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Ordinary Variations in Human Maternal Caregiving in Infancy and Biobehavioral Development in Early Childhood: A Follow-Up Study

ABSTRACT: *Rodent models of early caregiving find that pups reared by dams providing low levels of early stimulation subsequently display heightened stress reactivity and social aggression. We examined these effects in humans by investigating the effects of early caregiving on markers of biobehavioral development at ages 2 and 3 years. This study extended the findings reported by Hane and Fox (Hane and Fox [2006] Psychol. Sci. 17: 550–556) in which 185 mothers and infants were observed and scored for variations in maternal caregiving behavior (MCB) at age 9 months. Relative to young children who received high-quality MCB in infancy, those who received low-quality MCB showed significantly higher socially inhibited behavior with adults, right frontal electroencephalographam (EEG) asymmetry, aggressive play, and maternal reported internalizing behavior problems and anger proneness. These effects were independent of early temperamental reactivity. Results parallel rodent models and demonstrate that ordinary variations in MCB influence stress reactivity and social behavior in young children. © 2010 Wiley Periodicals, Inc.* Dev Psychobiol 52: 558–567, 2010.

Keywords: *maternal caregiving behavior; peer interactions; stress reactivity; frontal EEG asymmetry; infant*

INTRODUCTION

A rich and growing body of research has demonstrated the critical role of early experience in shaping development. It is now well documented that children who experience the extreme deprivation of institutional settings realize a host of suboptimal outcomes relative to peers reared under less aversive conditions, including atypical brain activity (Marshall, Fox, & BEIP Core Group, 2004); impaired cognitive functioning (O'Connor et al., 2000); emotional negativity; and behavioral incompetence (Smyke et al., 2007). Additional evidence suggests that the ill-effects of early deprivation, particularly sustained deprivation, are not entirely reversible (Beckett et al., 2006), a sobering reminder that the nature of plasticity is constrained by sensitive periods in early development.

A smaller, more emergent body of research has revealed that less extreme gradations in early rearing environments of human infants may also influence, or "program," the systems underlying stress reactivity. Neuroendocrine response to stress, as assessed via salivary cortisol reactivity in infancy, appears to be sensitive to nonextreme variations in early rearing contexts, including quality of care provided by both mothers (Gunnar, Broderson, Krueger, & Rigatuso, 1996) and nonfamilial caregivers (Gunnar, Larson, Hertsgard, Harris, & Brodersen, 1992). Complementary evidence points to the role of maternal sensitive responsiveness in regulating behavioral reactivity (Crockenberg & Leerkes, 2006).

This evidence for the social regulation of the developing stress response system is consistent with findings from

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rodent models of maternal caregiving that have focused on postnatal programming by examining maternal contributions to the development of stress reactivity and social behavior. Meaney and his colleagues have demonstrated that naturally occurring individual differences in the frequency of licking and grooming behavior (occurring largely in the context of arch-backed nursing) are associated with neurological and behavioral differences that persist into adulthood. They have shown that rat pups who experienced low levels of licking and grooming (LG) displayed, as adults, a stress-reactive neuroendocrine profile (Liu et al., 1997) and a corresponding behavioral profile of elevated stress reactivity to novelty, including higher frequencies of startle responses, less open-field exploration, and elongated latencies to eat food presented in a novel environment (Caldji et al., 1998; Francis, Diorio, Liu, & Meaney, 1999).

More recent research has extended this behavioral profile by revealing higher levels of defensive aggression in offspring of low LG dams. Parent and Meaney (2008) found that juvenile male offspring who received low LG as pups engaged in more play fighting in a multiple play partners housing environment, showing higher frequencies of pouncing, pinning, and social/aggressive grooming than high LG males (Parent & Meaney, 2008). Similarly, Menard and Hakvoort (2007) found that adult offspring receiving low LG as pups manifested more aggressive and defensive behavior during a resident-intruder test, including increased anogenital sniffing and faster display of the on-the-top posture, as compared to adult offspring who received high LG as pups. Parent et al. (2005) have suggested that a general profile of *defensive reactivity* develops in low LG rodents because behavioral defensiveness and the associated release of stress-related hormones are adaptive, allowing for detection of threat and the mobilization of metabolic resources under suboptimal early care conditions. However, the costs of defensive reactivity across the life span appear to be considerable and include risk for chronic illness, including depression, diabetes, and heart disease (Parent et al., 2005).

In a previous report, we applied the methodological approach and analytic strategy of Meaney and his colleagues to examine the role of ordinary variations in maternal caregiving of human infants on infant stress reactivity in a sample of low-risk mothers and their 9-month-old infants (Hane & Fox, 2006). Hane and Fox (2006) rated the quality of human maternal behavior for sensitive, nonintrusive interventions during the course of routine care in the home, including snack preparation, feeding, application of lotion, and dressing. A quality of maternal caregiving behavior (MCB) variable was derived from ratings of maternal sensitivity (Ainsworth, 1976) and intrusiveness (Park, Belsky, & Putnam, 1997). This variable was normally distributed, encapsulating ordinary variability in maternal behavior during the course of routine care-focused tasks. Relative to infants who received high-quality MCB, those who experienced low-quality MCB displayed a stress-reactive biobehavioral profile, marked by more fearfulness during the presentation of novel stimuli, less positive joint attention to a shared object with an experimenter, and more negative affect during mother–child interaction. Infants who experienced low-quality MCB also showed a pattern of resting relative right frontal electroencephalographam (EEG) asymmetry, which previous research has shown to be associated with negative reactivity in infants (Calkins, Fox, & Marshall, 1996); higher basal and stress-induced salivary cortisol concentrations in 6-month-olds (Buss et al., 2003); and withdrawal motivation across early development (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001; Hane, Fox, Henderson, & Marshall, 2008).

Both the caregiving and stress reactivity data in the Hane and Fox (2006) article were collected when infants were 9 months of age. Thus, it was not possible to examine the direction of effects in that study. Here we provide a longitudinal follow-up to the findings reported in Hane and Fox (2006) in order to examine whether (1) the effects of the quality of MCB in infancy persist across time and (2) differences in behavior are consistent with a more specific profile of stress reactivity and relational difficulties. To this end, we examined the effects of MCB on behavioral development and frontal EEG asymmetry in young children, incorporating markers of stress reactivity that parallel those used in Hane and Fox (2006), as well as observed social behavior during peer play and maternal perceptions of behavioral difficulties. We hypothesized that, relative to children who experienced high-quality MCB, or sensitive and nonintrusive behavior during feeding and changing in the home at 9 months, children receiving low-quality MCB would show a profile marked by: *Increased stress reactivity*, including social inhibition with adults at age 2 and frontal EEG asymmetry at age 3; *Difficulties during peer play*, manifest as social wariness or aggressive play behavior at age 2; and *Maternal perceptions of behavioral and social difficulties*, including internalizing and/or externalizing behavior problems at age 2 and proneness to anger in social situations at age 3. Further, we examined if the effects of maternal caregiving were independent of earlier observed measures of temperamental reactivity (4 months).

METHODS

Participants

Participants were drawn from a longitudinal investigation of temperament and the growth of social competence from infancy through middle childhood. For this study, 779 low risk, developmentally healthy infants were screened for emotional and motor reactivity to novelty at age 4 months (see Hane, Fox, Henderson, & Marshall, 2008). Reactivity was coded from video recordings obtained during the presentation of novel and auditory stimuli in the laboratory and included ratings for motor reactivity (frequencies of arm waves, arm wave bursts, leg kicks, leg kick bursts, back arches, and hyper extensions); negative affect (frequencies of fussing and crying); and positive affect (frequencies of smiling and positive vocalizations). Of the 779 infants observed at age 4 months, the first 100 infants were used as the criterion group to determine cut-offs for selection and placement into reactivity groups: infants who scored above the criterion sample mean on negative affect and gross motor arousal, and below the criterion sample mean for positive affect were selected to be in the negatively reactive group. Infants who scored above the criterion sample mean on positive affect and gross motor arousal, and below the mean on negative affect were selected to be in positively reactive group. There was a symmetric distribution of these two temperament groups within the criterion sample, such that of these first 100 infants screened, 14 met criteria for positive reactivity and 14 met criteria for negative reactivity. A sample of infants who did not meet criteria for either temperament group was also included to serve as controls.

Of the 234 families who were selected to remain in the study based on the above criteria, 185 participated in a home visit when their infants were age 9 months (84 males; 101 females). Of the 185 who were observed in the home, 72 met selection criteria for negative reactivity, 61 met criteria for positive reactivity, and 52 did not meet criteria for placement in either temperament group (i.e., unselected controls). Demographics of this middle-class, educated, low-risk subsample of the larger temperament study are reported in Hane and Fox (2006).

9-Month Assessment

Quality of MCB. Mothers and infants were observed in the home and videotaped as they interacted in a series of routine caregiving contexts, including mother being busy in the kitchen (8 min), snack (i.e., spoon-feeding of solids; 5 min), and changing (i.e., change of clothing and application of lotion; 5 min) paradigms. Maternal behavior during the home visit was video-recorded and subsequently rated for degree of sensitivity (Ainsworth, 1976) and intrusiveness (Park et al., 1997). Of Ainsworth's original 28 scales, the following 9-point rating scales were used: Acceptance-Rejection, Sensitivity-Insensitivity, Degree of Availability, and Appropriateness of Pace in Feeding. Maternal intrusiveness was rated globally using the 4-point scale of Park et al. (1997) and Ainsworth's Cooperation-Interference scale (reverse-scored); these ratings were then averaged, such that higher scores indicated more maternal intrusiveness. The intrusiveness composite for each episode (i.e., mother busy in the kitchen, snack, caregiving, and changing) was subtracted from the sensitivity composite for that episode to ensure that the measure of MCB was not confounded by intrusive maternal behavior. A final MCB composite was derived by averaging these episode aggregates, such that higher scores indicated higher quality of MCB, or maternal behavior that was both sensitive and nonintrusive. In this context, for instance, a highly sensitive mother would be one who attended and responded to her infant's signals while she prepared a snack, including using her voice to establish proximity periodically; spoon feeding her infant at a pace determined by the infant's cues, tolerating temporary loss of interest in the feeding activity and moments of disengagement; warming lotion prior to application; applying lotion with gentle, massaging strokes; and clothing the infant with careful attention to ensure postural supports and minimization of discomfort. Two independent raters achieved sound inter-rater reliability across 40 cases, with intraclass correlation coefficients (ICCs) in each interactive episode ranging from .59 to .84, an overall sensitivity reliability coefficient of .80, and an overall intrusiveness reliability coefficient of .76. The internal consistency of all scales entering into the MCB composite (sensitivity and intrusiveness scales combined) was examined, with Cronbach's alpha = .80.

2-Year Assessment

Social inhibition with adults. Children were observed in the laboratory during free play with mother (5 min) and during a stranger approach, which included stranger entry (1 min); stranger solitary play (1 min); and stranger initiated invited play with a dump truck (2 min). Videotapes obtained from this paradigm were subsequently rated for inhibition. For free play, codes included: Latency to third vocalization (third discrete sound from the child); latency to touch a toy; and proximity to mother (duration of total time spent within an arm's reach of mother during that episode). The stranger episodes were rated for latency to first vocalization; latency to touch the stranger; number of prompts required for child to approach the stranger, refusal to play with the stranger, and proximity to mother. During free play and stranger episodes, presence/absence of positive facial affect was independently rated in 30-s epochs. The frequencies of positive affect across all epochs were then summed and the inverse of the normalized sums was averaged with the normalized inhibition codes, such that a final *Social Inhibition* score represents more hesitancy to explore the environment or speak in a novel environment in the presence of the mother, hesitancy to approach, or speak to the stranger, and low levels of positive facial affect in the presence of mother and stranger. Two research assistants achieved sound inter-rater reliability across 40 cases for inhibition codes with ICCs ranging from .72 to .97. A separate, independent pair of coders achieved inter-rater reliability across 40 cases for positive facial affect (kappas range from .59 to .92).

Peer play behavior. Children returned to the laboratory for a play assessment in which they were paired with a same-sex unfamiliar peer who was within 2 months of their age. Of interest in the current study were children's behaviors during the initial observation segment in which they took part in a 10-min free play session. Mothers were in the room, but were asked to work on a series of questionnaires and not to initiate any interactions with their child during the play session. Videotapes of the dyad sessions were coded at the University of Miami under the direction of the second author. Using a 7-point Likert scale, children received global ratings on eight variables: (1) social interest (acknowledgement, initiation, and engagement in interactions with peer), (2) wariness (hesitance and uneasiness), (3) unfocused behavior (lack of engagement in social or nonsocial activities), (4) adult contact (child initiated contact with parent), (5) activity level, (6) positive affect (excited tones, smiling, laughing, and jumping), (7) negative affect (sadness, crying, and anger), and (8) aggression (object struggles, harsh language directed at peer, physically forceful play). Two trained coders overlapped on 16% of cases and ICCs ranged from .68 (unfocused) to .87 (aggression). Scores were entered into a principal components analysis (PCA) for data reduction. Standard factor-analytic procedures were followed, first entering the variables into a PCA using a varimax rotation, then specifying eigenvalues ≥ 1 (Kaiser's criteria), and using the scree plot and percent variance accounted for to determine the number of factors. The results justified a three-factor solution: *Social Engagement* (social interest, activity level, and positive affect), *Social Wariness* (wariness, adult contact, and unfocused), and *Aggressive Play* (negative affect, aggression). Scores on the three factors were calculated by standardizing and summing the respective dimensions. Of interest in the current article were individual differences in Social Wariness and Aggressive Play.

Internalizing and externalizing behavior problems. Mothers completed the Child Behavior Checklist/*1.5-5* (Achenbach & Rescorla, 2000). This measure is a widely used, reliable, and valid measure consisting of 100 items assessing child behavior problems. The broadband *Externalizing* score is an average of narrow band scales for attention deficit/hyperactivity, aggression, and oppositional defiance; the broadband *Internalizing* score consists of narrow band subscales for affective problems, anxiety, and withdrawal (Rescorla, 2005). The Internalizing and Externalizing behavior problems scores are standardized *t*-scores, with higher scores indicative of more problematic behavior.

3-Year Assessment

Proneness to anger. To examine proneness to anger, the Toddler Behavior Assessment Questionnaire (TBAQ; Goldsmith, 1996) was completed by mothers. The TBAQ is a valid and internally consistent (Goldsmith, 1996) instrument that assesses temperament in children ages 16–36 months. The anger proneness subscale includes 28 items that specifically measure negative affect (e.g., crying, protesting) and aggression (e.g., hitting) in relational contexts, including those with caregivers and other children. Incidence of anger-related behaviors are rated on a scale from 1 (never) to 7 (always), such that a higher score indicates more *Proneness to Anger in Social Contexts*.

Frontal EEG asymmetry. Baseline EEG was acquired for each child as they quietly listened to a story read by an experimenter. While the child was quietly attending to the book, EEG was collected during four 30-s epochs—two epochs while the room was illuminated and two epochs while the room was darkened. Epochs alternated between light and dark conditions. In addition, glow-in-the-dark stars were pasted on the wall facing the child to distract them from the darkness of the room.

The procedures for collection and processing of the EEG data at age 3 are similar to those used at age 9 months, as reported in Hane and Fox (2006), and include collection at 14 electrode sites, sampling rate of 512 Hz, re-referencing with an average reference configuration, derivation of power with discrete Fourier transform analysis, and computation of power in the 6–9 Hz frequency band (Hane & Fox, 2006; Hane, Fox, Henderson, & Marshall, 2008). A significant number of children with otherwise usable EEG data had poor quality or no electrooculogram (EOG) signal. For those infants with good EOG data, EOG–EEG propagation factors were computed and found to be of very low magnitude, indicating that the eyeblinks had little effect on the EEG signal, including frontal leads. Therefore, eyeblink regression was not applied during the processing of the EEG data. Natural log power data from the frontal and parietal regions (F3 and F4, P3 and P4) were used to calculate two asymmetry indices (frontal and parietal). For each, asymmetry was computed as the natural log of the power in the right lead minus the natural log of the power in the left lead for homologous leads (for both frontal and parietal leads). In as much as activation and power in the alpha band are reciprocally related (Davidson, 1988), negative asymmetry scores represent *Right Frontal EEG Asymmetry*, and positive scores represent *Left Frontal EEG Asymmetry.*

RESULTS

Preliminary Analyses

Attrition. Of the 185 infants who underwent a home visit at age 9 months, 18.4% failed to continue participation in the larger project to age 3. Children who dropped out ($n = 34$) did not differ on measures of positive/negative affect and gross motor arousal at 4 months and MCB at 9 months compared to those who remained in the project ($n = 151$).

Table 1 provides descriptive statistics for each measure across the 185 infants with MCB data. A series of correlations among continuously scored 4-month temperament variables (positive reactivity and negative reactivity), MCB, and outcome measures were computed (see Tab. 2) and showed that higher positive reactivity at 4 months was associated with significantly lower social inhibition, higher externalizing behavior problems, more aggressive peer play, and increased proneness to anger. No significant associations between 4 months negative reactivity and key variables were found. Significant negative correlations show that lower quality MCB was associated with significantly more social inhibition with adults, higher internalizing problems, increased aggressive peer play, and more proneness to anger. Aggressive peer play was significantly and positively related to proneness to anger and externalizing problems. Internalizing and externalizing problems were also significantly positively correlated. Sex differences on continuous MCB scores and all outcome variables were examined and

Table 1. Descriptive Statistics

Variable	N	M	SD
9 Months			
Quality of maternal caregiving behavior	185	4.00	1.40
Age 2			
Aggressive play with peer	144	.14	1.65
Social wariness with peer	144	.25	2.42
Social inhibition with adults	164	.48	.95
Internalizing problems	157	47.03	9.51
Externalizing problems	157	50.15	8.33
Age 3			
Proneness to anger	166	3.56	.78
Frontal EEG asymmetry	144	.01	.28

showed one significant difference, with males ($M = .73$, $SD = .82$) showing higher levels of social inhibition than females ($M = .27$, $SD = 1.00$), $t\,(162) = 3.15$, $p < .01$.

Creation of Caregiving Groups

High- and low-quality MCB groups used by Hane and Fox (2006) were defined as those who were ± 1 *SD* of the MCB sample mean. However, in order to account for attrition over time, we redefined the MCB groups: The high-quality MCB group consisted of mothers who scored higher than .75 *SD* above the sample mean ($n = 41$) and the low-quality MCB group consisted of mothers who scored lower than .75 *SD* below the sample mean ($n = 40$). Neither the distribution of 4-month temperament groups (see Tab. 3) nor sex, χ^2 (1) <1, *ns*, differed significantly across MCB groups.

Early Maternal Caregiving and Markers of Biobehavioral Development in Early Childhood

In order to examine the role of early MCB on key outcomes, we computed a series of one-way analyses of covariances (ANCOVA's). In each analysis, the continuous negative and positive reactivity scores obtained at age 4 months were entered as covariates. Separate ANCOVA's were computed for each of the key outcomes: Social inhibition with adults, internalizing problems, externalizing problems, frontal EEG asymmetry, aggressive play, social wariness, and proneness to anger. Compared to children who received high-quality MCB, those receiving low-quality MCB in infancy showed significantly more social inhibition with adults, $F(1, 66) = 4.56$, $p < .05$, $\eta^2 = .07$[1]; significantly higher maternal ratings for internalizing problems, $F(1, 69) = 3.92$, $p = .05$, $\eta^2 = .05$ and proneness to anger, $F(1, 67) = 7.62$, $p < .01$, $\eta^2 = .10$; more aggressive play, $F(1, 53) = 4.98$, $p < .05$, $\eta^2 = .09$; and a pattern of right frontal EEG asymmetry, $F(1, 3) = 4.24$, $p < .05$, $\eta^2 = .11$. A similar analysis of degree of EEG asymmetry in the parietal region yielded no significant main effect of MCB group, suggesting that the group difference in EEG asymmetry is specific to the frontal region. No significant group differences were yielded for the effects of MCB on social wariness with peer or externalizing behavior problems.

Figure 1 shows a depiction of the MCB group mean differences on the standardized scores for social inhibition, aggressive peer play, internalizing problems, proneness to anger, and frontal EEG asymmetry.

[1]The effects of MCB on social inhibition remain statistically significant when controlling for the effects of infant sex, $F(1, 67) = 5.75$, $p < .05$, $\eta^2 = .08$.

DISCUSSION

This longitudinal follow-up investigation examines a cohort of children first described in a previous report of the contemporaneous associations between the quality of MCB and indices of stress reactivity in human infants (Hane & Fox, 2006). In that article we examined the effects of individual differences in MCB in infancy on behavior and physiology in young children. In the current study we find that relative to children who experienced high-quality MCB as infants (high MCB children), those who received low-quality MCB (low MCB children) continued to show increased stress reactivity, including inhibited social behavior with adults and right frontal EEG asymmetry. We also examined social and behavioral differences and found that, relative to the high MCB children, the low MCB children exhibited more aggression during peer play and were reported by their mothers to show more internalizing behavior problems and proneness to anger in social contexts. Contrary to our expectations, children who received high and low-quality MCB did not differ on maternal report of externalizing behavior problems or observed social wariness during peer play.

Table 2. Relations Among Key Variables

	1	2	3	4	5	6	7	8	9	10
1. Positive reactivity	—									
2. Negative reactivity	(185) .311**	—								
3. MCB	(185) −.040	(185) −.037	—							
4. Social inhibition with adults	(164) −.155*	(164) −.085	(164) −.233**	—						
5. Social wariness with peer	(144) −.065	(144) −.098	(144) .042	(142) .054	—					
6. Aggressive play with peer	(144) .158	(144) .001	(144) −.198*	(142) −.017	(144) .103	—				
7. Internalizing behavior problems	(157) .126	(157) .064	(157) −.205**	(146) .052	(128) .113	(128) .138	—			
8. Externalizing behavior problems	(157) .193*	(157) .093	(157) −.073	(146) −.015	(128) −.016	(128) .216*	(157) .605**	—		
9. Proneness to anger	(166) .360**	(166) .130	(166) −.194*	(151) .021	(134) −.015	(134) .177*	(146) .079	(146) .315**	—	
10. Frontal EEG asymmetry	(99) .016	(99) .117	(99) .088	(97) −.107	(86) .037	86 −.070	(87) .043	(87) −.065	(98) .014	—

Note: MCB, maternal caregiving behavior (Hane & Fox, 2006).
Values in the parentheses represent the valid *N* for each correlation.
*$p < .05$, two-tailed significance.
**$p < .01$, two-tailed significance.

Table 3. Number of Infants in MCB Groups Within Temperament Groups

Temperament group	Maternal caregiving behavior group	
	Low quality	High quality
Control	17	10
Positively reactive	12	17
Negatively reactive	11	14

Note: χ^2 (2) 3.03, $p > .10$.

The findings reported here mirror those of animal models, which show that rodent offspring receiving low LG in the postnatal period are behaviorally and physiologically fearful (Caldji et al., 1998; Liu et al., 1997) and, more recently, socially aggressive and defensive (Menard & Hakvoort, 2007; Parent & Meaney, 2008) compared to animals who receive high LG. Parent et al. (2005) suggest that behavioral defensiveness serves an adaptive function during the experience of suboptimal care, but costs the organism across the lifespan due to the health byproducts associated with chronic dysregulation of stress response systems. Our findings suggest that among those costs are relational consequences. Previously, we speculated that certain features of the early caregiving environment may yield contemporaneous phenotypic changes to the systems involved in the regulation of stress and also to the organism's future propensity to manifest these phenotypic changes when confronted with similar contexts in the future, a phenomenon documented by evolutionary biologists and referred to as phenotypic plasticity (Hane & Fox, 2006, 2007; Fox & Hane, 2008). Results of this study support this model, as the sequelae of low-quality MCB in infancy are marked by heightened stress reactivity, higher internalizing problems, and anger and aggression in social contexts in early childhood. The

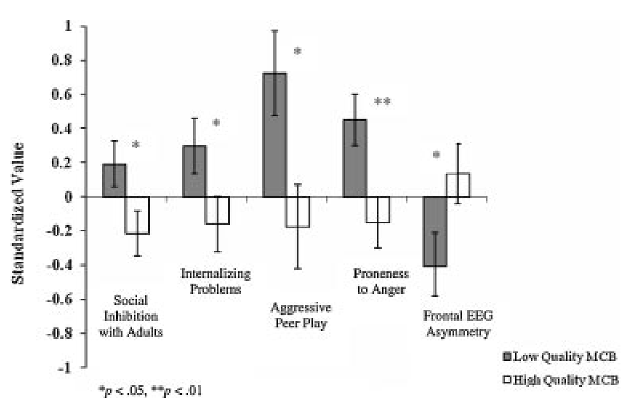

FIGURE 1 Statistically significant group mean differences on behavioral measures and frontal EEG Asymmetry among young children who experienced low- and high-quality maternal caregiving behavior as infants. Error bars show standard errors.

inhibited interactions with adults and aggression with peers seen in low MCB children may mark outward manifestations of an internal stress response triggered specifically by social stimuli. Future research should examine if the biobehavioral profile of low MCB children varies in social and nonsocial contexts.

It is noteworthy that the profile seen in young children who received low-quality MCB parallels characteristics of children who engage in bullying behavior, which includes aggressive behavior with peers, as well as proneness to anger (Camodeca & Goossens, 2005); self-reported negative relations with caregivers and low social involvement in the family context (Stevens, De Bourdeaudhuij, & Van Oost, 2002); and concurrent and future depression and/or anxiety (Klomek, Marrocco, Kleinman, Schonfield, & Gould, 2007; Sourander et al., 2007; Swearer, Song, Cary, Mickelson, & Eagle, 2001). However, here we examined the effects of MCB on very early markers of biobehavioral development, and future research that tracks social development is necessary to examine if the influence of MCB persists across childhood. We surmise that similar to temperamentally extreme children (Fox et al., 2001), the trajectories of low MCB children will be mitigated by other key variables, with low MCB children perhaps particularly sensitive to the quality of ongoing relationships with peers and parents. Rodent models have shown that postweaning contextual factors interact with (normative or extreme) differences in early care environments to shape development, providing evidence for *environment–environment* interactions (Champagne & Meaney, 2007). For instance, Francis, Diorio, Plotsky and Meaney (2002) showed a functional reversal of the deleterious effects of experimentally induced maternal separation, a rodent model of maternal neglect, via environmental enrichment in the peripubertal period. Champagne and Meaney (2007) found that enriched postweaning environments led to increased exploratory behavior in adult low LG offspring. In humans, research with institutionalized children has demonstrated that placement into high-quality foster care yields significant and rapid improvement in the expression of positive affect and attention to emotion-eliciting stimuli (Ghera et al., 2009).

Our findings contribute to the body of research showing that early care environments influence the developing stress response system (see Gunnar, 2006, for a review) by illustrating that normative variations in caregiver behavior impact biobehavioral development. It is critical to note that MCB is by no means a simple, monotonic construct, in rodent or human models. For the rat, maternal caregiving is embedded within the larger ecology of the nest, which includes the presence of littermates. An individual pup's early caregiving environment is characterized by three-way reciprocal relationships, with each pup influencing and influenced by the dam and littermates (Pryce & Feldon, 2003). Maternal nursing behavior (crouching and quiescence) and milk ejection are dependent upon receipt of sufficient sucking stimulation from several members of the litter (Stern and Johnson, 1989). The social ecology of the nest is more complex for biparental species and emergent evidence is revealing that paternal deprivation is associated with altered neurological development for such animals (Ovtscharoff, Helmeke, & Braun, 2006; Pinkernelle, Abraham, Seidel, & Braun, 2009).

In this report our measure of MCB was derived from home visits at age 9 months and by this point in development, dyads have already established a rich interactional history, which is dynamic in nature (Lohaus, Keller, Ball, Voelker, & Elben, 2004). This interactional history is influenced by temperament and other endogenous infant traits (Crockenberg & Acredolo, 1983; Ghera, Hane, Malesa, & Fox, 2006; Hane & Fox, 2006; Mangelsdorf, Gunnar, Kestenbaum, Lang, & Andreas, 1990; van den Boom & Hoeksma, 1994). Though we controlled for an early measure of temperamental reactivity, it is important to note that trajectories of temperamentally extreme children change across time (Fox et al., 2001). Quality of mother–child interaction is a well-established contributor to temperament trajectories, with high-quality interactions serving as a buffer against, and low-quality interactions a catalyst toward, suboptimal outcomes for temperamentally extreme children (Calkins, 2002; Hane, Cheah, Rubin, & Fox, 2008). Given the bi-directionality of influence within the mother–child dyad, true disentanglement of maternal versus child contributions to development is implausible. However, elucidation of the mechanisms of influence involved in person-by-environment transactions is a tenable goal, and the findings reported here suggest that the influence of early caregiving on the developing stress response system may be one such important mechanism.

Parallel to the rodent work, our measure of MCB encapsulates commonplace variations in maternal behavior, not extreme instances of neglect or abuse. Mothers in this low-risk sample showing relatively low-quality MCB were insensitive or intrusive during routine caregiving tasks. Lower MCB scores were a function of a lack of responsiveness to the infant during meal preparation, lack of social engagement and sensitive pacing during feeding, and/or harsh or vigorous touching during the application of lotion and changing of clothing. Our findings suggest that such nonextreme, nuanced, yet ordinary variations in MCB are of developmental relevance to the human, revealing perhaps a parallel between the species, with maternal behavior in the context of routine care serving a regulatory function on the developing stress response systems and social behavior of both. However, it is critical to note that the dimensions of maternal behavior and the associated mechanisms of influence for each conceivably vary across species in accordance with the contextually determined priorities of early motherhood within each—be these basic processes such as thermoregulation and somatosensation for altricial species (Hofer, 2006) or priorities of a higher order, such as the experience of a mutually rewarding social exchange in humans. Contingent social responsiveness may be a critical regulator of developing stress physiology (Crockenberg & Leerkes, 2004, 2006; Gunnar, 2006) and our measure of MCB is based on the construct of maternal sensitivity, defined by Ainsworth (1976) as appropriate and responsive maternal behavior. However, this measure is global in nature and the function and relevance of specific maternal behaviors cannot be determined from this approach. For the human infant, maternal efforts to maximize physical comfort (satiety, warmth), induce physical pleasure and social reward, and minimize distress during routine care may each represent critical dimensions of caregiving that are uniquely related to biobehavioral regulation (Hofer, 2006). Determining the relative contribution and function of each facet of maternal caregiving may bridge the translational gap between the rodent and human caregiving models.

The findings reported here converge with those of our earlier report (Hane & Fox, 2006) to demonstrate behavioral and physiological differences for infants who receive low-quality versus high-quality MCB in infancy. Children who received low-quality MCB as infants continued to show signs of stress reactivity as well as newly identified difficulties in relational settings in early childhood. Equally noteworthy, perhaps, are the children who received high-quality MCB in infancy, as these children showed lower levels of stress reactivity and more optimal social behavior. Cross-fostering (Francis et al., 1999) and postweaning enrichment (Champagne & Meaney, 2007) studies affirm the exquisite contextual sensitivity of the developing stress response system. Such evidence points to the promise of intervention programs that focus directly on optimizing maternal behavior in the context of routine caregiving such as changing and feeding—tasks that pervade the daily routines of mothers and infants and in which mothers may be particularly affected by infant distress signals (Hane, Fox, Polak-Toste, Ghera, & Guner, 2006). Recent work has shown that high-quality maternal play behavior in infancy attenuates risk for the development of dysregulated HPA functioning in infants of mothers diagnosed with a mood or anxiety disorder during pregnancy (Kaplan, Evans, & Monk, 2008) and infants of rural, low-income families (Blair et al., 2008). Examining the role of MCB in the development of at-risk populations such as these may serve not only to further elucidate the paths to resilience in at-risk samples, but also allow for the development of highly focused interventions that target enhancing maternal behavior during the course of ordinary, frequent, and, essential care-focused activities such as feeding and changing.

NOTES

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