC in mothers alone. These studies suggest that infant cries can elicit SC responses, particularly in mothers who hear their own infants cry (Weisenfeld & Klorman, 1981) and adults with personal histories of abuse or higher potential to abuse their children (Casanova, Domanic, McCanne, & Milner, 1994; Crowe & Zeskind, 1992).

SC is particularly interesting in the context of bridging mother–infant and psychotherapy research because in both contexts the ability of the partners to coordinate their behavior and empathic responsiveness is critical. In fact, a 2007 psychotherapy research study examined SC as a potential marker of therapist empathy (Marci, Ham, Moran, & Orr, 2007). This study served as a guide for the current study, so its method is presented in some detail. Marci et al. (2007) hypothesized that concordant fluctuations of SC activity between patient and therapist would meaningfully relate to empathic moments during the psychotherapeutic process. The power of today’s technological and computing advances made this type of labor-intensive analysis possible and feasible unlike ever before. SC from both patient and therapist was sampled 100 times per second for the duration of a 50-min psychotherapy session, producing time-series data files of 300,000 bits of information. Each time series was transformed into an average slope (the first-order derivative) within a 5-s window. Each 5-s window was sampled for every second of the time series, creating a new time series of average slopes. This process created overlapping sampling windows, which some may argue is problematic because contiguous windows were based on mostly redundant information. However, this method increased the sensitivity for identifying all slopes and minimized the impact of peaks and valleys. The new time series of average slopes for each patient–therapist dyad was then correlated together in 30-s windows that were also sampled at every second of the time series. Finally, a single index score summarizing this time series of running correlations was calculated as the ratio of positive correlations over negative correlations, such that higher ratio scores indicated a greater prevalence of positive correlations throughout the psychotherapy session.

Confirming their hypothesis, Marci et al. (2007) found that concordant fluctuations in SC between patient and therapist during a psychotherapy session were significantly related to patient ratings of therapist empathy during the session. Furthermore, the 2-min periods of highest concordance contained significantly more positive, affirming statements between patient and therapy versus the 2-min periods of lowest concordance within the same psychotherapy session. To our knowledge, the only other methodologically similar study in psychotherapy was published more than 20 years ago and reported similar results. Robinson, Herman, and Kaplan (1982) used analog physiology equipment (and pencils and rulers to measure SC activity). They calculated SC in a slightly different way but also found that concordance in SC activity was related to therapist empathy. Other early studies, mostly in the 1950s, examined concordance in heart rate rather than SC and found that therapists’ heart rate changed with patients’ heart rate (Coleman, Greenblatt, & Solomon, 1956; Di Mascio, Boyd, Greenblatt, & Solomon, 1955; Lacey, 1959; Stanek, Hahn, & Mayer, 1973).

In summary, it appears that only a few researchers, separated by decades, have attempted to study psychophysiology and psychotherapy. However, we believe that this line of research may prove fruitful, particularly in the context of our thoughts on the dyadic expansion of states of consciousness and the growing interest in integrating neurophysiological science into clinical theory and practice (e.g., Schore, 1999; Siegel, 1999). We believe that psychophysiological concordance may represent a form of dyadically driven organization of self and the self–other relational complex and serves as an index of what T. Lewis et al. (2001) called “limbic resonance.”

Our current work extends the examination of concordant physiology into the realm of mother–infant relationships. We examine whether similar SC concordance might be found and whether it is related to engagement behaviors during the classic FFSF paradigm. We also measured RSA because it is such a widely used and clinically relevant physiological marker of emotion regulation. We believe that psychophysiological data can illuminate two important components of our dynamic systems model. First, we assume that the abilities to regulate physiological state and flexibly respond to the demands of any given situation are important foundations of self-organization in a complex dynamic system. Second, we hypothesize that the physiological domain may
also reveal moments of dyadically expanded states of self-organization or consciousness (and even organization of the self–other system), during which there is heightened coherence of the emotional, behavioral, and physiological systems within and between individuals. We operationalize dyadic coherence in behavioral terms as second-to-second synchrony in mother–infant engagement activities, which in prior studies has been linked to maternal sensitivity (Isabella & Belsky, 1991). We operationalize it in physiological terms as concordance in fluctuations of SC between mother and infant, similar to the method of Marci et al. (2007).

Method

Participants

Dyads were recruited through a database of families at the Child Development Unit of Children's Hospital Boston who had participated in a newborn assessment after delivery at a local hospital. All infants in this study were born physically healthy and full term and insure that SC could be validly measured. The first 11 infants were involved in a practice run to solve the many technical issues involved in collecting SC data from infants (see Ham & Tronick, 2008, for further details). A subsequent 18 dyads participated in the present study. Data for some dyads were missing because of technical issues or infant noncompliance; thus, this study comprised 18 face-to-face episodes, 17 still-face episodes, and 13 reunion episodes. All infants were 5 months old at the time of participation. Eleven of the 18 infants were male. Mothers were, on average, 33 years old (SD = 5) and represented diversity in race and ethnicity.

Procedures

On arrival to the lab, families were given the opportunity to settle into the waiting room and ensure that infants were comfortable and alert. At this time, the researcher described the study and collected informed consent. Next, researchers applied electrodes to the infants and placed them in the infant seats. Video cameras and physiological software were started and synchronized. Infants then participated in the first protocol, in which one of the authors sat in front of the infant and administered a series of claps designed to elicit SC responses. Results from this protocol are discussed in another report (Ham & Tronick, 2008). In the second protocol, the mother and infant engaged in the standard FFSF paradigm. The Children's Hospital Boston Institutional Review Board approved this study.

FFSF Paradigm

The FFSF is a standard laboratory-based observational procedure for studying infant social capacities and capacity to cope with perturbations of social interaction. The FFSF consists of three successive 2-min episodes: an episode of ordinary mother–infant face-to-face interactive play (FF); a perturbation episode called the still face (SF), in which the mother looks at the infant and remains immobile; and a reunion play episode (RE) in which the mother reengages with her infant in her usual manner.

Mother–infant interactions were video recorded and coded using the Observer 5.0 software by Noldus Information Technology (Leesburg, VA, USA). Mother and infant behaviors were coded using the Infant Caregiver Engagement Phases (ICEP; Weinberg & Tronick, 1999; see Tronick et al., 2005, for details on coding) system. This system codes mother and infant behaviors separately for facial expression (positive and negative affect), direction of gaze, and vocalizations on a second-by-second basis. For infants, the categories from most negative to most positive are protest, negative engagement with mother, withdrawn/avoidant, engagement with environment, monitoring of mother, and positive engagement with mother. Similarly, engagement categories for mothers are hostile/intrusive, negative engagement with infant, withdrawn/avoidant of infant, engagement with environment, monitoring of infant with neutral face and no vocalizations, monitoring of infant with neutral face and vocalizations, positive engagement with infant, and exaggerated positive engagement. Because some of these engagement categories were seen so infrequently, the codes were collapsed into the following four categories:

Negative engagement: any negative expression of affect, including protest, fussing, frowns, and so on.
Withdrawn/avoidant: any turning away from the other person so as to avoid contact while not showing clear interest in other objects.
Environment engagement: any looking at nonsocial objects with interest.
Social engagement: any looking at the other person, including neutral observation, positive engagement, or maternal attempts at soothing infant.

Jacob Ham was trained to use the ICEP by the original authors of the ICEP and coded all videos. He was blind to physiological data at the time of coding. Total percent times for each engagement category were used for all analyses except when calculating mother–infant synchrony, which was based on the first-order correlation between the original mother–
infant engagement categories for each second of the interaction (Cohn & Tronick, 1988).

**Physiological Measure**

Physiology is readily measured using many commercially available systems. These systems are continuously improving, and in fact some of the more popular ones were recently enhanced to simultaneously measure video and physiology. For this study, we recorded physiology with the PowerLab 8SP by ADInstruments, Inc. (Sydney, Australia), which includes the Chart (version 4.2) software to digitally record, store, and analyze physiological recordings. We chose this system because of its capacity to export physiological signals as a digital movie, which we overlaid onto the split-screen videos so that we could review simultaneous changes in physiology and behavior for qualitative exploratory analysis and demonstration purposes.

Electrodes, electrode placement, and the issue of movement artifact. It is important to discuss electrodes for physiological recording and their placement because of the significant issue of movement artifact. Cardiac activity was measured using disposable, general purpose foam electrodes (Biopac Systems [model EL501], Goleta, CA). Electrodes for infants were placed in nontraditional locations to reduce infant handling of electrodes and leads. The positive and negative electrodes were placed on the back of the infant’s shoulders, and the ground electrode was placed on the infant’s side, near the lower left rib cage. Electrodes for mothers were placed in a standard Type II lead placement, with positive and negative electrodes near each clavicle and the ground electrode near the lower left rib cage.

To measure SC, disposable, self-adhesive, “wet” electrodes from Biopac Systems (model EL507) were retrofitted to the PowerLab machine. For infants, these paired electrodes were placed on the outer side and heel of the foot. Then the electrodes were wrapped with a self-adhering elastic bandage (Ace Wrap) to further stabilize the signal and prevent infants from tampering with them. For mothers, electrodes were placed in the standard locations: the distal palmar surfaces of the third and fourth digits of the nondominant hand. We also instructed mothers to rest their hand in their lap as still as possible to minimize movement artifact.

Calculation of physiological variables. RSA was calculated using the algorithm in Chart version 4.2. This algorithm produces a quantitative description of RSA amplitude based on a spectral analysis of the common frequency band of respiration. The commonly used frequency band for adults is 0.15 to 0.5 Hz (Fox, Schmidt, & Henderson, 2000). For infants, we used a respiration frequency band of 0.24 to 1.04 Hz, which is equivalent to 15 to 60 breaths per minute (Izard et al., 1991).

SC was analyzed similarly to Marci et al. (2007), although with some modifications. In our approach, we transform the raw SC time series in a series of average slopes in consecutive 1-s windows, without overlap. Then we correlated the time series of slopes for each mother-infant dyad using 3-s windows, which run in 1-s steps. This time series of running correlations was summarized by calculating the ratio of the sum of positive correlations over the negative correlations. Finally, we took the natural log of this ratio to normalize the distribution. We call this variable the SC ratio. Higher SC ratio scores indicate greater frequency or amplitude of positive correlations versus negative correlations between changes in mother-infant SC activity. Negative SC ratio scores (which we have never encountered) indicate that the SC of one person was changing in a direction opposite of the other.

**Results**

We examined the relations between mother and infant behaviors and their own and each other’s physiologies. The results are organized by FFSF episode because each is a wholly different interaction context and makes meaningfully different demands on the mother-infant dyad. Results highlight correlations with effect sizes greater than 0.40, which is slightly greater than what Cohen (1988) defined as a large effect.

**Normal Interaction (FF Episode)**

In this episode, mothers are instructed to interact with their infants as they normally would. In our experience, many mothers appear to experience some pressure to perform in this circumstance, especially because their interaction is being video recorded. Thus, they are likely to work harder to engage their infant and make them smile than they might otherwise. Infants are typically either affectively neutral and attentive to the new surrounding or positively engaged with their mothers. Table I presents correlations between behavior and physiology during this episode. Infants who display more positive engagement with their mother show lower mean heart rates and higher RSA, although as with any correlation the causal direction cannot be presumed. This constellation likely suggests an infant state of pleasure and stable regulation (as evidenced by the higher RSA). Inversely, infants who
display any protest or other negative engagement behaviors, which is not typical in this episode, show higher heart rates and lower RSA. Interestingly and in parallel, maternal RSA is significantly and negatively related. Possible interpretations of this correlation are that infant protest upsets the mother, who then reacts physiologically with a decrease in RSA or that mothers who are more stressed during the FF episode (as evidenced by lower RSA) induce negative engagement in their infants.

Maternal engagement sensitivity, as defined by the second-to-second correlation between mother-infant engagement behaviors, is not strongly or significantly correlated to mother or infant physiology during the FF episode. Physiological concordance in SC fluctuations is also not strongly related to any mother or infant engagement behaviors.

Still Face (SF Episode)

During the SF episode, mothers are instructed to hold an unresponsive, still face to their infant. Infants increase their negative engagement behaviors during this episode (FF episode: $M = 11.82\%$, $SD = 12.68$; SF episode: $M = 53.24\%$, $SD = 37.25$), $t(16) = -4.98$, $p < .001$, and their heart rate follows suit and significantly increases (FF episode: $M = 143.57$ bpm, $SD = 9.97$; SF episode: $M = 151.67$ bpm, $SD = 11.93$), $t(16) = -4.94$, $p < .001$. As shown in Table II, infant negative engagement behaviors are still positively related to higher infant heart rate but are no longer related to infant RSA, suggesting that RSA becomes uncoupled from the infant’s immediate behaviors. Interestingly, SC concordance approaches a significant correlation with the amount of negative infant engagement behaviors. We speculate that this finding may be attributed to the fact that, because mothers have to sit very still and just “absorb” their infant’s distress, their own activities no longer contribute to their SC activity and their SC activity becomes coherent with their infant’s SC activity.

Reengagement (RE Episode)

Asked to resume interaction, mothers typically spent much of their time trying to reengage and soothe their infants. Negative infant engagement behaviors remained correlated to infant heart rate but uncoupled from infant RSA (Table III). Infant positive engagement behaviors begin to show the same pattern of relation with cardiac physiology as in

Table I. Correlations Between Infant and Mother Engagement Behaviors and Physiology During Normal Face-to-Face Episode ($n = 18$)

<table>
<thead>
<tr>
<th>Engagement behavior</th>
<th>Infant HR</th>
<th>Infant RSA</th>
<th>Mother HR</th>
<th>Mother RSA</th>
<th>M-I SC ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td>.50*</td>
<td>-.50*</td>
<td>-0.64**</td>
<td>.46</td>
<td></td>
</tr>
<tr>
<td>Withdrawn/avoidant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment engagement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social engagement</td>
<td>-.40</td>
<td>.43</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mother</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.45</td>
</tr>
<tr>
<td>Withdrawn/avoidant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment engagement</td>
<td>.46</td>
<td>.65**</td>
<td>-.64**</td>
<td>.43</td>
<td></td>
</tr>
<tr>
<td>Social engagement</td>
<td>-.66**</td>
<td>.65**</td>
<td>.43</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. All correlations $< .40$ are omitted. M-I = mother-infant; HR = heart rate; RSA = respiratory sinus arrhythmia; SC = skin conductance; NC = cannot be computed because at least one of the variables is constant.

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

Table II. Correlations Between Infant and Mother Engagement Behaviors and Physiology During Still-Face Episode ($n = 17$)

<table>
<thead>
<tr>
<th>Engagement behavior</th>
<th>Infant HR</th>
<th>Infant RSA</th>
<th>Mother HR</th>
<th>Mother RSA</th>
<th>M-I SC ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.64**</td>
</tr>
<tr>
<td>Withdrawn/avoidant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-.45</td>
</tr>
<tr>
<td>Environment engagement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social engagement</td>
<td>.45</td>
<td>.47</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. All correlations $< .40$ are omitted. Maternal engagement behaviors do not exist in this episode. M-I = mother-infant; HR = heart rate; RSA = respiratory sinus arrhythmia; SC = skin conductance.
the FF episode (i.e., lower heart rate and higher RSA). Infant environment engagement, in which the infant is intently looking around the room, but not at the mother, is also related to lower heart rate but also to lower RSA. Interestingly, whereas maternal RSA was negatively correlated with infant negative engagement behaviors in the FF episode, it is now significantly positively correlated to it. We speculate that mothers are now activating their own parasympathetic systems and calming themselves in the service of calming their infants. In fact, about 50% of the RE episode involves matches between infant negative engagement and maternal social engagement (primarily soothing behaviors such as cooing at the infant). There is another interesting finding: SC concordance, our physiological index of dyadic coherence, is now positively correlated to mother-infant synchrony, our marker of maternal sensitivity (Tronick, 1989). These results appear to pair nicely with Marci et al.’s (2007) result. At first, we were disappointed that SC concordance was not related to mother-infant synchrony during the normal FF episode. However, we realized that psychotherapy is also not a normal FF interaction but is more like the RE episode, in which one participant (the mother or therapist) is actively focusing on and perhaps even soothing the other (infant or patient). Thus, one might conclude that physiological concordance is most likely to occur when one person is actively attending to another. This conclusion would also be consistent with Marci et al.’s finding that concordance is related to therapist empathy and positive, affirming behaviors. It is also consistent with the findings that the coherence of what we refer to as dyadically expanded states of consciousness (Tronick, 2007). We found that physiological concordance in fluctuations of sympathetic activity between mothers and infants was related to different social engagement states depending on the contextual demands of the interaction. When mothers are asked to sit still and simply watch their infants without responding, greater SC concordance occurred more when infants spent the most time protesting, fussing, or showing other forms of negative engagement. However, when mothers are asked to resume interaction and make every effort to soothe and attend to their infants, their own parasympathetic systems appear to become more active in relation to how much their infant fusses and protests during the reunion, as if they are calming themselves in order to calm their infants. Furthermore, greater SC concordance between mothers and infants is no longer related to infant distress, as in the SF context, but instead becomes related to greater synchrony in mother-infant engagement behaviors, our marker of maternal sensitivity (Tronick, 1989).

Table III. Correlations Between Infant and Mother Engagement Behaviors and Physiology During Still-Face Episode ($n=13$)

<table>
<thead>
<tr>
<th>Engagement behavior</th>
<th>Infant</th>
<th></th>
<th>Mother</th>
<th></th>
<th>M-I SC ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HR</td>
<td>RSA</td>
<td>HR</td>
<td>RSA</td>
<td></td>
</tr>
<tr>
<td>M-I synchrony*</td>
<td></td>
<td>.74**</td>
<td></td>
<td>.43</td>
<td></td>
</tr>
<tr>
<td>Infant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td>.75**</td>
<td></td>
<td>.43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Withdrawn/avoidant</td>
<td>-.42</td>
<td>-.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment engagement</td>
<td>-.45</td>
<td>.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social engagement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mother</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negative</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Withdrawn/avoidant</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment engagement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Social engagement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. All correlations < .40 are omitted. M-I = mother-infant; HR = heart rate; RSA = respiratory sinus arrhythmia; SC = skin conductance.

*For mother-infant synchrony, $n=10$ because for three dyads at least one of the variables is constant.

**$p < .01$. The results of this exploratory study support the concept that physiology can be used to measure the relational processes that may facilitate the development of emotion regulation capacities and enhance the coherence of what we refer to as dyadically expanded states of consciousness (Tronick, 2007).
with McCraty, Atkinson, and Tomasino's (2001) proposal that focal unconditional positive regard toward a target person causes entrainment between the target person’s cardiac activity and the subject’s cortical activity, as measured by electroencephalogram. At the same time, simply interpreting what goes on in mother–infant or therapeutic interactions in a unidirectional fashion is not adequate, because it is not only the mother or the therapist who are responsible for the emergence of synchrony. As research demonstrates, the interaction between mothers and infants is bidirectional and infants are active, intentional partners in the interaction. Similarly, it is foolish to think that patients are simply passive recipients of the therapist’s actions or generally so totally self-focused on self-regulation that they do not attend to what the therapist is doing and intending. Rather, the therapeutic exchange is bidirectional, and patients are active and engaged, such that even something like focal positive regard requires the object to be actively engaged with its expression.

Additionally, we speculate that our findings are reminiscent of Winnicott’s (1971/2005) notion of potential space. Winnicott argued that when the mother’s holding of the infant (an unfortunately unidirectional idea) was adequate, the infant was free to take initiative. Taking initiative means that the coordination among systems may actually be reduced as infant (and mother) become less predictable because they are doing new things with each other. From this notion, we might expect that interactions have periods of high coherence, which are followed by periods of lower coherence marked by positive affect. Thus, we found less coherence in the normal interaction but greater coherence in the more stressful reunion episode. That is, in normal play the infant (and mother) “play around” and coherence is lower, whereas in the reunion episode both mother and infant work hard to recoordinate their behavioral and physiological systems to generate a new, more open space (Sander, 1988).

Something similar may happen in the therapeutic exchange as well. Periods of high empathy may allow for the patient to take initiative and create something new and therapeutic.

Certainly, we present these results very tentatively given the small sample size and the use of a single rater (without the establishment of reliability). There is a need for replication, and we have undertaken a much larger study of similar design and with a wider age range of infants.

Future studies might, of course, begin with finding convergent support for our proposition that physiological concordance is related to empathy and other forms of attentive, supportive engagement with another person. Future psychotherapy studies might examine whether physiological concordance predicts therapy outcome. It would also be interesting to examine whether therapists’ capacity for physiological emotion regulation influences psychotherapeutic process and outcome. Similar to our speculation that mothers activate parasympathetic tone for the sake of more effectively regulating their infants, we might hypothesize that therapists who are better able to activate parasympathetic tone may be better able to manage and negotiate conflict-ridden or emotionally intense relationship ruptures in the psychotherapeutic process.

We conclude by reiterating our excitement for the horizon of possibilities in studying relational psychophysiology and the application of nonlinear dynamic systems theory to quantify how dyadic interactions impact the development of emotion regulation capacities. Modern computer software and recording instruments make it readily feasible to record both video and physiology simultaneously. In fact, some companies have recently marketed updates to their software that automatically synchronize and display video and physiological signals simultaneously. Some companies have also created portable, ambulatory instruments, which can be worn like a vest and may diminish the intrusiveness of these instruments. Ongoing challenges to studying relational physiology may be the cost of purchasing the necessary equipment ($10,000–20,000), the labor-intensive resource cost of coding videos (e.g., coding our 6 min of interaction typically took 45–60 min), and, of course, the historic challenge of confidently and accurately making sense of and connecting physiological activity to behavioral and psychological phenomena. With regard to the future of truly applying nonlinear dynamic systems theory and other branches of chaos theory not only in theory but in actual mathematical, quantifiable application, we refer the interested reader to the work of Gottman, Murray, Swanson, Tyson, and Swanson (2005) and M. D. Lewis, Lamey, and Douglas (1999), who, respectively, quantified marital interactions and parent–child interactions using mathematical approaches based on nonlinear dynamic systems theory.

Note
1 For studies of short duration, RSA has been calculated for durations as short as 15 s (Huffman et al., 1998).

References


development: Recent research advances (pp. 293–315). Cambridge, UK: Oxford University Press.