Published in final edited form as:

Infant Behav Dev. 2008 January ; 31(1): 92–106.

Cortisol Reactivity, Maternal Sensitivity, and Learning In Three-Month-Old Infants

Laura A. Thompson and Wenda R. Trevathan

Psychology and Sociology/Anthropology Departments New Mexico State University

Abstract

This study investigated the effects of adrenocortical functioning on infant learning during an emotionally challenging event (brief separation from mother). We also explored possible relationships between maternal sensitivity and both infant and maternal cortisol reactivity during the learning/maternal separation episode. 63 three-month-olds and their mothers were videotaped for a 10-min normal interaction period, and mother-infant behavioral synchrony was measured using Isabella and Belsky's (1991) coding scheme. The percentage of synchronous behaviors served as a measure of maternal sensitivity. Learning and short-term memory involved relating the infant's mother's voice with a moving colored block in a preferential looking paradigm. Infants whose cortisol increased during the session showed no learning or memory, infants whose cortisol declined appeared to learn and remember the association, while infants whose cortisol did not change evidenced learning, but not memory for the voice/object correspondence. Sensitivity and cortisol reactivity were correlated for mothers, but not for infants. Infant and maternal cortisol values for the first sampling period were highly correlated, but their cortisol reactivity values were uncorrelated, supporting the notion that infants and mothers have coordinated adrenocortical functioning systems when physically together, but become uncoordinated during a separation/learning event.

Keywords

Cortisol; cortisol reactivity; infant learning; behavioral synchrony

Young infants are in possession of many cognitive abilities that aid them in acquiring an expressive vocabulary of 50 words by the time they are about 16 months old (Bates, Bretherton, & Snyder, 1988). For example, they have highly developed visual and auditory sensory systems (Aslin, 1987) for encoding the auditory and visual components of objects or events that are named by their caregivers, and an attention system that is particularly responsive to human speech. Even newborns are differentially responsive to listening to their mothers' voices, compared to other female voices (DeCasper & Fifer, 1980), and by two months of age, can discriminate sentences differing by a single phoneme (Mandel, Jusczyk, & Kemler Nelson, 1994). Another prelinguistic ability needed to learn first words is visual-auditory integration. During stimulus encoding, very young infants can coordinate visual objects with sounds (Spelke, 1979) and faces and voices (Walker, 1982). Finally, evidence for rapid word learning in 13-month-old infants can be found in recognition measures (e.g., Woodward, Markman, &

Address correspondence to: Laura A. Thompson Department of Psychology MSC 3452/Box 30001 New Mexico State University Las Cruces, NM 88003 Phone: 505-646-4024 Fax: 505-646-6212 Email: thompson@nmsu.edu.

Publisher's Disclaimer: This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final citable form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.

Fitzsimmons, 1994). Long-term recognition of lengthy speech passages spoken by infants' mothers has even been demonstrated in 1- to 2-month-old infants (Spence, 1995).

Importantly, in studies such as these, after removing data from infants that were fussy during the experimental event, who fell asleep, or who showed biases in their responses to a region of the stimulus field, a final data set remains that is comprised of averaged data demonstrating the ability in the group at large; however, contained in this averaged set are data for infants who clearly possess the cognitive ability under question, as well as infants that do not. Ascertaining the nature of individual differences in cognitive processing is a central focus of many child developmental researchers (e.g. Siegler, 1978; Thompson, 1994). However, relatively little is known about the sources of individual variability potentially affecting infant learning.

One widely varying factor is infants' social-interactive environments. For example, infants' primary caregivers differ in how often they speak to their infants, in the prosodic variation of their speech, and in terms of the contingent nature of their language input. Nine- and 13-month-old infants whose mothers responded contingently to their vocalizations and play activities outperformed infants of less responsive mothers on several indices of language development, including timing in the onset of their first words and in combinatorial speech productions (Tamis-LeMonda, Bornstein, & Baumwell, 2001). Our primary interest is in furthering knowledge about the psychophysiological parameters affecting infant learning in the experimental context. That is, what differences inherent in infants, such as temperament and psychophysiological responding, contribute to differences amongst infants in their ability to attend to learn and remember speech/visual representations during a novel learning event?

One commonly studied psychophysiological measure is cortisol, an adrenal steroid hormone, which is secreted in response to physical and emotional stress and is also associated with high states of arousal. When the brain perceives a stress, corticotropin-releasing hormone is released from the hypothalamus, which then stimulates the pituitary gland to release adrenocorticotrophic hormone, which, in turn, stimulates the release of cortisol from the adrenals (Sapolsky, 1992). Research on human adult populations shows that, up to a point, cortisol elevation is adaptive, but if the response is prolonged or severe, there appear to be negative effects on health, behavior, and learning and memory processes (e.g., Flinn & England, 2003). Maternal trauma experienced during pregnancy has even been shown to affect infant adrenocortical functioning *in utero* (Yehuda et al., 2005).

In most infant cortisol studies, the objective has been to understand how situational, emotional, and/or temperamental factors are associated with different patterns of adrenocortical functioning. As an example of situational variables, infant cortisol has been found to be higher at home than when tested at the same time of day in the laboratory following a car ride (Gunnar et al., 1989b), and is higher in the afternoon for preschoolers in poorer quality child care settings than in higher quality settings (Dettling et al., 2000). Regarding behavioral emotional reactions, Lewis and Ramsay (2005) recently reported a study relating anger and sadness to cortisol response in 4- and 6-month-old infants. For both age groups, a goal blockage paradigm was used to activate the emotional response system. Four-month-old infants learned a contingency between an arm movement they initiated and a pleasant event, and subsequently learned that their behavior no longer reinstated the event. The researchers employed a still-face paradigm (Tronick, 2003) to test the 6-month-old infants, in which mother displayed a still face instead of a communicative response to her infant. Infants' facial and vocal affective displays were coded to determine the degree to which they felt anger, sadness, joy, and other emotions. Results showed that in both age groups, greater incidence of infants' expression of sadness was related to increasing cortisol response, but anger was not.

In some infant cortisol studies, a specific event occurred, and the adrenocortical response to the stressor was assessed and compared to a subsequent session. Any difference in the pattern of cortisol responding across sessions implied that infants remembered something about the original event. For example, across two sessions separated by 24 hours, healthy newborn infants exhibited significantly reduced cortisol response to physical exam, and significantly greater cortisol response to heelstick (Gunnar et al., 1989a; Gunnar et al., 1992a). Cortisol levels also decreased in 6.5- to 13-month-old infants during two mother-infant swim classes (Hertsgaard et al., 1992), which was interpreted as an example of a novel event producing positive emotions, being remembered as pleasant, resulting in decreased cortisol levels over time (Gunnar & Donzella, 2002). However, in these studies, no measurements of infant cognitive abilities were reported.

To our knowledge, there is only one reported study attempting to investigate relations between cortisol responsiveness and learning in the context of a relatively stress-free experimental paradigm. Haley, Weinberg, and Grunau (2005) used a conjugate reinforcement mobile task (Rovee-Collier et al., 1980) to assess the relationship between adrenocortical reactivity and contingency learning in preterm and full-term 3-month-old infants. Infants were tested at various times of the day in their homes, in the presence of both the experimenter and the infants' mothers, at a time of day when the infant should have been alert and active. The procedure involves attaching a ribbon to the infant's foot, attaching the ribbon to the mobile, and measuring the infant's rate of kicking to cause the mobile to move during several phases, including baseline, learning, and extinction. Researchers operationalized infants' rate of kicking in specific ways as evidence for learning (Day 1), recognition memory (Day 1), and long-term retention (Day 2). Saliva sampling was undertaken two times both immediately before and 20 minutes after the introduction of the mobile task, and on two consecutive days. Two groups of infants were compared, those whose cortisol levels increased ($\pm 0.01 \mu\text{g/dl}$) and those whose cortisol levels decreased. Results showed no difference in recognition memory for cortisol increasers compared to cortisol decreasers. However, infants whose cortisol levels increased .15 and .30 $\mu\text{g/dl}$ across sampling periods on Day 1 ($n = 5$) showed strong evidence for long-term retention of the kicking/mobile movement contingency on Day 2, while decreasers and infants whose cortisol either increased minimally or more than .30 $\mu\text{g/dl}$ showed no evidence for long-term retention. These results are consistent with the findings and perspectives of some researchers who argue that moderately increasing cortisol reactivity is associated with better memory (Abercrombie et al., 2003; Buchanan & Lovallo, 2001; de Kloet, Oitzl, & Joels, 1999).

van Bakel and Riksen-Walraven (2004) conducted a study on cortisol reactivity to a stressful event (a stranger/robot episode) and cognitive competence (measured using the Bayley Scales of Infant Development) in 15-month-old infants. They also assessed infant attachment security and anger proneness. Anger-prone infants, and infants with higher Bayley scores, showed greater cortisol reactivity to the stressful event than infants who were less prone to anger and who had less cognitive competence. Further, among those infants showing an insecure attachment with their mother, greater cortisol reactions occurred in the high cognitive competence group than in the low cognitive competence group, while no such relation existed in the secure attachment group.

The association between mother-infant behavior and infant psychophysiological responding has been extensively studied. Gunnar and her colleagues explored the relationship between infant stress reactivity in cortisol and attachment security (e.g., Gunnar et al., 1996). They found that pretest cortisol levels in 2-, 4-, and 6-month-old infants were not associated with mother's greater responsiveness during a physical exam, but were associated with later attachment security. Specifically, higher cortisol levels in 2- to 6-month-olds were associated with later insecure attachment classifications assessed when the infants were 18 months old.

In a sample of 9-month-old infants, Gunnar et al. (1992) found that providing infants with a sensitive and responsive substitute caregiver completely prevented elevations in cortisol normally observed in a 30-minute maternal separation period; importantly, elevations across this interval were witnessed when these substitute caregivers ignored the infants. Similar findings were reported in studies of 18-month-old infants (Nachmias et al., 1996), and younger infants (Spangler et al., 1994). In their recent literature review, Gunnar and Donzella (2002) concluded that, in general, highly fearful, insecurely attached and disorganized infants had higher cortisol reactivity than those more securely attached to their mothers. However, some studies have reported a lack of a relationship between maternal sensitivity and infant cortisol response (e.g., Fleming, Steiner, & Corter, 1997; Haley & Stansbury, 2003).

Haley and Stansbury (2003) investigated 5- and 6-month-old infants' behavioral and psychophysiological responses using a modified version of the still-face paradigm that included an additional still-face reunion sequence. Parent responsiveness was coded from videotaped interactions, wherein parental behavior that was contingent upon infant facial affect or vocalizations contributed to the percentage of observed responsive behaviors. Measures of infant psychophysiological response included heart rate and cortisol change between pre-test and 30 minutes after the start of testing, while the percentage of time infants looked at the parent's face and the frequency of negative affective responses comprised the infant behavioral response measures. Results showed that parental responsiveness was associated with greater regulation of heart rate and lowered negative affect during the still-face procedure, but that infant cortisol response remained unaffected by parental responsiveness. In summary, the picture of infant psychophysiological, and in particular, cortisol, response is complex, and is affected by intrinsic factors, the social-interactive environment, and situational factors.

Our empirical paradigm was designed so that we could focus on these questions: (a) How are different patterns of infant cortisol response associated with demonstrations of infant learning in an experimental context?, and (b) How is maternal sensitivity associated both with infants' initial cortisol level at the start of a learning event and with infants' cortisol response to the learning situation? Given the complex, and as yet, sparse picture of infant cortisol response to learning situations, we deemed it important to outline the theoretical groundwork and specific design parameters of our investigation that are relevant to our predictions.

We are guided in part by some recent findings that, in toddlers, the control of both emotion and cognitive processes resides in common brain areas (Posner & Rothbart, 2000). If this is also true earlier in development, consistent with this finding, our general expectation is that infants who can manage their emotional response to a moderately stressful situation would be more likely to show learning during an experiment than infants who manage their emotional response less well. Further, in line with other researchers, we assume that cortisol elevations reflect a failure of the infant's behavioral coping system (e.g., Gunnar et al., 1996; Levine & Wiener, 1988; Spangler & Grossman, 1993), and further, that a maternal separation episode constitutes a challenge to the 3-month-old infant's emotional response system (e.g., Ahnert, Gunnar, Lamb, & Barthel, 2004). Lastly, empirical work is supportive of the phenomenon that prolonged or severe stressors interfere with encoding and memory processes (e.g., Hellfinger & Newcomer, 2001). Taken together, past theoretical and empirical work implies that if the infant is left to cope without the physical presence of his/her mother while simultaneously experiencing a novel experimental learning task, failures in emotion coping may be associated with reductions in infants' capacities for learning and remembering aspects of an experienced event.

There are three notable differences between this, and the single other (Haley et al., 2005), published investigation into relations between infant cortisol reactivity and learning in young infants. First, we include measurements of maternal cortisol. Studies investigating associations

between human maternal behavior and cortisol have found that mothers with higher levels of cortisol show the most affectionate behaviors (Fleming, Steiner, & Anderson, 1987), and are better able to identify their own infants' odors when tested two days after birth (Fleming et al., 1997). Spangler (1991) studied cortisol levels in newborn and several-month-old infants and observed that mean infant cortisol levels were significantly related to mean maternal cortisol for newborn and older infants, which could be due to shared genetics, shared environment, or the interaction. Our study is the first to explore potential links between maternal and infant cortisol reactivity, and between maternal cortisol and maternal behavior, in the context of an infant learning experiment. Second, in the Haley et al. (2005) experiment, infants demonstrated contingency learning by making kicking movements. Studies on children show a direct relationship between cortisol levels and physical activity (e.g., Cielslak, Frost, & Klentrou, 2003). Our design used an experimental paradigm where infants were confined to an infant seat, allowing much less opportunity for body movements, thereby minimizing the contributing influence of physical exertion in infant cortisol response. Third, we provide a measure of maternal sensitivity to assess whether or not sensitivity is associated both with infants' cortisol levels at the start of the learning task, and infants' changing cortisol levels resulting from their experiences during the learning task.

Assessment of Mother-Infant Synchronous and Asynchronous Co-occurrences

The quality of early mother-infant interaction plays a significant role in the formation of a secure attachment bond (Ainsworth, Blehar, Waters, & Wall, 1978; Bowlby, 1969). When mothers notice their infant's signals and respond in a sensitive manner throughout the first year, a secure attachment bond is a more likely outcome than an insecure bond (Atkinson et al., 2000; de Wolff & van Ijzendoorn, 1997). Recognizing that maternal sensitivity is made manifest both through the initiation of a sensitive behavior, and by a sensitive response to an infant signal, Isabella, Belsky, and von Eye (1989) developed a bidirectional system for coding mother-infant interaction that is used extensively in research (e.g., Isabella & Belsky 1991; Wendland-Carro, Piccinini, & Millar, 1999). They used 13 mother-infant interaction categories to define both synchronous and asynchronous behavioral exchanges. A synchronous exchange such as *infant vocalizes—mother vocalizes/smiles* is an indicator of caregiver sensitivity, while an asynchronous exchange, such as *infant vocalizes/cries—mother unresponsive* is an indicator of caregiver insensitivity. As in Isabella et al. (1989), we determined the incidence of both synchronous and asynchronous exchanges between mother and infant in a 10-min videotaped free play session, and calculated the percentage of total codable behaviors that fit their synchronous and asynchronous behavioral exchange categories. The percentage of synchronous behavioral exchanges thus served as a measure of maternal sensitivity in our study, and was assumed to be indicative of the interactive experiences typically shared by each mother-infant pair.

The Present Study

Learning in 3-month-old infants was tested using a two-monitor standard preferential looking procedure (Kemler Nelson et al., 1995), a common tool used in investigating infants' speech (Hirsh-Pasek et al., 1994) and visual (e.g., Thompson, Madrid, Westbrook, & Johnston, 2001) processing abilities. The procedure we employed most closely resembled one used by Courage and Howe (1998) in their study of novelty and familiarity preferences in 3-month-olds. Acquisition and retention constituted two phases of the procedure that are indicative of progressive steps in the learning process. During acquisition, a consistent auditory stimulus (a recording of the infant's mother) co-occurred with the presentation of a moving colored block (either red or yellow), with the trial length contingent upon the infant's head turning behavior. The other color block was never paired with mother's voice. All infants accumulated 90-sec of total looking time during this phase. We compared infants' looking times to the monitor with the voice/color block correspondence against looking times to the other monitor displaying the

color block that was not paired with mother's voice. *Learning* was operationalized as a significant preference in looking times for the voice/color block pairing, compared to the colored block that was not paired with mother's voice. A retention phase immediately followed the acquisition phase, during which the red and yellow block stimuli were again presented on the two side monitors, without the voice stimulus. Evidence for *short-term memory* was operationalized as a significant difference in looking times toward the color block previously associated with mother's voice, compared to the block that was not. This procedure is not informative of the degree of learning or the degree of retention exhibited by infants; rather, significant differences between the two categories of stimuli are indicative of whether the infant group in question learned and/or remembered the visual/object correspondences.

The time course of events in the experiment was important for establishing what aspects of psychophysiological functioning are reflected in cortisol values. Table 1 presents the sequence of activities during the testing session. Testing occurred at a time of day that was most convenient for the mother, and when the baby was likely to be alert and awake--typically, in the morning hours. Most mothers drove to the laboratory. Upon entering the laboratory, mothers chatted with the experimenter, settling in for several minutes before participating in a 10-min videotaped session. Basal saliva sampling took place roughly 20 minutes after entering the lab for both infant and mother. Then the learning experiment occurred, when the infant was put in the seat and the mother disappeared out of view from the infant. The duration of the learning experiment varied, depending on the infants' looking behavior, but never exceeded 25 minutes. Finally, a second saliva sampling event occurred between 20-30 min after the beginning of the learning experiment. Given that peak cortisol response is typically 20-30 min following an event (e.g., de Weerth & van Geert, 2002) we assume that the cortisol level for the basal sampling period (T1) primarily reflects infants' (and mothers') psychophysiological response to the novel lab context as experienced in each other's physical presence, and that this level reflects a certain degree of physiological, and perhaps emotional, arousal due to the physical activities in getting to the lab and to the novelty of the laboratory environment. We further assume that the difference in cortisol levels between sampling periods ($\Delta T1 - T2$) is reflective of infants' reactions to both maternal separation and the novel learning event. And finally, we believe it is important to categorize infants as "increasers" or "decreasers" based on T1 and T2 cortisol values that are different enough to be indicative of true change. To this end, we used a stringent criterion of requiring one-half standard deviation difference in cortisol levels between sampling periods as evidence for either increasing or decreasing cortisol reactivity. This amount of change was approximately the same as the interassay coefficient of variation in our sample.

Hypotheses

We hypothesize that infants who experience a decline in cortisol levels during the experimental session will show learning and memory for the object associated with their mothers' voices, whereas infants who experience an increase in cortisol levels will not learn, nor consequently remember, the object associated with their mothers' voices. Based on our literature review, we also predict an association between maternal sensitivity and infant cortisol values; this hypothesis would receive support in correlations between behavioral synchrony scores assessed in the videotaped 10-min mother-infant interaction period and both infant T1 scores and infant $\Delta T1 - T2$ scores. Specifically, lower absolute values of infant T1 scores and less reactivity are predicted to be positively correlated with our maternal sensitivity measure.

Several additional, more exploratory hypotheses will be entertained. This is the first study to explore whether or not there is a relationship between maternal sensitivity and *maternal* cortisol response. While past research has shown a relationship between positive attitudes toward mothering and cortisol response (Fleming et al., 1987), it is unknown whether a similar relation

exists between maternal sensitivity and maternal cortisol. Finally, because mothers and infants were in close physical proximity to each other prior to T1 sampling, and consistent with past research, we predict that infant and maternal values will be significantly positively correlated at T1 (Spangler, 1991). However, research has not yet addressed whether maternal and infant cortisol reactivity are correlated during a separation/learning event. A lack of a correlation between mothers and babies in $\Delta T1 - T2$ could occur given that they could plausibly have differing emotional reactions to the separation experience and the learning experiment. On the other hand, it might also be expected that mothers would have an empathic psychophysiological response to their infants during the separation/learning event, which would be reflected in a positive correlation.

Method

Participants

The final sample of 63 3-month-old infants (26 females, 37 males) and their first-time mothers came from a larger set of 107 participating mother-infant pairs. All infants were full-term at birth and were free of any known neurological or sensory impairments. They were recruited through television, radio, and newspaper advertisement, and by posting fliers at business establishments throughout Las Cruces, NM. Forty-four infants were eliminated for the following reasons: 23 were too fussy to complete the preferential looking experiment, five did not meet the looking time criterion during the retention phase (500 msec each trial), and 16 infants did not contribute sufficient amounts of saliva in one or both samples. Their ethnic composition was: 50.8% Non-Hispanic Caucasian; 44.4% Hispanic; 4.8% "other". The infants were tested within two weeks of their 3-month birthdays ($M = 13.2$ weeks; $SD = 0.84$ weeks). Mothers were on average 24.6 years old ($SD = 6.55$ years), averaging 14.8 years ($SD = 2.8$) of education. Financial status was assessed by questionnaire, yielding the following outcome: 12.7% "do not have enough money to meet basic needs"; 17.5% "barely pay the bills but manage on my own"; 54.0% "have enough for basic needs plus extra spending money"; and 15.9% "rarely have to worry about money". Mothers came to the lab for a preliminary session to become familiar with the lab setting and to provide speech samples. They were also given a demographics questionnaire and the Beck Depression Inventory. None of the mothers in the final sample scored in the moderate or severe range for depression. They were paid for their participation.

Preferential Looking Task

Stimuli and design—There were two phases of the preferential looking experiment: acquisition and retention. In the acquisition phase, the mother's prerecorded voice sample was paired with either a brightly colored yellow block or a red block, moving in a slow, wave-like pattern across the monitor. The audio recording of the infant's mother was presented through a speaker mounted 4 inches above each monitor. Each mother spoke "Oh! Look at that block!" in a manner that she would normally use to get her infant's attention. Volume and length of the samples were consistent across participants.

For one-half of the infants, their mother's voice was paired with the red block; for the other half the voice pairing occurred for the yellow block. Within these two groups, the first trial pairing occurred on the infants' right or left sides equally across participants. This pairing alternated in random fashion after the first four trials, each with a maximum trial time of 30 seconds. Mother's voice was presented up to five times at equally spaced intervals during each trial. Trials were added until the infant's total looking time to the stimuli during acquisition reached 90 seconds. This criterion was established so that all infants had equal and sufficient familiarization with the stimulus events before beginning the retention phase.

The retention phase consisted of two trials with silent presentations of the moving red and yellow block images, for a maximum trial duration of 60 seconds. Right-left presentation was counterbalanced across infants.

Procedure—The experimenter viewed the infant from behind a one-way window, located centrally in front of the infant. The experimenter held switches in the right and left hands, indicating infants' looking toward the right side, left side, or neither side. He/she also wore headphones that presented auditory masking stimuli. A video camera was situated at center, recording the infant during the entire procedure. This data was used for reliability coding of infant looking times (Cronbach's alpha was .97).

Infants sat secured in an infant seat that rested on a wooden stool. Foam pads were inserted behind the infant's head for support. The seat faced two identical 15-in color video monitors that were separated by a distance of 62 in. A large gray area surrounded the video monitors and blocked the infant's view of equipment and people behind it. The monitors and speakers were oriented at a 45-degree angle to the infant.

A blinking light and a ringing bell sound were used to capture the infant's attention. A trial began when the infant looked centrally for two seconds, and ended when the infant looked away for one second. At the end of each trial, there was a two-sec pause. After a two-minute break, the two-trial retention phase began, and looking times were recorded to the moving red and yellow block stimuli without accompanying voice. The mother stood throughout the session behind a partition, looking out a window at her infant but out of her infant's view.

Video-Recording and Observational Coding

Upon entering the laboratory, mothers engaged in conversation with the experimenter, and readied the infants for the experiment for approximately 10 minutes. The experimenter then asked mothers to “play with” their infants in any way they felt to be comfortable and appropriate during 10-min videotaped time period. The room was 6.17 × 7.83 ft, and contained a carpeted area, a small couch, a table with magazines on it, and a basket of toys.

We used a modification of the methods developed by Belsky, Isabella and their colleagues (Isabella et al., 1989; Isabella & Belsky, 1991), in which observations of mother-infant interaction were done in their homes as mothers were asked to “go about their daily routines” (Isabella & Belsky, 1991, p. 375). We included 11 of the 12 maternal behaviors (e.g., no behavior, leisure activity, leisure and attend to infant, attend to infant, vocalize to infant, stimulate/arouse, stimulate arouse and vocalize to infant, en face interaction, response to infant vocalization, soothe, response to vocalization and soothe) and 10 of the 11 infant behaviors (e.g., sleep/drowsy, no behavior, explore, look at mother, vocalize, vocalize and look at mother, en face interaction, response/explore, fuss/cry, response/explore and en face) that Isabella and Belsky used in their study. The 3-step interaction behavior for the mother and infant were the only behaviors left out of their coding scheme due to the difference in coding interval length between Isabella and Belsky's research (15 sec) and our research (10 sec), which did not allow for enough time for reliable coding of 3-step behaviors. The 10-min videotaped interactions were digitized and imported into the Observer software program (Noldus Corporation). Two individuals who were extensively trained on Isabella and Belsky's maternal-infant interaction coding system separately coded the *entire set* of mother and infant videos. The 10-sec sampling period was prompted by a timer. The same two individuals reviewed every interval where their codes differed, and discrepancies were resolved by discussion. Prior to discussion, reliability between coders was high (> 90%). All of the mother and infant behaviors coded are listed in Appendix A.

Synchronous dyadic interactions are characterized by mutually rewarding and reciprocal exchanges by the mother and infant, while asynchronous interactions are those that seem one-sided, unresponsive, or intrusive on the part of the mother. For a synchronous exchange to occur, the mother responded to the infant in a manner that was sensitive and contingent upon the infant's behavior. For example, if the infant vocalized and the mother's response appeared to be contingent on that vocalization, by soothing and/or making some other sensitive behavioral response to that vocalization, the dyadic interaction was classified as synchronous. On the other hand, if the infant explored and the mother stimulated, aroused, or vocalized to the infant, those were seen as asynchronous in that her behavior interfered with the infant's independent exploring. Co-occurrences not listed in the tabled categories were considered neutral and were used only in the denominator representing total numbers of behaviors coded. Two individuals not involved in behavioral coding independently determined the synchrony category for each pair of codes for mother and infant. Any differences in categorizing mother-infant behaviors were resolved by revisiting the tabled codes. The percentage of synchronous behaviors (number of synchronous behaviors divided by the total number of intervals coded, times 100) served as the final measure of behavioral synchrony. The same algorithm was used to determine the percentage of asynchronous behaviors exhibited in mother-infant interaction.

Cortisol Collection and Analysis

The experiment was conducted at times when it was most convenient for the mother. Saliva samples were collected from the mother and infant twice: at the end of the videotaped period and 20-30 min ($M = 24.8$ min) after the experiment was initiated. If the mother needed to feed her infant, we waited at least thirty minutes from feeding to take the first sample (Spangler, 1991). Mothers chewed on a cotton dental roll, the roll was placed in a tube, stored at -20°C , and shipped to Salimetrics, Inc. for radioimmunoassay analysis (Fleming, et al. 1997). The roll or braid was applied to the tongue, cheeks and gums of the infant (Lewis & Ramsay, 1995). Duplicate assays were performed at the lab, with an intraassay coefficient of variation of 7.60%.

Results

This research concerns how infant learning and short-term memory are affected by changes in cortisol concentration from Time 1 (prior to the looking time experiment; T1) to Time 2 (post-experiment; T2), termed "cortisol reactivity", and how maternal sensitivity assessed prior to the learning experience may be related to infant adrenocortical functioning during a learning experience. We explored possible additional relationships between mothers' and infants' cortisol levels at T1, between maternal and infant cortisol reactivity, and between behavioral synchrony and mothers' cortisol reactivity.

We first conducted Pearson R tests for relations between study variables (preferential looking during acquisition, preferential looking at retention, degree of synchrony, $\log_{10}$ cortisol values at T1 and T2) and potentially confounding variables (gender, mother's age, ethnicity, education, and income). None of these correlations were significant (all p 's $> .05$), with one exception: gender was correlated with cortisol values at Time 2, ($r(62) = .32, p = .01$), indicating that boys' T2 cortisol values tended to be lower than girls' values.

The cortisol data from the entire set of participants with obtained cortisol data was examined for outliers, defined as ± 3 SD from the mean for each sample (Gunnar & White, 2001). In the data for the 63 complete and final mother-infant sets, there were no scores that fit this criterion. The raw cortisol values at T1 and at T2 were not normally distributed, so the raw scores were transformed to $\log_{10}$ scores (Larson et al., 1998). All subsequent statistics were conducted on the $\log_{10}$ values. A value of 0.5 SD from the mean of the raw score sample was used in establishing the cortisol change category for the difference in cortisol between T1 and T2, or $\Delta\text{T1-T2}$ cortisol (M. Gunnar, personal communication, May 30, 2006). Thus, if an

individual's $\Delta T1-T2$ cortisol was positive and changed 0.5 *SD* or more, this was categorized as a decrease in cortisol (infant $n = 16$; mother $n = 8$). If $\Delta T1-T2$ was negative and greater than 0.5 *SD*, this was categorized as an increase (infant $n = 14$; mother $n = 2$). No change from T1 to T2 was categorized as such (infant $n = 33$; mother $n = 53$). Table 2 presents descriptive statistics for the cortisol data for the final 63 mother-infant pairs.

Figure 1 graphically displays the infant T1, T2 and $\Delta T1-T2$ data for all three cortisol change categories. A post-hoc analysis showed infants in the decreasing cortisol category had T1 values that were significantly higher than infants in the increasing cortisol category, $t(28) = 6.14, p < .0001$. As in other recent studies (e.g., Haley et al., 2005; Ramsay & Lewis, 2003) time of day for saliva collection and $\Delta T1-T2$ cortisol were not correlated in either the mother's data or the infant's data (p 's $> .05$), and was not considered in further analyses.

To test the hypothesis that infants with decreased $\Delta T1-T2$ cortisol levels would both learn and remember object fields associated with mother's voices, while infants with increased $\Delta T1-T2$ cortisol would not, separate t-tests were conducted on the infants' preferential looking data at acquisition and retention phases who fell into these two categories, as well as the infants with no $\Delta T1-T2$ cortisol change. Data were averaged across trials within each phase. In the decreased $\Delta T1-T2$ cortisol group, infants' looking times were significantly greater for the color block associated with their mothers' voices both during the acquisition phase, $t(15) = 2.44, p = .028, d = .61$, and during the retention phase, $t(15) = 2.25, p = .04, d = .56$, looking longer at the monitor with the color block that also presented their mothers' voices, and showing that they expected to hear their mothers' voices again associated with the same color block during the retention trials. In contrast, in the increased $\Delta T1-T2$ cortisol group, looking times across conditions were not significantly different both for acquisition ($t(13) = 0.21, p = .840, d = .06$) and retention ($t(13) = -0.877, p = .396, d = .23$) phases, showing that they did not encode the color/voice association, nor did they demonstrate a memory or expectation of the association. For the no change in $\Delta T1-T2$ cortisol infant group, looking times were significantly greater for associated voice/color trials at the acquisition phase ($t(32) = 3.40, p = .002, d = .59$), but not at the retention phase ($t(32) = -0.98, p = .334, d = .17$), revealing a looking time preference for block color/mother's voice combination with voice presentations, but no expectation of her voice during later silent moving block trials. These data are shown in Figures 2 and 3 for acquisition and retention phases, respectively.

In investigating the relationships between mother-infant behavioral synchrony and infant and maternal cortisol response, preliminary tests were conducted to determine if covariates should be included in subsequent tests. Cortisol responses are subject to the Law of Initial Values (LIV; Wilder, 1956). Greater $\Delta T1-T2$ increase should occur in a system that is at a lower level of activity at T1 than when the system is at a higher level of activity at T1. As explained by Gunnar and White (2001), two conditions must be met before a researcher should be concerned about the LIV. Namely, (a) there must be significant difference between T1 cortisol and T2 cortisol values, and (b) T1 and T2 values must be significantly positively correlated. Looking at infant cortisol first, T1 and T2 cortisol values were positively correlated ($r(62) = .47, p < .0001$), however, a paired samples t-test showed no significant change between T1 and T2 values ($t(df) = -0.21, p > .05$). For mother, T1 and T2 values were also positively correlated ($r(62) = .86, p < .0001$), and there was a significant decrease in cortisol from T1 to T2 ($t(62) = 5.54, p < .0001$). Thus, in the infant sample, no steps needed to be taken to remove the variance from change scores that might be associated with T1 scores. However, for correlations involving mothers' $\Delta T1-T2$ values, T1 scores were included as a covariate due to LIV considerations.

To investigate whether or not maternal sensitivity was associated with infant cortisol response, partial correlations were conducted on the set of mother-infant behavioral synchrony scores and infant $\Delta T1-T2$ values, controlling for maternal T1 values. The resulting correlation was

nonsignificant ($p's > .05$). The next test of a correlation between mothers' cortisol change scores and behavioral synchrony revealed a marginally significant positive correlation, $r(58) = .25$, $p = .056$, showing that mothers with greater decreasing cortisol reactivity (on this scale, higher scores) showed higher degrees of sensitivity to their infants in the 10-min videotaped normal interaction period. Finally, as Table 3 shows, synchrony and asynchrony were significant negatively correlated ($r(58) = -.29$, $p < .05$), indicating that those mothers exhibiting a greater percentage of synchronous behaviors with their infants also exhibited a lower percentage of asynchronous behaviors.

Furthermore, a bivariate correlation conducted on infant and maternal $\log^{10}$ T1 cortisol values yielded the predicted significant positive correlation, $r(62) = .381$, $p < .005$; and further, mothers' and infants' $\Delta T1-T2$ values were uncorrelated, $p > .05$. Taken together, the correlation analyses show that the degree of behavioral synchrony, or sensitivity, mothers display in their interactions with their infants is significantly related to their own, but not with their infants', cortisol reactivity to a separation/learning event. Furthermore, mothers' and infants' cortisol levels were significantly correlated with each other when they began the experiment, but their patterns of cortisol reactivity in response to the separation episode/learning event were uncorrelated.

Discussion

We found that infants showing a decline in cortisol levels between T1 (prior to learning experiment) and T2 (after learning experiment) were the only group that showed both learning and short-term memory for the voice/object association. The group with unchanged cortisol levels showed learning of the voice/object association during the acquisition phase, but no evidence of remembering the association in the retention phase, while the group with increased cortisol reactivity neither learned nor remembered the voice/object association. Thus, our data are consistent with our predictions that decreasing stress reactivity would enhance learning, while increasing stress reactivity would impair learning. Our predictions and our view about cortisol's relationship to learning follow from the argument that similar brain areas are responsible for the control of emotion and cognition in infancy and toddlerhood (Posner & Rothbart, 2000; Rothbart & Bates, 1998). New evidence shows an association between some measures of cognitive function in preschool children and a pattern of moderate increase in cortisol followed by a down-regulation of this increase (Blair, Granger, & Razza, 2005). Similarly, in our study, those infants evidencing greater control over their emotional reactions were expected to, and did, show greater control of attention and memory processes during a learning event.

This is a very new topic of investigation, but the only other published investigation on how learning and memory are affected by increasing and decreasing cortisol reactivity in young infants found different results (Haley et al., 2005). In their study using a conjugate mobile reinforcement task, cortisol reactivity was not predictive of Day 1 assessments of learning or short-term memory. However, infants whose cortisol *increased* moderately during the learning interval on Day 1 were the only group showing long-term memory of the kicking/mobile movement pairing on Day 2. A simple way to reconcile our differing patterns of findings across studies would be to postulate that increasing cortisol response might be associated with only those processes that involve long-term retention in infants, and decreasing cortisol response may sometimes be associated with better learning and short-term memory processes. A second contributing factor for the differing results is the procedure for inclusion in cortisol change categories. Haley et al. (2005) used a minimal change value, $.01 \mu\text{g/dl}$, and we used $.5 \text{ SD}$ of the group data set ($.10 \mu\text{g/dl}$ in infants) to identify and categorize increasing and decreasing cortisol response patterns. Given that there is a degree of imprecision in the measurement process for determining cortisol levels in saliva, we argue that small $\Delta T1-T2$ differences should

not be regarded as “true” cases of decreasing or increasing cortisol reactivity. Indeed, when Haley et al. (2005) looked more closely at the amount of change exhibited in infants in their increasing cortisol change category, and related gradations of change to long-term memory results, they found that those infants whose cortisol increased .01 - .14 µg/dl did not evidence long-term memory. Many of the infants in their minimally increasing set would have been placed in the “no change” category in our study, and, consistent with their findings, infants in this category did not demonstrate short-term memory. There are two positive outcomes of using our system for classifying $\Delta T1$ -T2 values. First, it is possible to make separate predictions for “no change”, versus “increasing” and “decreasing” response patterns when three, instead of two, categories are used. And second, because of the issue of intrassay variation, we believe the classification system requiring greater dispersion between T1 and T2 values is a more valid tool to measure change between sampling periods, leaving less doubt concerning the true nature of the relationship between cortisol response and learning/memory processes.

These factors aside, it still remains to be explained why our study yielded evidence for a relationship between reactivity and learning and short-term memory, and their results did not. One likely factor pertains to the degree of motor behavior infants engaged in as part of the learning task. In Haley et al.'s (2005) study, infants made kicking movements throughout the testing interval; in contrast, in our paradigm, infants were confined to a chair and moved only their head, eyes, and upper bodies in order to look at the side monitors. Exercise is associated with higher cortisol levels in children (Cieslak et al., 2003). Research on the relationships between cortisol response and infant learning would benefit by efforts to investigate the potential role played by bodily movement.

In addition, in the Haley et al. (2005) study, the infants were tested at home, in their own beds, where they probably felt fairly comfortable prior to and during saliva collection. Varying emotional reactions to the novel experience of the reinforcement task were not considered. In contrast, our intention was to use a paradigm that would elicit varying emotional reactions which would in turn affect the learning process. Part of the variability in response occurred at the very beginning of the experiment, when infants were exposed to the novel setting while the mothers were in close physical contact with them during the “settling in” process. These experiences had differing effects on infants, with some infants showing much higher levels of cortisol at T1 than other infants. In sum, the obtained variability in infant response to the laboratory and to the maternal separation/novel learning event allowed us to focus on the question of how different patterns of emotional response might promote, or hinder, learning in young infants. However, we acknowledge that the link between cortisol reactivity and learning is mediated by infants' emotional responses to maternal interaction and maternal separation.

Finally, we predicted a relationship between maternal sensitivity and stress in infants, specifically greater synchrony values were predicted to be associated with lower infant cortisol at T1, and with less cortisol reactivity. Caregivers are often attributed with the role of being a powerful resource for infants to cope with stress (e.g., Bowlby, 1969; Spangler et al., 1994). Findings from a plethora of studies support the notion that mothers serve as an organizer of young infants' emotional regulatory systems, until they more fully develop their own abilities in emotion regulation. One possible reason we did not find evidence to support this notion is that our assessment of sensitivity did not occur during the separation/learning event, rather, it occurred prior to it. Perhaps at this young age, infants' stress responses during active learning would be related to maternal sensitivity only when both measures are conjointly assessed, because of the dependency on the infants' mothers for emotional regulation.

This research is the first of its kind to establish a relation between *maternal* cortisol reactivity and maternal-infant behavioral synchrony. While we cannot conclude a causal connection,

further research could address whether mothers use sensitive caregiving activities as a means of assisting their own emotion regulation patterns. In one early intervention study, researchers implemented a brief intervention that was successful in producing a significant increase in new mothers' sensitive behaviors (Wendland-Carro, et al., 1999). Further research could address the question of whether mothers, by engaging in greater degrees of synchronous behavior with their infants, consequently experience a down-regulation of cortisol response under varying situations of proximity and separation from their infants.

Finally, in line with previous research, our results also showed a positive correlation between mothers' and infants' T1 values. Correlations between mothers' and infants' basal cortisol values owe partly to their shared genetic makeup. However, our study contributed new evidence that the correlated values can diverge at the onset of a separation/learning event. What are the situational and temperamental variables that affect whether or not mothers and babies will experience similar patterns of emotional reactivity when in close physical proximity to each other? Other studies propose that cortisol synchrony between partnered males and females may occur at the time of pregnancy and birth, suggesting that people who are especially close, both emotionally and physically, may experience parallel physiological responses to certain events, such as infant crying (Storey et al., 2000). The lack of a correlation between mothers and their young infants in cortisol change scores obtained in our study could be surprising to some. It may be that there are key events in the social-interactive experience that must happen in order to trigger an empathic caregiver cortisol response—for example, the infant cries or displays a sad facial expression.

Further Research Questions

Recent evidence shows that emotional reactivity (high or low intensity of initial response to a stressor) and emotional regulation (rapid or slow response dampening following reactivity), operate as independently functioning systems in infants (Ramsay & Lewis, 2003). Our data support a linkage between the direction of *emotional reactivity* to the experimental learning event and cognitive control in young infants, but did not address emotional regulation. One viable and interesting next step would be to extend our experimental paradigm to investigate emotional regulation processes as they continue beyond an initial response to a new learning event. In light of Blair et al.'s (2005) recent findings with preschoolers, it would also be important in future infant studies to extend the experimental session on the front end, by including a pre-T1 saliva sampling measure, while controlling the intervening interval up to the point of T1 sampling, in order to ascertain more precisely what factors contribute to the infant's T1 level of arousal.

Finally, it might be profitable for future research to focus on identifying the emotions infants are feeling as they are exposed to learning events. While it is not always the case that neuroendocrine stress reactions map in expected ways onto behavioral emotional reactions (e.g. Lewis, Hitchcock, & Sullivan, 2004; White et al., 2000), exciting new research shows congruence between some emotional behavioral reactions and cortisol reactivity. For example, Lewis and Ramsay found that, in preschoolers, greater expression of shame about task failure (Lewis & Ramsay, 2002), and in 4- and 6-month-old infants, greater expression of sadness (but not anger) in goal-blockage situations (Lewis & Ramsay, 2005) was related to increased cortisol response. If during a novel learning event infants are simultaneously feeling sad, they might be less inclined to initiate cognitive functions for learning, as opposed to when they feel joyful, content, or even angry.

Acknowledgements

The research was funded by a NIH NIGMS grant (#3S06 GM008136) and the NIH MBRS RISE grant program (#6M61222). We thank Elizabeth Arias, Leila Diaz, Carla Escabi-Ruiz, Lori Fields, Erin Johns, Denisse Licon, Xavier

Pena, Katie Silva, and Roseanna Villarreal, for help with data collection and coding, Dr. Megan Gunnar for her helpful comments, and the mothers and infants who participated in this study.

Appendix A

Maternal and Infant Behaviors Coded, and Their Inclusion Into Synchronous and Asynchronous Categories (modified only slightly from Isabella and Belsky, 1991)

Maternal behaviors		Infant behaviors	
1	no behavior	A.	Sleep/drowsy
2	leisure activity	B.	No behavior
3	leisure and attend to infant	C.	Explore
4	attend to infant	D.	Look at mother
5	vocalize to infant	E.	Vocalize
6	stimulate/arouse	F.	Vocalize and look at mother
7	stimulate/arouse, and vocalize to infant	G.	en face interaction
8	en face interaction	H.	Response/explore
9	response to infant vocalization	I.	Fuss/cry
10	soothe	J.	Response/explore and en face
11	response to vocalization and soothe		
Synchronous behaviors:		Asynchronous behaviors:	
<i>Infant</i>	<i>Mother:</i>	<i>Infant</i>	<i>Mother</i>
C	8	A	5, 6, 7
E	9, 11	B	5, 6, 7
F	9, 11	C	6, 7
G	5, 6, 7, 8, 9, 10	E	1, 2, 3, 4, 5, 6, 7
H	6, 7, 8, 9, 10, 11	F	1, 2, 3, 4, 5, 6, 7
I	10, 11	I	1, 2, 3, 4, 5, 6, 7, 8, 9
J	9, 10, 11		

References

- Abercrombie HC, Kalin NH, Thurow ME, Rosenkranz MA, Davidson RJ. Cortisol variation in humans affects memory for emotionally laden and neutral information. *Behavioral Neuroscience* 2003;117:505–516. [PubMed: 12802879]
- Ainsworth, MDS.; Blehar, MC.; Waters, E.; Wall, S. Patterns of attachment: A psychological study of the strange situation. Erlbaum; Hillsdale, NJ: 1978.
- Ahnert L, Gunnar MR, Lamb ME, Barthel M. Transition to child care: Associations with infant-mother attachment, infant negative emotion, and cortisol elevations. *Child Development* 2004;75:639–650. [PubMed: 15144478]
- Aslin, RN. Visual and auditory development in infancy. In: Osofsky, JD., editor. *Handbook of infant development*. 2d ed.. Wiley; New York: 1987. p. 5-97.
- Atkinson, I.; Niccols, A.; Paglia, A.; Coolbear, J.; Parker, KCH.; Poulton, L.; Guger, S.; Sitarenios, G. A meta-analysis of time between maternal sensitivity and attachment assessments: Implications for internal working models in infancy/toddlerhood. *Journal of Social and Personal Relationships* 2000;17:791–810.
- Bates, E.; Bretherton, I.; Snyder, L. Cambridge University Press; New York: 1988. *From first words to grammar: Individual differences and dissociable mechanisms*.
- Blair C, Granger D, Razza RP. Cortisol reactivity is positively related to executive function in preschool children attending Head Start. *Child Development* 2005;76:554–567. [PubMed: 15892778]
- Bowlby, J. Attachment and loss. 1. Basic books; New York: 1969.
- Buchanan TW, Lovallo WR. Enhanced memory for emotional material following stress-level cortisol treatment in humans. *Psychoneuroendocrinology* 2001;26:307–317. [PubMed: 11166493]

- Ciislak TJ, Frost G, Klentrou P. Effects of physical activity, body fat, and salivary cortisol on mucosal immunity in children. *Journal of Applied Physiology* 2003;95:2315–2320. [PubMed: 12909608]
- Courage ML, Howe ML. The ebb and flow of infant attentional preferences: Evidence for long-term recognition memory in 3-month-olds. *Journal of Experimental Child Psychology* 1998;70:26–53. [PubMed: 9679078]
- DeCasper AJ, Fifer WP. Of human bonding: Newborns prefer their mothers' voices. *Science* 1980;208:1174–1176. [PubMed: 7375928]
- de Kloet ER, Oitzl MS, Joels M. Stress and cognition: Are corticosteroids good or bad guys? *Trends in Neurosciences* 1999;22:422–426. [PubMed: 10481183]
- Dettling AC, Parker s. Lane SK, Sebanc AM, Gunnar MR. Quality of care and temperament determine whether cortisol levels rise over the day for children in full-day childcare. *Psychoneuroendocrinology* 2000;25:819–836. [PubMed: 10996476]
- de Weerth C, van Geert P. A longitudinal study of basal cortisol in infants: Intra-individual variability, circadian rhythm and developmental trends. *Infant Behavior & Development* 2002;25:375–398.
- de Wolff M, van Ijzendoorn MH. Sensitivity and attachment: A meta-analysis on parental antecedents of infant attachment. *Child Development* 1997;68:571–591. [PubMed: 9306636]
- Fleming AS, Steiner M, Anderson V. Hormonal and attitudinal correlates of maternal behaviour during the early postpartum period in first-time mothers. *Journal of Reproductive and Infant Psychology* 1987;5:193–205.
- Fleming AS, Steiner M, Corter C. Cortisol, hedonics, and maternal responsiveness in human mothers. *Hormones and Behavior* 1997;32:85–98. [PubMed: 9367716]
- Flinn, MV.; England, BG. Childhood stress: Endocrine and immune responses to psychosocial events. In: Wilce, JM., editor. *Social & cultural lives of immune systems*. Routledge Press; London: 2003. p. 107-147.
- Gunnar MR, Brodersen L, Nachmias M, Buss AK, Rigatuso J. Stress reactivity and attachment security. *Developmental Psychology* 1996;29:191–204.
- Gunnar MR, Connors J, Isensee J. Lack of stability in neonatal adrenocortical reactivity because of rapid habituation of the adrenocortical response. *Developmental Psychobiology* 1989a;22:221–233. [PubMed: 2707494]
- Gunnar MR, Donzella B. Social regulation of the cortisol levels in early human development. *Psychoneuroendocrinology* 2002;27:199–220. [PubMed: 11750779]
- Gunnar MR, Hertsgaard L, Larson M, Rigatuso J. Cortisol and behavioral responses to repeated stressors in the human newborn. *Developmental Psychobiology* 1992a;24:487–505. [PubMed: 1797593]
- Gunnar MR, Larson M, Hertsgaard L, Harris M, Brodersen L. The stressfulness of separation among 9-month-old infants: Effects of social context variables and infant temperament. *Child development* 1992b;63:290–303. [PubMed: 1611934]M.
- Gunnar MR, Mangelsdorf S, Larson M, Hertsgaard L. Attachment, temperament, and adrenocortical activity in infancy: A study of psychoendocrine regulation. *Developmental Psychology* 1989b; 25:355–363.
- Gunnar, MR.; White, B. Salivary cortisol measures in infant and child assessment. In: Singer, a. P. S. Z. L.T., editor. *Biobehavioral Assessment of the Newborn*. Guilford Press; New York: 2001.
- Haley DW, Stansbury K. Infant stress and parent responsiveness: Regulation of physiology and behavior during still-face and reunion. *Child Development* 2003;74:1534–1546. [PubMed: 14552412]
- Haley DW, Weinberg J, Grunau RE. Cortisol, contingency learning, and memory in pre- and full-term infants. *Psychoneuroendocrinology* 2005;31:108–117. [PubMed: 16122876]
- Heffelfinger AK, Newcomer JW. Glucocorticoid effects on memory function over the human life span. *Development and Psychopathology* 2001;13:491–513. [PubMed: 11523845]
- Hertsgaard L, Gunnar MR, Larson M, Brodersen L, Lehman H. First time experiences in infancy: When they appear to be pleasant, do they activate the adrenocortical stress response? *Developmental Psychobiology* 1992;25:319–334. [PubMed: 1526320]
- Hirsh-Pasek K, Kemler Nelson DG, Jusczyk PW, Wright Cassidy K, Druss B, Kennedy L. Clauses are perceptual units for young infants. *Cognition* 1987;26:269–286. [PubMed: 3677573]

- Isabella RA, Belsky J. Interactional synchrony and the origins of infant-mother attachment: A replication study. *Child Development* 1991;62:373–384. [PubMed: 2055128]
- Isabella RA, Belsky J, Von Eye A. Origins of mother-infant attachment: An examination of interactional synchrony during the infant's first year. *Developmental Psychology* 1989;25:12–21.
- Kemler Nelson DG, Jusczyk PW, Mandel DR, Myers J, Turk A, Gerken L. The head-turn preference procedure for testing auditory perception. *Infant Behavior and Development* 1995;18:111–116.
- Larson MC, White BP, Cochran A, Donzella B, Gunnar MR. Dampening of the cortisol response to handling at 3 months in human infants and its relation to sleep, circadian cortisol activity, and behavioral distress. *Developmental Psychobiology* 1998;33:327–337. [PubMed: 9846236]
- Levine S, Wiener SG. Psychoendocrine aspects of mother-infant relationships in nonhuman primates. Special Issue: Psychoneuroendocrine aspects of maternal behavior. *Psychoneuroendocrinology* 1988;13:143–154. [PubMed: 3287413]
- Lewis M, Hitchcock DFA, Sullivan M,W. Physiological and emotional reactivity to learning and frustration. *Infancy* 2004;6:121–143. [PubMed: 16718305]
- Lewis M, Ramsay D. Developmental change in infants' responses to stress. *Child Development* 1995;66:657–670. [PubMed: 7789193]
- Lewis M, Ramsay D. Cortisol response to embarrassment and shame. *Child Development* 2002;73:1034–1045. [PubMed: 12146731]
- Lewis M, Ramsay D. Infant emotional and cortisol responses to goal blockage. *Child Development* 2005;76(2):518–530. [PubMed: 15784097]
- Mandel DR, Jusczyk PW, Kemler Nelson DG. Does sentential prosody help infants organize and remember speech information? *Cognition* 1994;53:155–180. [PubMed: 7805352]
- Nachmias M, Gunnar M, Mangelsdorf S, Parritz RH, Buss K. Behavioral inhibition and stress reactivity: The moderating role of attachment security. *Child Development* 1996;67:508–522. [PubMed: 8625725]
- Posner MI, Rothbart MK. Developing mechanisms of self-regulation. *Development and Psychopathology* 2000;12:427–441. [PubMed: 11014746]
- Ramsay D, Lewis M. Reactivity and regulation in cortisol and behavioral responses to stress. *Child Development* 2003;74(2):456–464. [PubMed: 12705566]
- Rothbart, MK.; Bates, JE. Temperament. In: Damon, W.; Eisenberg, N., editors. *Handbook of child psychology, Vol. 3. Social, emotional, and personality development*. Wiley; New York: 1998. p. 105-176.
- Rovee-Collier CK, Sullivan MW, Enright M, Lucas D, Fagan JW. Reactivation of infant memory. *Science* 1980;208:1159–1161. [PubMed: 7375924]
- Sapolsky, RM. Neuroendocrinology of the stress-response. In: Becker, SMBJB.; Crews, D., editors. *Behavioral Endocrinology*. MIT Press; Cambridge MA: 1992.
- Siegler, RS. The origins of scientific reasoning. In: Siegler, RS., editor. *Children's thinking: What develops?*. Lawrence Erlbaum Associates; Hillsdale, NJ: 1978. p. 109-149.
- Spangler G. The emergence of adrenocortical circadian function in newborns and infants and its relationship to sleep, feeding, and maternal adrenocortical activity. *Early Human Development* 1991;25:197–208. [PubMed: 1935741]
- Spangler G, Grossman KE. Biobehavioral organization in securely and insecurely attached infants. *Child Development* 1993;64:1439–1450. [PubMed: 8222882]
- Spangler G, Schieche M, Ilg U, Maier U, Ackerman C. Maternal sensitivity as an external organizer for biobehavioral regulation in infancy. *Developmental Psychobiology* 1994;27:425–437. [PubMed: 7843497]
- Spelke E. Perceiving bimodally specified events in infancy. *Developmental Psychology* 1979;15:626–636.
- Spence MJ. Young infants' long-term auditory memory: Evidence for changes in preference as a function of delay. *Developmental Psychobiology* 1995;29:685–695. [PubMed: 8958481]
- Storey AE, Walsh CJ, Quinton RL, Wynne-Edwards KE. Hormonal correlates of paternal responsiveness in new and expectant fathers. *Evolution and Human Behavior* 2000;21:79–95. [PubMed: 10785345]

- Tamis-LeMonda CS, Bornstein MH, Baumwell L. Maternal responsiveness and children's achievement of language milestones. *Child Development* 2001;72:748–767. [PubMed: 11405580]
- Thompson LA. Dimensional classification strategies predominate in perceptual classification. *Child Development* 1994;65:1627–1645. [PubMed: 7859546]
- Thompson LA, Madrid V, Westbrook S, Johnston V. Infants attend to second order relational properties of faces. *Psychonomic Bulletin & Review* 2001;8:769–777. [PubMed: 11848598]
- Tronick E. Things still to be done on the still-face effect. *Infancy* 2003;4:475–482.
- van Bakel HJA, Riksen-Walraven JM. Stress reactivity in 15-month-old infants: Links with infant temperament, cognitive competence, and attachment security. *Developmental Psychobiology* 2004;44:157–167. [PubMed: 15054884]
- Walker AS. Intermodal perception of expressive behaviors by human infants. *Journal of Experimental Child Psychology* 1982;33:514–535. [PubMed: 7097157]
- Wendland-Carro J, Piccinini CA, Millar WS. The role of an early intervention on enhancing the quality of mother-infant interaction. *Child Development* 1999;70:713–721. [PubMed: 10368917]
- White BP, Gunnar MR, Larson MC, Donzella B, Barr RG. Behavioral and physiological responsivity, sleep, and patterns of daily cortisol production in infants with and without colic. *Child Development* 2000;71:862–877. [PubMed: 11016553]
- Wilder J. The law of initial value in neurology and psychiatry. *Journal of Nervous and Mental Diseases* 1956;125:73–86.
- Woodward AL, Markman EM, Fitzsimmons CM. Rapid word learning in 13-and 18-month-olds. *Developmental Psychology* 1994;30:553–566.
- Yehuda R, Engel SM, Brand SR, Seckl J, Marcus SM, Berkowitz GS. Transgenerational effects of posttraumatic stress disorder in babies of mothers exposed to the World Trade Center attacks during pregnancy. *Journal of Clinical Endocrinology & Metabolism* 2005;90:4115–4118. [PubMed: 15870120]

Figure 1. Mean $\log_{10}$ cortisol values at T1, T2, and $\Delta T1-T2$ values for infants in all three cortisol change categories. (bars = 1 SE).

Figure 2. Average looking times to blocks associated with mother's voice compared to blocks not associated with mother's voice, for all three cortisol change categories of infants, during the acquisition phase (bars = 1 SE).

Figure 3.

Average looking times to blocks associated with mother's voice compared to blocks not associated with mother's voice, for all three cortisol change categories of infants, during the retention phase (bars = 1 SE).

Table 1
Sequence of Events During an Experimental Session

Event	Duration	Events Reflected in Cortisol
Car ride to lab	variable	
Enter lab		
Settling in	10 – 15 min	
Videotaped observation	exactly 10 min	
Total time before T1	20 – 25 min	
T1 saliva sampling		Response to new lab context in presence of mother
Acquisition phase	variable	
Short break	2 – 3 min	
Retention phase	2 – 3 min	
Wait	variable	
Total time T1 to T2	20 – 30 min ($M = 24.8$ min)	
T2 saliva sampling		New learning situation & mother separation

Table 2
Means, Standard Deviations and Ranges of the Cortisol Values of Mothers and Infants

Measure	n (%)	Raw Mean (SD)	Raw Range	Log-Transformed Mean (SD)
Infants				
T1 Cortisol in µg/dl	63 (100)	.26 (.21)	.04 – 1.0	–.70 (.31)
T2 Cortisol in µg/dl	63 (100)	.23 (.13)	.05 – .66	–.69 (.23)
ΔT1-T2 Cortisol (µg/dl)	63 (100)	–.02 (.20)	–.74 – .54	–.01 (.28)
ΔT1-T2 Cortisol increased	14 (22.2)			
ΔT1-T2 Cortisol decreased	16 (25.4)			
ΔT1-T2 Cortisol no change	33 (52.4)			
Mothers				
T1 Cortisol in µg/dl	63 (100)	.22 (.12)	.08 – .80	–.72 (.22)
T2 Cortisol in µg/dl	63 (100)	.18 (.13)	.05 – .97	–.80 (.23)
ΔT1-T2 Cortisol (µg/dl)	63 (100)	–.03 (.07)	–.30 – .16	.09 (.12)
ΔT1-T2 Cortisol increased	2 (3.2)			
ΔT1-T2 Cortisol decreased	8 (12.7)			
ΔT1-T2 Cortisol no change	53 (84.1)			

Note: Cortisol values are presented as raw values and log-transformed to base 10. Statistical analyses were conducted with the transformed data.

Table 3

Partial Correlations Among Cortisol Reactivity in Mother and Infant, Behavioral Synchrony, and Behavioral Asynchrony^a

Variables	1	2	3	4
1. $\Delta T1$ -T2 Infant	—			
2. $\Delta T1$ -T2 Mother	-.04	—		
3. Behavioral Synchrony	.12	.25 ^b	—	
4. Behavioral Asynchrony	-.05	-.13	-.29*	—

Note: Cortisol values were log-transformed to base 10.

^aControlled for mothers' $\log_{10}T1$ values ($df = 58$ for all values).

^b
 $p = .056$

*
 $p < .05$