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PAPER

Biological and environmental initial conditions shape the trajectories of cognitive and social-emotional development across the first years of life

Ruth Feldman[1] **and Arthur I. Eidelman**[2]

1. *Department of Psychology and the Gonda Brain Sciences Center, Bar-Ilan University, Israel*
2. *Hebrew University School of Medicine, Israel*

Abstract

Human development is thought to evolve from the dynamic interchange of biological dispositions and environmental provisions; yet the effects of specific biological and environmental birth conditions on the trajectories of cognitive and social-emotional growth have rarely been studied. We observed 126 children at six time-points from birth to 5 years. Intelligence, maternal sensitivity, and child social engagement were repeatedly tested. Effects of neonatal vagal tone (VT) and maternal postpartum depressive symptoms on growth-rates were assessed. Cognitive development showed a substantial growth-spurt between 2 and 5 years and social engagement increased rapidly across the first year and more gradually thereafter. VT improved cognitive and social-emotional growth-rates across the first year, whereas maternal depressive symptoms interfered with growth from 2 to 5 years. Differences between infants with none, one, or two non-optimal birth conditions increased with age. Findings shed light on the dynamics of early development as it is shaped by biological and environmental initial conditions.

Introduction

Since the early debates on the relative contributions of genes and environment to shaping the course of development, theoretical models on development and psychopathology acknowledge that outcome depends on the dynamic interchange of biological dispositions and environmental provisions (Rutter, Moffitt & Caspi, 2006). Inborn traits interact with parenting practices in predicting children's development (Calkins & Fox, 2002), and genetic markers act in combination with environmental stressors to increase vulnerability to psychopathology (Caspi, Sugden, Moffitt, Taylor, Craig, Harrington, McClay, Mill, Martin, Braithwaite & Poulton, 2003). Similarly, studies have underscored the cumulative contributions of biological risk and social adversity to children's developmental outcomes (Gerhold, Laucht, Texdorf, Schmidt & Esser, 2002; Bendersky & Lewis, 1994). Yet, although the biology–environment controversy has permeated thinking on human development for several centuries, a repeated-measure, longitudinal assessment of specific outcomes in relation to specific biological and environmental conditions that begins at birth, focuses on the first years of life, and utilizes direct observations has rarely been conducted. Although several birth cohorts have been followed from infancy to adulthood (Elder, 1998; Werner & Smith, 1992), these studies typically rely on self-report measures, and their scant assessments during the early years preclude the ability to evaluate how biological and environmental neonatal conditions influence the rate of change in the maturation of fundamental skills.

Cognitive and social-emotional trajectories represent the two basic aspects of children's development. Cognitive development undergoes several periods of reorganization during the first 5 years. In the first year, cognitive growth primarily involves sensory learning, perceptual-motor integration, and simple attention. As the attention system matures during the second year and infants begin to use symbols, cognitive skills expand to include rudimentary concepts, planning, and goal-directed behavior (Posner, 2002). During the preschool age, with the rapid growth of language and the maturation of the prefrontal cortex, cognitive development involves the mastery of executive functions and the ability to employ complex semantic categories (Case, 1992). Notwithstanding these changes, the construct of intelligence presupposes that individual differences in cognitive performance are stable across time. Yet, during the first years of life the trajectories of cognitive development are more open to internal and external influences before settling into a relatively stable cognitive style (Sternberg, 1999). At what time-points during this dynamic phase do biological and environmental birth conditions exert their greatest impact is a question that has not yet received an empirical answer.

Social-emotional development has been investigated primarily from the attachment perspective. In general,

Address for correspondence: Ruth Feldman, Department of Psychology and the Gonda Brain Sciences Center, Bar-Ilan University, Ramat-Gan, Israel 52900; e-mail: feldman@mail.biu.ac.il

the attachment viewpoint suggests that social-emotional growth emerges within the matrix of the mother–infant relationship, particularly the mother's sensitive approach which is later internalized as a secure base and promotes social-emotional adaptation (Bowlby, 1969). Maternal sensitivity, the key concept in attachment research, facilitates the infant's social engagement and provides the arena for the practice of social skills. Similar to cognition, maternal sensitivity and infant social engagement undergo significant reorganizations across early childhood. Whereas during the first months mothers adapt their behavior fully to the infant's communications, toward the end of the first year the mother's and infant's contributions to the mutual exchange become more balanced (Stern, 1985), particularly as children become verbal during the second year and more socially competent in the preschool years (Feldman, 2007a). At the same time, infant social engagement progresses from the scant attention of newborns, to greater social involvement during the first two years, to the immersion in complex symbolic-interactive scenarios in the preschool stage. Little research, however, has examined the trajectories of maternal sensitivity or child social engagement across the first years in relation to biological and environmental conditions.

Two neonatal conditions – one infant biological, the other environmental – have been known to carry long-term effects on cognitive and social-emotional development; neonatal cardiac vagal tone (VT) and maternal postpartum depression. Cardiac VT, which measures the respiratory cycle in heart-rate variability, assesses the functioning of the parasympathetic system and its adaptive capacity to flexibly adjust to environmental stressors. Higher neonatal VT indexes a more adaptive physiological system and is observed in neonates with greater neurobehavioral maturation (Porges, 1995). Higher neonatal VT provides the biological foundation for the development of social engagement (Feldman, 2006; Porges, 2003) and has been shown to predict better cognitive development at 3 years (Doussard-Roosevelt, Porges, Scanlon, Alemi & Scanlon, 1997) and more adaptive social-emotional development at 6 years (Doussard-Roosevelt, McClenny & Porges, 2001). Maternal postpartum depression, a condition affecting 10–15% of Western women, similarly predicts less optimal cognitive and social-emotional development across childhood (Murray & Cooper, 1997). Yet, the effects of neonatal VT and maternal postpartum depression on the trajectories of cognitive and social-emotional growth across the first years have not been studied.

In light of the above, the present study had two primary goals. First, it sought to describe the trajectories of cognitive and social-emotional development in a cohort seen six times from birth to 5 years. It was of theoretical and empirical importance to describe the growth-curve of each fundamental skill and pinpoint periods of rapid growth and plateau. The second goal was to examine how biological and environmental birth conditions shape, independently and in combination, the trajectories of cognitive and social-emotional growth. Social development was studied on the basis of repeated direct observations of mother–infant interactions, which were considered to provide a more objective assessment of the child's real-time social behavior compared to maternal reports that may be colored by the mother's perceptions, mood, or condition (Feldman, 2007a). It was of particular interest to assess the timing of each effect and to examine whether the influence of neonatal conditions increases or decreases with age, in order to provide more specific guidelines for intervention. Assessing the interplay between initial conditions and growth trajectories was expected to shed further light on the dynamic process of development as it is shaped by biological and environmental conditions.

Method

Participants

One hundred and twenty-six healthy low-risk premature infants were enrolled from consecutive births in a tertiary care hospital in Israel over a 3-year period. Infants were free of neurological or genetic conditions and all but eight mothers approached agreed to participate. Children came from two-parent Israel-Jewish families that were considered middle class by Israeli standards, and all participants signed an informed consent. Attrition was minimal at 5% over 5 years.

Procedure

Mothers and children were seen six times; prior to discharge (term age); at 3, 6, 12, and 24 months (corrected to full gestation); and at 5 years. Cognitive testing was conducted by trained psychologists at each time-point from 6 months to 5 years and a 10-minute session of mother–child free interaction was videotaped at each time.

Measures

For cognitive development, the Bayley Scales of Infant Development (BSID; Bayley, 1993) were used at 6, 12, and 24 months and the Wechsler Preschool and Primary Scale of Intelligence (WPPSI; Wechsler, 1967) at 5 years. The Mental Development Index (MDI) of the BSID and the Verbal IQ score of the WPPSI were used. Different psychologists tested children at each age to avoid confounding by familiarity.

Maternal depressive symptoms were reported prior to discharge using the well-validated Beck Depression Inventory (Beck, 1978). Consistent with previous research (Kendall, Hollon, Beck, Hammen & Ingram, 1987), a score higher than 9 indicates dysphoric mood and a high risk for major depression disorder and was used to differentiate depressed from non-depressed

Table 1 *Means (SD) of study variables*

	Birth	3 months	6 months	12 months	24 months	5 years
Intelligence		92.11 (8.79)[a]	90.06 (10.63)[a]	90.45 (14.63)[a]	100.07 (22.60)[b]	
Maternal Sensitivity	3.21 (1.07)	3.99 (.79)	4.14 (.78)	3.30 (.80)	3.26 (.74)	3.33 (.93)
Child Social Engagement	1.48 (.63)	1.82 (.65)	2.51 (.72)	3.19 (.74)	3.53 (.77)	3.73 (.81)

[a] MDI scores-BSID.
[b] Verbal IQ-WPPSI.

mothers. BDI scores ranged from 0 to 23 (M = 6.52, SD = 5.64). High depressive symptoms were reported by 49 mothers (38.8%).

Cardiac VT was extracted from 10 minutes of infant heart-rate during quiet sleep. VT – the amplitude of respiratory sinus arrhythmia – was quantified with Porges' MXEdit system, which determines the periodicities of heart-rate with a 21-point moving polynomial, filters the time-series within the frequency band of neonates' breathing, and calculates the VT index. VT ranged from −1.09 to 7.72 (M = 2.03, SD = 1.31). Infants were divided into high- and low-VT groups based on the median split (Med = 1.93), consistent with previous research on VT in neonates (Arditi, Feldman & Eidelman, 2006).

Coding

Mother–infant interaction at each time-point was coded with the Coding Interactive Behavior manual (CIB; Feldman, 1998), a well-validated system for parent–child interactions that has shown sensitivity to infant age, biological and psychiatric risk, culture, and the effects of intervention (Feldman & Masalha, 2007; Feldman, 2007b; Feldman & Eidelman, 2005). The system includes 42 scales rated from 1 to 5, which are summed into eight constructs, and two constructs were used in the present study: maternal sensitivity and child social engagement. Constructs were theoretically based and considered the specific behaviors reported in the literature as central for maternal sensitivity and child social engagement. The internal consistency, test–retest reliability, and predictive validity of each construct have been validated in multiple studies in normative and high risk samples. *Maternal Sensitivity* included: mother acknowledgement of child communications, vocal clarity, positive affect, gaze, appropriate range of affect, resourcefulness, consistency of style, adaptation to child signals, and supportive presence. Internal consistency was .88–.94 (for newborns codes included adaptation, positive affect, and gaze). *Child Social Engagement* included: infant alertness, fussiness (negative), social initiation, vocalization, gaze, and positive affect. Additional codes from 12 months included: joint attention, competent use of environment, and symbolic-creative play. Internal consistency was .83–.91 (for newborns: alertness to mother and environment, cry (negative), and sleep (negative)). Coding was conducted following extensive training to 85% reliability on all codes and separate teams were used at each age. Twenty-five interactions at each age were used for reliability with an average of 93% (range = 85%–100%), *kappa* (for constructs) = .86 (range = .81–.94).

Results

Descriptive statistics appear in Table 1.

Cognitive trajectories

To assess cognitive trajectories, MANOVA with repeated-measures was computed with VT (high, low) and depression (yes, no) as the between-subject factors. The repeated polynomial was used to assess changes between each time-point and the next. Results indicated that IQ changed significantly with age, Sphericity Assumed $F(df = 3) = 12.48$, $p < .000$, $\eta^2 = .093$. The linear trend was significant. Significant cognitive growth occurred between 2 and 5 years, Sphericity Assumed $F(df = 1) = 19.10$, $p = .000$, $\eta^2 = .135$. It is important to note, however, that at 5 years a different instrument was used (WPPSI) from the one used in infancy (BSID) and although both tests are normed to M = 100, SD = 15, this change may have affected the results.

Neonatal VT had an effect on the rate of cognitive growth, Interaction $F(df = 3, 120) = 7.14$, $p = .000$, $\eta^2 = .15$, with its most significant effect occurring between 6 and 12 months, Sphericity Assumed $F(df = 1) = 5.71$, $p = .018$, $\eta^2 = .045$. Maternal depression impacted on cognitive trajectories, Interaction $F(df = 3, 120) = 5.53$, $p = .001$, $\eta^2 = .12$, and the strongest effect occurred between 2 and 5 years, Sphericity Assumed $F(df = 1) = 19.10$, $p = .000$, $\eta^2 = .045$. Correlations between maternal depressive symptoms and infant VT were not significant, $r = .10$, $p > .10$.

To further examine the effects of neonatal conditions, infants were divided into four groups; (1) High VT, Low depression (HL, N = 42), (2) High VT, High depression (HH, N = 25), (3) Low VT, Low depression (LL, N = 34), and (4) Low VT, High depression (LH, N = 24). ANOVAs with post-hoc Duncan's tests examined differences between means at each age. Results show that although groups did not differ at 6 months, $F(df = 4, 122) = 2.41$, $p > .05$, differences *increased* with age. At 12 months, the HL group (two optimal conditions) scored higher than the other groups, $F(df = 4, 122) = 4.42$, $p = .006$.

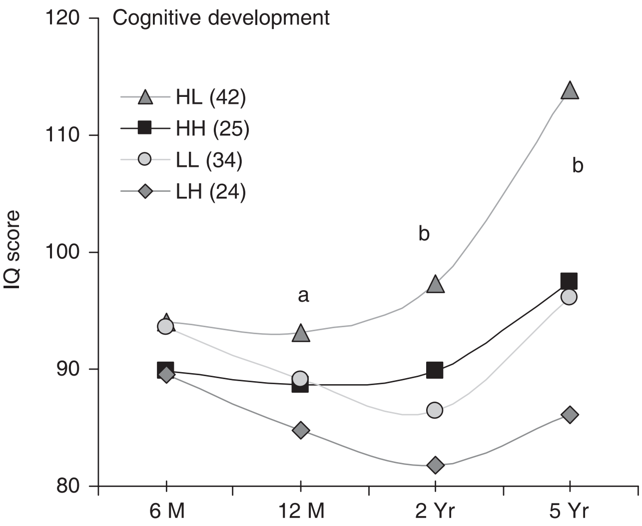

Figure 1 *Trajectories of cognitive development according to biological and environmental neonatal conditions.*
Trajectories assessed in four groups of children: High neonatal vagal tone (VT), low maternal depression (HL); High neonatal VT, high maternal depression (HH); Low neonatal VT, low maternal depression (LL); and low neonatal VT and high maternal depression (LH). (a) HL > LH; (b) HL > HH, LL > LH; (c) HL > HH, LL, LH; (d) HL, HH, LL > LH.

However, at 24 months the HL group had significantly higher and the LH group (two non-optimal conditions) significantly lower means than the HH and LL groups (one non-optimal condition), $F(df = 4, 122) = 8.69$, $p = .000$, and the same was found at 5 years, $F(df = 4, 122) = 11.03$, $p = .000$ (Figure 1).

Social-emotional trajectories

Results for Maternal Sensitivity showed substantial change over time, Sphericity Assumed $F(df = 3) = 36.81$, $p = .000$, $\eta^2 = .60$. The linear, quadratic, and cubic trends were significant, indicating that maternal sensitivity changed in non-linear ways. Highly significant changes occurred across the first year but not thereafter: sensitivity increased from birth to 3 months, Sphericity Assumed $F(df = 1) = 50.95$, $p = .000$, $\eta^2 = .268$, and from 3 to 6 months, Sphericity Assumed $F(df = 1) = 18.87$, $p = .000$, $\eta^2 = .12$; and decreased from 6 to 12 months, Sphericity Assumed $F(df = 1) = 67.69$, $p = .000$, $\eta^2 = .357$.

Maternal depression impacted on the development of maternal sensitivity, Interaction $F(df = 5, 118) = 7.14$, $p = .000$, $\eta^2 = .15$, and its strongest effects were on change from 3 to 6 months, Sphericity Assumed $F(df = 1) = 3.91$, $p = .050$, $\eta^2 = .031$, and from 2 to 5 years, Sphericity Assumed $F(df = 1) = 3.94$, $p = .049$, $\eta^2 = .032$. VT did not have a direct effect on change in maternal sensitivity, only in combination with maternal depression: Three-way interaction $F(df = 5, 118) = 2.53$, $p = .033$, $\eta^2 = .097$. Univariate tests of the four groups (Figure 2A) showed that at birth the HL group scored higher than the other three groups, at 3 and 12 months, differences emerged only between the HL and LH group, and at 6 months

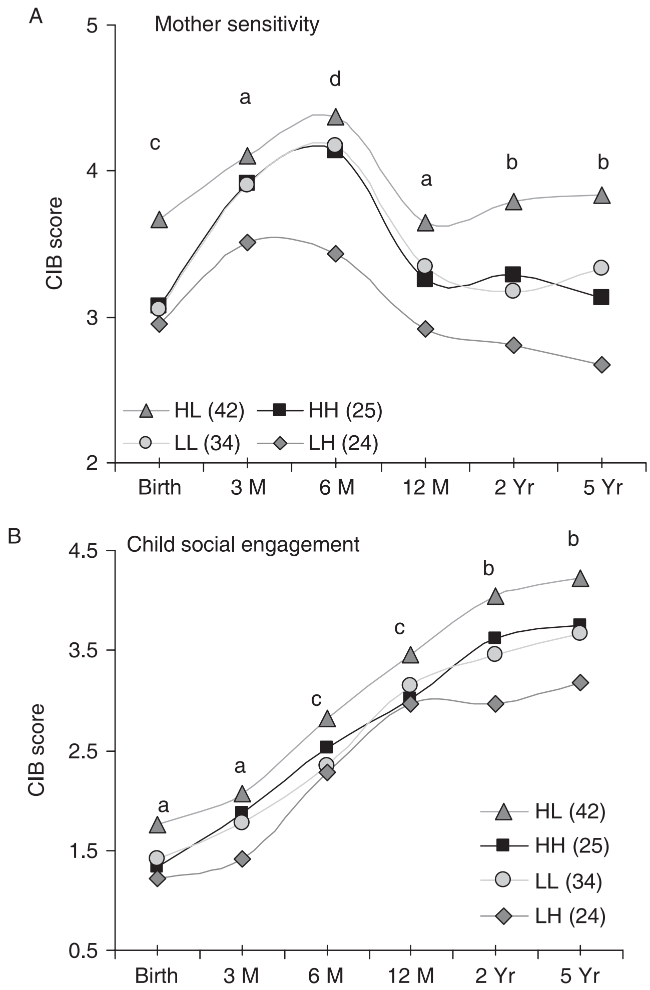

Figure 2 *Trajectories of maternal sensitivity (A) and child social engagement (B) according to biological and environmental neonatal conditions.*
Trajectories assessed in four groups of children: High neonatal vagal tone (VT), low maternal depression (HL); High neonatal VT, high maternal depression (HH); Low neonatal VT, low maternal depression (LL); and low neonatal VT and high maternal depression (LH). (a) HL > LH; (b) HL > HH, LL > LH; (c) HL > HH, LL, LH; (d) HL, HH, LL > LH.

the HL, HH, and LL groups were higher than the LH group. However, at 2 and 5 years a similar pattern to that observed for cognitive development emerged and differences were found between three groups – infants with none, one, or two risk conditions.

Child Social Engagement developed markedly over the first five years, Sphericity Assumed $F(df = 3) = 52.63$, $p = .000$, $\eta^2 = .71$. The linear trend was significant, suggesting that child social engagement increases steadily across childhood. Significant changes were observed between each level and the next: birth to 3 months, Sphericity Assumed $F(df = 1) = 42.95$, $p = .000$, $\eta^2 = .21$; 3 to 6 months, Sphericity Assumed $F(df = 1) = 38.11$, $p = .000$, $\eta^2 = .19$; 6 to 12 months, Sphericity Assumed $F(df = 1) = 8.63$, $p = .000$, $\eta^2 = .11$; 12 to 24 months, Sphericity Assumed $F(df = 1) = 5.36$, $p = .008$, $\eta^2 = .07$; and 2 to 5 years, Sphericity Assumed $F(df = 1) = 4.91$,

p = .03, η^2 = .06, indicating that the greatest strides in social development occur during the first year and the rate of change decreases thereafter.

Maternal depression had an effect on the development of Child Social Engagement, Interaction $F(df = 5, 118) = 6.98$, p = .000, η^2 = .14, with most significant effects observed between 3 and 6 months, Sphericity Assumed $F(df = 1) = 4.22$, p = .045, η^2 = .034, and 2 and 5 years, Sphericity Assumed $F(df = 1) = 4.53$, p = .04, η^2 = .042. VT had an effect on Child Social Engagement, Interaction $F(df = 5, 118) = 4.03$, p = .008, η^2 = .09: between birth and 3 months, Sphericity Assumed $F(df = 1) = 4.05$, p = .042, η^2 = .032, and between 6 and 12 months, Sphericity Assumed $F(df = 1) = 4.64$, p = .039, η^2 = .051.

Univariate tests (Figure 2B) showed that at birth and 3 months, only the HL and LH groups were different, and at 6 and 12 months, infants with two optimal birth conditions scored higher than the other three groups. However, at 2 and 5 years, similar to cognitive development and maternal sensitivity, differences emerged between the three groups – with none, one, and two non-optimal birth conditions.

Correlations between intelligence, maternal sensitivity, and child social engagement were significant at each time-point (range: r = .25 to .67). Regression models predicting cognitive development at 6, 12, and 24 months and 5 years showed that maternal sensitivity at a previous time-point (i.e. 3, 6, 12, and 24 months) predicted unique variance in cognitive development controlling for concurrent sensitivity. However, in models predicting the opposite trend – maternal sensitivity from cognitive development at $t - 1$ controlling for concurrent intelligence – cognitive development at $t - 1$ did not predict unique variance. These findings suggest that maternal sensitivity may buttress the development of cognitive competencies.

Discussion

This study is among the first to describe the trajectories of cognitive and social-emotional development from birth to 5 years in relation to biological and environmental neonatal conditions. The results point to differences in the timing of the two effects; whereas more optimal autonomic functioning increased the rate of development across the first year, maternal postpartum depression interfered with development during the preschool stage. Taken on the background of the cognitive and social-emotional growth-curves, these findings may illuminate the unique effect of each birth condition on the timing of development. The data also support a 'cumulative risk' model (Cicchetti & Cohen, 1995) by showing that the combination of biological and environmental risk conditions markedly increases the child's vulnerability to maladaptive development. It is important to note, however, that the results should be interpreted with caution as we examined the mother's depressive symptoms and did not assess clinical depression, the study did not include a behavior genetic design, and the sample was limited to middle-class families.

Cognitive development was measured beginning at 6 months, the first time-point at which mental scores can be reliably predictive to later stages (Feldman & Eidelman, 2005). The significance of the linear component, particularly from 2 to 5 years, highlights the significant growth in cognitive skills with the maturation of inhibitory functions, symbolic competence, and language. The trajectories of maternal sensitivity and infant social engagement, on the other hand, showed substantial changes during the first year and slower or non-significant changes thereafter. Maternal sensitivity increased dramatically during the first 6 months, a period when infants are initiated into the social world through the mother's second-by-second adaptation. With the development of intersubjectivity during the second 6 months, infants become more active social partners and the unidirectional maternal adaptation is replaced by reciprocal adjustment (Feldman, 2007a). Social engagement increased linearly from birth to 5 years, with major strides during the first year and smaller increments thereafter and the current data are the first to describe the steady increase in the child's social engagement as assessed through repeated observations across early childhood.

The effects of VT on the rate of cognitive and social-emotional development were most pronounced during the first year, not thereafter. Generally, the effects of VT occurred during the periods of fastest growth in each domain. The greatest reorganization in cognitive functioning across infancy occurs between 6 and 12 months, with the emergence of intentionality, cross-modal processing, and first use of symbols. Similarly, social involvement increases dramatically from the newborn's scant attention to the 3-month-old infant's affective involvement at play. During such dynamic periods, which tax the infant's inborn resources, a more adaptive physiological system that supports smoother adaptation to quick shifts in incoming sensory input or social signals may afford quicker development (Porges, 2003) and places the child at a better starting point. As seen from the comparison of the four groups, such children continued to score better than their peers, particularly in the context of low maternal depression.

In contrast, the effects of maternal depression on all domains of functioning were most notable between 2 and 5 years. At this stage, a developmental leap occurs in the child's autonomy and independence and significant brain reorganization expands the repertoire of cognitive and social-emotional skills. The findings, therefore, may suggest that depressed mothers have a special difficulty in supporting the child's independence, creativity, executive functions, empathy, and peer friendships, functions that emerge during the preschool stage. Additional effects of maternal depression on maternal sensitivity and child social engagement were observed between 3 and 6 months. Possibly, the rapid development in the infant's social involvement, which requires the mother's second-by-second adaptation, deplete the limited resources of the depressed mother and lead to lower child social engagement.

Differences between groups of children with none, one, or two neonatal risk indicators increased with age. This is consistent with follow-ups of birth cohorts, which showed that the number of risk factors in the infant's ecology predicted long-term outcomes (Sameroff & Fiese, 2000; Werner & Smith, 1992). Such cumulative risk models underscore the tendency of risk conditions to exacerbate each other over time, for instance, an unengaged child often decreases the mother's sensitivity. The present dynamic examination reveals that infants with two favorable conditions not only begin development at a slightly improved point but seem to possess enough resources to progress steadily upwards. Conversely, infants with two unfavorable conditions showed a flatter curve, indicating few resources to push development forward. As these children grow, the disparity between the groups tends to increase.

Several limitations of the study should be noted. First, maternal depression was assessed through a self-report measure, not by a clinical interview, and was assessed only once and, thus, the issue of chronicity was not addressed. Because there were no genetic analyses, the study can refer to biologically based dispositions and not to true 'biological' or genetic components. Furthermore, although mother depressive symptoms and neonatal VT were not correlated, maternal antenatal depression may impact the fetus' parasympathetic maturation and the two factors may not be fully independent. Finally, because the sample included only middle-to-high SES families, replication is needed before the findings can be generalized to lower SES or children growing in contexts of higher social adversity.

Future research should follow children born in a variety of social contexts, ethnic groups, and socio-demographic conditions beginning at birth and using closely-timed direct observations to assess the effects of multiple biological and environmental risks. It is also important to include assessments of specific genetic markers and their interaction with environmental conditions in shaping the development of cognitive and social-emotional skills across the first years of life. As the architecture of risk and resilience changes according to the cultural context (Feldman & Masalha, 2007), it is essential to examine cultural variability in growth trajectories. Finally, we need to understand how neonatal conditions affect individuals at developmental nodes across the lifespan, including the transition to adolescence, adulthood, and old age.

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