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SHORT REPORT

Maternal and infant affect at 4 months predicts performance and verbal IQ at 4 and 7 years in a diverse population

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Abstract

Using existing longitudinal data from 570 infants in the Maternal Lifestyle Study, we explored the predictive value of maternal and infant affect and maternal vocalizations during 2 minutes of face-to-face interactions at 4 months on IQ scores at 4.5 and 7 years. After controlling for demographic factors, maternal depression, and prenatal drug exposure, maternal positive affect and maternal positive vocalizations emerged as predictors of both verbal and performance IQ at 4.5 and 7 years. Although infant positive affect during the interaction with the mother was not predictive of these outcome measures, infant positive affect towards an examiner predicted verbal but not performance IQ at 4.5 years. These results suggest that maternal positive affect may index emotional engagement in interaction that facilitates both verbal and nonverbal cognitive development, while infant social positive affect is specifically related to the acquisition of verbal reasoning abilities. These findings are significant because they are based on a discrete snapshot of observable behavior in infancy (just 2 minutes of interaction), because they extend the range of maternal behaviors and characteristics known to support positive developmental outcomes, and because they are derived from high-risk infants where prevention efforts may be beneficial. Potential mechanisms for these associations are discussed, as are the clinical implications for identifying dyads most in need of targeted interventions.

Research highlights

- Mothers' positive affect and positive vocalizations during a 2-minute mother–infant interaction at 4 months of age positively predicted children's verbal and visual spatial cognitive abilities at 4 and 7 years.
- Infants' positive displays with an interactive examiner predicted verbal but not visual spatial cognitive outcomes.
- Results highlight the importance of interactive displays of mother positive affect toward the infant – a potential index of emotional enjoyment and

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investment – and infant positive affect toward another – a behavioral index of social engagement – in predicting *cognitive* outcomes.
- Relations between early maternal and infant positive affect and cognitive outcomes in this high-risk cohort have implications for refining programs to promote optimal developmental outcomes in at-risk populations.

Introduction

Learning in infancy often occurs in the context of dyadic interactions between mothers and their infants (Bakeman & Adamson, 1984; Bruner, 1983; Dunham & Moore, 1995; Schaffer, 1977). Previous research has shown that both maternal (Hart & Risley, 1992; Hurtado, Marchman & Fernald, 2008; Landry, Smith, Miller-Loncar & Swank, 1997; Lester, Boukydis, Garcia-Coll, Peucker, McGrath *et al.*, 1995; Tamis-LeMonda, Bornstein & Baumwell, 2001) and infant (Carpenter, Nagell & Tomasello, 1998; Morales, Mundy, Delgado, Yale, Neal *et al.*, 2000b; Slomkowski, Nelson, Dunn & Plomin, 1992) behaviors and characteristics during infancy hold predictive value for language and cognitive development later in childhood. Although we know that both infant and maternal behaviors and characteristics contribute to these developmental outcomes, the potential contribution of positive affect – a socially salient behavior – has received scant attention.

From the mother, the amount of language-related input (Hart & Risley, 1992; Hurtado *et al.*, 2008; Huttenlocher, Haight, Bryk, Seltzer & Lyons, 1991), quality or clarity of input (Song, Demuth & Morgan, 2010), content of the input (Hart & Risley, 1992), sensitivity to the child's attentional focus (Dunham & Dunham, 1992; Dunham, Dunham & Curwin, 1993; Landry *et al.*, 1997; Tomasello & Farrar, 1986), responsiveness to the child's utterances (Tamis-LeMonda *et al.*, 2001; Tamis-LeMonda, Bornstein, Baumwell & Melstein Damast, 1996), affective attunement (Nicely, Tamis-LeMonda & Bornstein, 1999), goodness of fit between infant cry and the mother's perception of that cry (Lester *et al.*, 1995), and levels of depression (Brennan, Hammen, Andersen, Bor, Najman *et al.*, 2000; Colombo, 2001; Hay & Kumar, 1995; Murray, Fiori-Cowley, Hooper & Cooper, 1996a; Murray, Hipwell, Hooper, Stein & Cooper, 1996b; Murray, Kempton, Woolgar & Hooper, 1993; Sharp, Hay, Pawlby, Schmücker, Allen *et al.*, 1995), have all been identified as predictors of language and cognitive development. Moreover, models of parenting that emphasize the importance of parental emotion and affective attunement are consistent with a prediction that contextually appropriate positive affect during dyadic interactions is supportive of later child competencies, including cognitive and language skills (Dix, 1991). For example, Steelman and colleagues (Steelman, Assel, Swank, Smith & Landry, 2002) found that maternal warmth observed during parent–child interactions at 12 months of age (including warm affective displays) had both direct and indirect associations with children's later language abilities.

From the infant, easy temperament and social engagement also predict positive developmental outcomes. For example, infants who are described as being more easily soothed, who pay attention for longer periods of time, and who are more likely to smile and laugh tend to have larger receptive vocabulary sizes at 12 months (Morales *et al.*, 2000b) and tend to have an early vocabulary with a high proportion of nouns (Dixon & Shore, 1997). Extroversion in toddlerhood has also been positively correlated with language ability in childhood (Slomkowski *et al.*, 1992). In addition, an infant's tendency to engage in joint attention (Carpenter *et al.*, 1998; Markus, Mundy, Morales, Delgado & Yale, 2000; Morales, Mundy, Delgado, Yale, Messinger *et al.*, 2000a; Vaughan Van Hecke, Mundy, Acra, Block, Delgado *et al.*, 2007) and infants' attention to social stimuli (Morales *et al.*, 2000b; Tenenbaum, Sobel, Sheinkopf, Malle & Morgan, 2015; Young, Merin, Rogers & Ozonoff, 2009) also predict these positive developmental outcomes.

It is particularly important to understand the relationship between infant characteristics, parent characteristics and developmental outcomes in poor and at-risk children. Children with prenatal risks and children from disadvantaged backgrounds are at risk for delays (McLoyd, 1998; Morisset, Barnard, Greenberg, Booth & Spieker, 1990). Weisleder and Fernald (2013) have found that the amount of child-directed speech used in low-income families is predictive of vocabulary size at 2 years. Cates, Dreyer, Berkule, White, Arevalo *et al.* (2012) reported that enhanced environments (cognitive stimulation) at 6 months influenced infant communication behaviors and later language outcomes at 2 years in a low-income sample of infants. These findings point to the influence of parental factors on outcomes in low-income families. The accumulation of risks in infants with prenatal drug exposure, including disadvantaged low-income environments, places these children at high risk for poor developmental outcomes. It is not clear to what extent an infant's tendency to display positive affect may also influence outcomes in such high-risk scenarios. It is possible that infant characteristics that invite communication from adults may serve as a protective factor in these high-risk environments.

Also unclear is the extent to which parent and child characteristics may be related to each other, and the degree to which they have additive influences on cognitive and language development. Further, previous research has not generally addressed the extent to which the behavioral characteristics of mother and child may relate differentially to verbal and nonverbal cognitive abilities. Different mechanisms may account for relations between maternal and infant affect and cognitive outcomes.

Links between maternal positivity and general cognitive abilities may be due to a reward cycle in which attention to a mother displaying positive affect provides reinforcement that increases the infant's desire to engage with her more often and for longer periods, thus increasing opportunities for learning during dyadic interactions. Indeed, prior research with infants of depressed mothers has demonstrated disruptions in learning that may be associated with 'nonreinforcement' among depressed mothers who tend to display relatively flat affect (Kaplan, Bachorowski, Smoski & Hudenko, 2002).

With respect to language specifically, maternal positive affect in early interactions may be associated with mothers' use of infant-directed speech, a form of speech characterized by higher fundamental frequency, greater pitch variation, shorter sentences and slower speech rate (Fernald & Kuhl, 1987). Infants at 4 months prefer to listen to infant-directed speech over adult-directed speech (Fernald, 1985) and mothers who tend to use more infant-directed speech have children who demonstrate better language abilities (Liu, Kuhl & Tsao, 2003).

With respect to infant positive affect, the link between positive affect and language ability may be related to a social engagement account of language learning. Kuhl (2007) proposes that the social brain 'gates' language development either by increasing the infant's motivation to engage with others or because increased social interactions provide increased opportunities for disambiguating the aspects of language that require social input (e.g. word learning). Infant positive affect may therefore be associated with higher language levels specifically because positive affect invites socialization and language learning relies so heavily on social interactions.

In the current study, we tested the relations between infant and maternal positive behaviors and later verbal and nonverbal IQ in a sample of high-risk infants. We looked specifically at behavioral interactions when the infants were 4 months old and verbal and performance IQ measures attained at 4.5 and 7 years. We also explored measures of language outcomes specifically at 6 years. Based on previous evidence (Hay & Kumar, 1995; Murray *et al*., 1996a; Murray *et al*., 1996b; Murray *et al*., 1993; Sharp *et al*., 1995), we hypothesized that the tendency for mothers to approach their infants with positive affect would predict higher verbal and nonverbal reasoning abilities in the preschool and early school age period. We also hypothesized that the infant's own affective state, a proxy for their level of engagement in the interaction (Kuhl, 2007), would predict verbal abilities specifically (Dixon & Shore, 1997; Morales *et al*., 2000b; Slomkowski *et al*., 1992).

Method

Data for this investigation were taken from the Maternal Lifestyle Study (MLS), a multisite study of the effects of prenatal cocaine/opiate exposure on child outcome in a longitudinal study that followed 1388 children from 1 month to adolescence (Bada, Bauer, Shankaran, Lester, Wright *et al*., 2002; Bauer, Shankaran, Bada, Lester, Wright *et al*., 2002; Lester, Tronick, LaGasse, Seifer, Bauer *et al*., 2002). Prenatal drug exposure was not a focus of the hypotheses tested in this study. Instead, prenatal drug exposure was treated as a covariate in models testing the relations between early parent and infant affect on child outcomes in a high-risk sample. The study sample varied with respect to the presence or absence of prenatal exposure to cocaine or opiates (defined by maternal report or positive meconium assay), alcohol, tobacco, and cannabis (defined by maternal self report; for further details see Lester, ElSohly, Wright, Smeriglio, Verter *et al*., 2001; Lester, LaGasse, Seifer, Tronick, Bauer *et al*., 2003). Although drug exposure was not a primary focus of the current investigation, a major advantage of using this sample was to allow for exploration of the effects of behavioral interactions within a diverse sample not typically represented in longitudinal studies.

Participants

Participants were mothers (at least 18 years with no history of psychosis) and their infants (single birth, with birth weight greater than 501 g), who were recruited at four urban university-based medical centers (Brown University, University of Miami, Wayne State University, and the University of Tennessee at Memphis). From the original 1388 mothers enrolled in the MLS study, we examined data from the 695 mother-infant dyads for whom data were successfully collected during the face-to-face still-face (FFSF) paradigm at 4 months (M = 3.96 months, SD = .24) (the same sample used in Tronick, Messinger, Weinberg, Lester, LaGasse *et al*., 2005). Because our focus was on the mother-infant dyad, 35 nonmaternal familial caregivers and 11 nonrelated caregivers were excluded, leaving the 695 biological mothers and their infants. Of the 695 dyads, 570 children (305 male, 265 female) returned for cognitive testing at 4.5 years (n = 467, M = 4.53 years, SD = .11) and/or 7 years (n = 498, M = 7.05 years, SD = .13). Within this sample of 570 children, 78% were African American, 14% were Caucasian, and 6% were Hispanic; 36% were exposed to cocaine, 57% were exposed to alcohol, 47% were exposed to tobacco, 19% were exposed to marijuana, and 7% were exposed to opiates in utero.

Participants who were excluded for missing data did not differ from those who were included (i.e. those who had data at the 4-month face-to-face visit and at least one IQ measure) on birth weight, exposure to alcohol, language ability scores, performance or verbal IQ at 4.5 years or performance IQ at 7 years (p-values > .10). Those with missing data were more likely than those who were included in the analysis to come from low-SES backgrounds (excluded: 29.1% vs. included: 22.1%, p < .01), to report lower levels of maternal depression at the 4-month visit (excluded: 1.46 on a 4-point scale, included: 1.60, p < .01), and to have been exposed to cocaine (excluded: 49% vs. included: 36%, p < .01), opiates (excluded: 10% vs. included: 7%, p < .05), tobacco (excluded: 58% vs. included: 47%, p < .01), and marijuana (excluded: 26% vs. included: 19%, p < .01). Verbal IQ scores at 7 years were higher on average among those included in the analysis (excluded: 85.07, included: 87.11, p = .05). Characteristics of the sample included in this analysis are presented in Table 1.

Table 1 *Descriptive statistics for predictor and outcome measures (standard deviations)*

Prenatal cocaine	n = 570
Birth weight	2636.21 (851.39)
SES** Low (%)	21.41%
High (%)	78.58%
Depression (BDI) No	61.22%
Mild	19.65%
Moderate	13.86%
Severe	4.03%
Exposure: Cocaine	35.79%
Opiates	6.67%
Alcohol	56.84%
Marijuana	18.95%
Tobacco	47.37%
Mother Social Positive	.27 (.20)
Mother Positive vocalizations	.60 (.21)
Infant Positive affect with mother	.11(.15)
Infant Positive affect with examiner	.08 (.12)
WPPSI Performance IQ	83.58(14.29)
WPPSI Verbal IQ	83.24(13.92)
WISC Performance IQ	87.21(14.15)
WISC Verbal IQ	87.11 (16.38)
CELF Receptive Score	88.29 (15.00)
CELF Expressive Score	84.13 (13.38)

Note: SES: socioeconomic status; BDI: Beck Depression Inventory; WPPSI: Wechsler Preschool & Primary Scales of Intelligence; WISC: Wechsler Intelligence Scale for Children; CELF: Child Evaluation of Language Fundamentals Preschool Edition.

Procedures

At 4 months, infants and mothers participated in the face-to-face still-face (FFSF) paradigm (Tronick, Als, Adamson, Wise & Brazelton, 1978; Tronick *et al.*, 2005). In the FFSF paradigm, the infant is placed in a car seat facing his or her mother or an examiner while the facial expressions and behaviors of both are recorded for four 2-minute episodes. In the first episode, the mother was instructed to interact with the child as she normally would. This was followed by the still-face episode during which the mother was instructed to maintain a still face and the reunion episode during which the mother could re-engage with the infant. Finally, a female experimenter trained in administration of the FFSF paradigm took the mother's place and interacted with the infant for an additional 2 minutes. Because we were most interested in the infant's baseline engagement states (rather than response to a still-face), we analyzed data from the initial interaction with the mother and the interaction with the examiner.

Infant and mother behaviors were coded offline using the Infant Caregiver Engagement Phases (ICEP; Weinberg & Tronick, 1998). These mutually exclusive codes included phases during which the infant was demonstrating passive-withdrawn behaviors, protest behaviors, object-environment engagement, social monitoring, and positive engagement. For the mother, codes included negative affect, social monitoring without vocalization, social monitoring with positive vocalization, and social positive affect. For the purpose of exploring positivity specifically, we focused on infant positive affect, maternal social monitor with positive vocalization, and maternal positive affect. Infant positive affect was coded when the infant was smiling at the caregiver and/or cooing, laughing, babbling or squealing while looking at the caregiver. For mothers, there were two separate codes that could be described as displays of positive affect: social monitor with positive vocalizations and social positive engagement. Social monitoring with positive vocalization was used when the mother displayed neutral affect but spoke to the infant in infant-directed speech, sang, or made noises directed at the infant (e.g. kissing sounds). Social positive engagement was coded if the mother expressed positive affect in smile, laughter or by making playful faces.

All coders were trained to reliability with a gold standard sample of 10 tapes by an author of the coding system. Reliability denoted agreement ≥ 80% and Cohen's kappa (Cohen, 1960), which corrects for chance agreement ≥ .70. Ongoing reliability was monitored on a random 15% of sessions and included regular cross-checks between the two coding sites. Percentage agreement was high for coding of infant and maternal engagement states and behaviors: infant engagement (85%, kappa = .74); maternal engagement (84%, kappa = .74). For further description of the coding procedures and reliability of coding, see Tronick *et al*. (2005).

Children returned for cognitive and language testing using the Wechsler Preschool and Primary Scales of Intelligence, Revised (WPPSI-R; Wechsler, 1989) at 4.5 years of age, the Clinical Evaluation of Language Fundamentals–Preschool (CELF-P; Wiig, Secord & Semel, 1992) at 6 years, and the Wechsler Intelligence Scale for Children, 3rd edition (WISC-III; Wechsler, 1991) at 7 years of age. On the IQ measures at both ages and on both measures, children's Performance IQ scores were derived as a measure of fluid reasoning and visual spatial skills, and Verbal IQ scores were derived as a measure of verbal knowledge and reasoning. CELF scores were based on linguistic concepts, sentence structure, recalling sentences, formulating labels, and word structure.

Covariates

Covariates used in the current analysis included a binary measure of low vs. high SES based on the Index of Social Position score from the Hollingshead Scale (SES; Hollingshead, 1978), infant birth weight, study site, and presence or absence of cocaine exposure, opiate exposure, and other drug exposure (alcohol, marijuana, and tobacco; see Tronick *et al*., 2005). Race and ethnicity (Black, White, Hispanic, other) was included as a covariate because it was significantly correlated with the outcome measures of IQ ($p < .01$). Given the known relation between depression and cognitive and language measures, Beck Depression Inventory (Beck, 1961) scores for the mothers, collected at the 4-month visit, were also included as a covariate. BDI scores were based on the clinical cutoffs and ranged from 1 (no depression) to 4 (severe depression).

Results

Preliminary analyses

Measures of infant positive affect, maternal positive affect, and maternal positive vocalizations were calculated as proportions of time during the interactive episode (time spent in that affective state/length of episode). Infants displayed significantly more positive affect towards their mothers ($M = .11$, $SD = .15$) than towards the examiners ($M = .08$, $SD = .12$), paired samples t-test, $t(1, 569) = 3.76$, $p < .01$. Mothers displayed significantly more positive affect towards their infants ($M = .27$, $SD = .20$) than did the examiners ($M = .24$, $SD = .19$), paired samples t-test, $t(1, 569) = 3.23$, $p < .01$. Examiners spent a significantly greater proportion of the episode in social monitoring with positive vocalizations ($M = .71$, $SD = .20$) than did the mothers ($M = .60$, $SD = .20$), paired samples t-test, $t(1, 569) = 10.63$, $p < .01$.

Hypothesis testing

Our primary goal was to examine the relations between infant and parent characteristics and outcome in the context of pre- and post-natal risk factors. To explore the relation between these predictor and outcome measures, we ran linear regressions on outcome measures of verbal reasoning (WPPSI-R and WISC–III Verbal IQ) and visual spatial reasoning (WPPSI-R and WISC-III Performance IQ) scores at 4.5 and 7 years and language skills (CELF Expressive and Receptive) scores at 6 years with covariates in the first step (study site, race, SES, birth weight, cocaine exposure, opiate exposure and other drug exposure, BDI clinical cutoff scores), and maternal and infant behaviors in the second step (maternal positive affect and maternal positive vocalizations during the baseline interaction and infant positive affect during the baseline interaction with the mother and infant positive affect during the interaction with the examiner). Results are shown in Tables 2–4.

In the regression on Verbal IQ at 4.5 years, the overall model was statistically significant, $F(14, 445) = 5.74$, $p < .001$. Both steps resulted in significant change in R^2, Step 1: $F(10, 449) = 6.11$, $R^2 = .12$, $p < .001$; Step 2: $F(4, 445) = 4.36$, $\Delta R^2 = .03$, $p < .01$. In the full model, study site, SES, BDI scores, maternal positive affect, maternal positive vocalizations, and infant positive affect with the examiner were significant predictors of verbal IQ at 4.5 years. Alcohol exposure was a marginally significant predictor of verbal IQ at 4.5 years. Infant positive affect with the mother was not a significant predictor of verbal IQ at either age.

For Verbal IQ at 7 years, the overall model was statistically significant, $F(14, 477) = 6.52$, $p < .001$. Both steps were again significant with significant changes in R^2, Step 1: $F(10, 481) = 7.60$, $R^2 = .14$, $p < .001$; Step 2: $F(4, 477) = 3.45$, $\Delta R^2 = .02$, $p < .01$. In the full model, study site, Race, SES, birth weight, marijuana exposure, maternal positive affect and maternal positive

Table 2 *Beta weights for linear regression on Verbal IQ*

	Verbal IQ 4.5 years		Verbal IQ 7 years	
	(WPPSI)		(WISC)	
	Step 1 $R^2 = .12$***	Step 2 $\Delta R^2 = .03$**	Step 1 $R^2 = .14$***	Step 2 $\Delta R^2 = .02$**
Study site	.19**	.20**	.15**	.15**
Race	.09†	.05	.14**	.11*
Birth weight	.02	.02	.09*	.09*
SES (Hollingshead)	−.15**	−.15**	−.11*	−.11**
Cocaine exposure	−.02	−.02	−.04	−.04
Opiate exposure	.07	.06	.03	.03
Alcohol exposure	.08	.09†	.08	.08†
Tobacco exposure	.07	.06	.05	.04
Marijuana exposure	−.05	−.04	−.12*	−.10*
BDI clinical cut-off	−.12**	−.10*	−.11*	−.08†
Mother Positive affect		.17**		.21**
Mother Positive vocalizations		.20**		.18**
Infant Positive affect with mother		−.03		−.06
Infant Positive affect with examiner		.13**		.07

Note: † = $p < .10$; * = $p < .05$; ** = $p < .01$; *** = $p < .001$; WPPSI: Wechsler Preschool & Primary Scales of Intelligence; WISC: Wechsler Intelligence Scale for Children.

Table 3 *Beta weights for linear regression on Performance IQ*

	Performance IQ 4.5 years		Performance IQ 7 years	
	(WPPSI)		(WISC)	
	Step 1 $R^2 = .13$***	Step 2 $\Delta R^2 = .02$*	Step 1 $R^2 = .15$***	Step 2 $\Delta R^2 = .02$†
Study site	.05	.05	.10†	.10†
Race	.19**	.17**	.20**	.19**
Birth weight	.10*	.10*	.10*	.10*
SES (Hollingshead)	−.18**	−.19**	−.16**	−.17**
Cocaine exposure	−.05	−.05	.05	.05
Opiate exposure	.00	.00	.00	.00
Alcohol exposure	.06	.06	.02	.03
Tobacco exposure	.06	.05	−.05	−.05
Marijuana exposure	.02	.02	−.04	−.03
BDI clinical cut-off	−.11*	−.09†	−.10*	−.08†
Mother Positive affect		.13*		.17**
Mother Positive vocalizations		.19**		.15*
Infant Positive affect with mother		−.04		−.02
Infant Positive affect with examiner		.04		.00

Note: † = $p < .10$; * = $p < .05$; ** = $p < .01$; *** = $p < .001$; WPPSI: Wechsler Preschool & Primary Scales of Intelligence; WISC: Wechsler Intelligence Scale for Children.

vocalizations were significant predictors of verbal IQ at 7 years. The effect of infant positive affect with the examiner was no longer significant. The effects of alcohol exposure and BDI scores were marginally significant. See Table 2.

For Performance IQ at 4.5 years, the overall model was statistically significant, $F(14, 447) = 5.65$, $p < .001$. Both steps resulted in significant changes in R^2, Step 1: $F(10, 451) = 6.72$, $R^2 = .13$, $p < .001$; Step 2: $F(4, 447) = 2.71$, $\Delta R^2 = .02$, $p < .05$. In the full model, race, birth weight, SES, maternal positive affect and maternal positive vocalizations emerged as significant predictors of Performance IQ at 4.5 years. BDI scores were marginally significant. At 7 years, while the overall model was statistically significant, $F(14, 477) = 6.53$, $p < .001$, the change in R^2 was significant for Step 1

Table 4 *Beta weights for linear regression on CELF scores*

	Receptive language		Expressive language	
	Step 1 R^2 = .14***	Step 2 ΔR^2 = .01, *ns*	Step 1 R^2 = .10***	Step 2 ΔR^2 = .02†
Study site	.09†	.09†	.09	.08
Race	.16**	.14**	.10†	.08
Birth weight	.09†	.09†	.02	.02
SES (Hollingshead)	−.16**	−.17**	−.19**	−.20**
Cocaine exposure	.02	.03	−.07	−.06
Opiate exposure	.05	.04	.05	.04
Alcohol exposure	.08	.08	.11*	.11*
Tobacco exposure	.09†	.09†	.08	.08
Marijuana exposure	−.11*	−.11*	−.05	−.05
BDI clinical cut-off	−.12**	−.11*	−.08†	−.07
Mother Positive affect		.06		.14*
Mother Positive vocalizations		.11†		.14*
Infant Positive affect with mother		−.06		−.08
Infant Positive affect with examiner		.05		−.01

Note: † = $p < .10$; * = $p < .05$; ** = $p < .01$; *** = $p < .001$.

which included the covariates, but only marginally significant at Step 2 which included the relevant predictors, Step 1: $F(10, 481) = 8.22$, $R^2 = .15$, $p < .001$; Step 2: $F(4, 477) = 2.11$, $\Delta R^2 = .02$, $p < .10$. See Table 3.

For CELF receptive language scores at 6 years, the overall model was significant, $F(14, 456) = 5.52$, $p < .001$. The first step in the model was significant, but the change in R^2 for the second step was not statistically significant, Step 1: $F(10, 460) = 7.16$, $R^2 = .14$, $p < .001$; Step 2: $F(4, 456) = 1.37$, $\Delta R^2 = .01$, *ns*. For CELF expressive language scores, the overall model was significant, $F(14, 454) = 4.11$, $p < .001$, as was the first step, but the second step in the model was only marginally significant, Step 1: $F(10, 458) = 4.86$, $R^2 = .10$, $p < .001$; Step 2: $F(4, 454) = 2.12$, $\Delta R^2 = .02$, $p = .08$. See Table 4.

Discussion

This study explored the degree to which maternal affect and vocalizations and infant affect during dyadic interactions at 4 months of age contributed to cognitive and language outcomes in early childhood. Two main findings emerged from this work. First, infants whose mothers displayed more positive affect and used more positive vocalizations during face-to-face interaction had higher Verbal IQ scores at 4.5 and 7 years and higher Performance IQ scores at 4.5 years (effects at 7 years were marginally significant). These results were reliable after controlling for the effects of SES, race, birth weight, maternal depression, and prenatal drug exposure. Second, children who displayed more positive affect when interacting with an examiner at 4 months had higher verbal IQ scores at 4.5 years. This finding was also reliable after controlling for covariates. The positive relation between infant positive affect with an examiner and verbal IQ was significant and independent of the relation between maternal positive affect, maternal vocalizations, and verbal IQ. Infants' direction of positive affect towards their mothers was not predictive of performance or verbal IQ scores at either age. The effects of infant and maternal positive affect and maternal positive vocalizations did not emerge as significant predictors of receptive language ability at 6 years. The model for expressive language ability at 6 years was only marginally significant, with both maternal vocalizations and maternal positive affect accounting for unique variance in the outcome measure.

These findings have implications for understanding the processes affecting positive cognitive outcomes. The relations between positive maternal affect and later verbal and performance IQ are consistent with models of parenting (Dix, 1991) and emprical findings (Steelman *et al.*, 2002) linking early affective processes and responsiveness of parenting with child outcomes, including language and cognitive abilities. The current results extend this work by demonstrating that expressions of positive affect specifically toward the young infant are associated with positive developmental outcomes at 4 and 7 years of age. While maternal positive affect and responsivity have been associated with higher levels of compliance and rule following (Kochanska, 1997) and maternal synchrony and response to infants has been associated with later IQ (Feldman, Greenbaum, Yirmiya & Mayes, 1996) to our knowledge, this is the first direct association between positive maternal affect specifically and later IQ. These results are consistent with a reinforcement account of the benefits of positive maternal affect on infant development (Kaplan *et al.*, 2002) whereby positive affect encourages an infant to maintain engagement with the mother and increases opportunities for learning.

The finding that positive maternal vocalizations predict verbal and performance IQ scores is consistent with previous work linking the amount and content of parental input, measured from monthly hour-long recordings, to later IQ scores (Hart & Risley, 1992). The findings reported here suggest that the extent to which a mother directs positive vocalizations towards her infant during play may index the mother's ongoing availability for engagement which might in turn support positive learning experiences. The observation that individual differences in maternal behaviors predict verbal IQ in a high-risk sample including prenatal drug exposure is also consistent with recent findings showing that the amount of child-directed talk (Weisleder & Fernald, 2013) is predictive of later language and developmental outcomes in high-risk samples. Lewis and colleagues (Lewis, Singer, Short, Minnes, Arendt *et al.*, 2004) suggested that improved language skills in drug-exposed infants who had been placed in adoptive care may be the result of enriched environments that stimulated better outcomes. However, their research did not directly assess the home environment of children. The current results provide evidence that dyadic interactions with high levels of positive affect directed at the infant may support the development of verbal skills in high-risk samples.

The infant affect results are consistent with temperament research demonstrating that positive infant affect predicts later language success (Dixon & Shore, 1997; Morales *et al.*, 2000b). A novel contribution of this work is to demonstrate that the quantity of positive affect displayed during a brief dyadic interaction at 4 months of age holds predictive power for developmental outcomes up to 7 years later. Infants' affective expressions emerged as a predictor when measured during interaction with the examiner. This finding is consistent with a social engagement account of language learning which suggests that infants who are more motivated to engage with others create more opportunities for themselves to engage in language learning (Falck-Ytter, Fernell, Gillberg & Von Hofsten, 2010; Kuhl, 2007; Mundy, Kasari, Sigman & Ruskin, 1995; Sheinkopf, Mundy, Claussen & Willoughby, 2004; Trevarthen & Aitken, 2001; Vaughan Van Hecke *et al.*, 2007). These opportunities may arise because the socially engaged infant is more attentive to social information relevant to language learning (Morales *et al.*, 2000b; Young *et al.*, 2009). An additional account supported by the current findings is that socially engaged infants demonstrate positive affect which encourages their interlocutors to remain engaged with them and thus offers greater opportunity for language learning. While this behavior does not override the effects of maternal affect, it does contribute uniquely to the variance in verbal IQ at 4 years.

The lack of significant associations between maternal or infant affect and language scores as measured on the CELF at 6 years may reflect differences in the types of verbal knowledge assessed on the WPPSI-R and WISC-III and those assessed on the CELF-P. With subtests including information, comprehension, arithmetic, vocabulary, and similarities, verbal reasoning on the WPPSI-R and WISC-III is strongly linked to knowledge of vocabulary specifically (Wechsler, 1989, 1991). In contrast, the CELF-P, with subtests that include receptive language, linguistic concepts, sentence structure, basic concepts, expressive language, recalling sentences in context, formulating labels and word structure, also assesses knowledge of syntax and higher level language processing (CELF-P; Wiig *et al.*, 1992). As Kuhl (2007) suggests, increased positivity on the part of the infant (and perhaps the caregiver) may increase opportunities for the child to engage socially with others, which may in turn provide increased opportunities for disambiguation of word references to facilitate word learning specifically. If social affect is indeed related to word learning specifically, it is not surprising that the link between this predictor and language as it is assessed on the WPPSI-R and WISC-III would be stronger than associations with language as it is assessed on the CELF-P.

It is interesting to note that within this sample, infant affect directed to the mother was not related to language outcomes. It is possible that the maternal drug use history in this population may have led to disruptions in the reward system such that mothers using drugs during pregnancy had atypical responses to their child's positive affect. Landi and colleagues (Landi, Montoya, Kober, Rutherford, Mencl *et al.*, 2011) and Rutherford, Williams, Moy, Mayes and Johns (2011) argue that the neural circuits associated with parenting behaviors (e.g. frontal, striatal and limbic systems) are also involved in the perpetuation of addiction. These authors suggest that parenting cues may trigger stress reactivity rather than reward among addicted adults for whom even positive infant cues have been shown to be less salient and triggering of a stress response. If the mother does not perceive the infant's positive affect as rewarding, she is less likely to increase her engagement with the child and thus the potential for increased learning opportunities is not realized. To explore this hypothesis, we examined the subset of infants who were not drug exposed and still found no significant relations between infant affect with the mother and later language abilities. This lack of relation could, however, be due to the limited sample size when drug-exposed infants were removed from the analysis.

An additional contribution of this work is to suggest that exogenous and endogenous affective behaviors are differentially related to developmental outcomes. Specifically, while maternal affect predicts both performance and verbal IQ, infant affect was related only to verbal IQ. Because these behaviors were measured over a single 2-minute window, it is not possible to determine what specific factors contributed to the mother's positive expressions. It may be that mothers who express positive affect in this context are feeling more positive about their infants and thus devote more time and effort to engaging with them. Mothers who express more positive affect might draw the attention of the infant more consistently and for longer periods of time, thus increasing the opportunities for the infants to learn. Whatever the mechanism, these results suggest that thin observational slices of social behaviors can serve as reliable indicators of interactional tendencies related to long-term developmental outcomes.

These results hold clinical implications and may inform efforts to improve developmental outcomes in at-risk populations. The notion that one can predict differences in verbal and performance IQ at 4.5 and 7 years based on a 2-minute interaction at just 4 months suggests that maternal affect in the baseline of the face-to-face still-face paradigm might provide clinicians with information about which dyads are most in need of intervention. That is, the degree to which mothers direct positive affect towards their infants during brief interactions may be a marker of ongoing dyadic developmental processes that support infants' cognitive development. Thus, these results point to potentially malleable targets for intervention which merit further testing. If an intervention as basic as inviting mothers of at-risk infants to use positive affect when engaging with their children has the potential for such long range implications, further testing of this approach is warranted.

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