

Maternal Warmth and Affective and Neurocognitive Outcomes in Term- and Preterm-born toddlers

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Abstract

Affective regulation and cognitive control develop rapidly in early childhood and are shaped by both biological maturation and early caregiving experiences. Caregiver warmth and emotional responsiveness may support offspring regulatory development, whereas maternal depressive symptoms and socioeconomic disadvantage may increase developmental risk. This study examines associations between maternal warmth at 18 months and child affective regulation and neurocognitive functioning.

Participants were 297 mother-toddler dyads from the Developing Human Connectome Project. Maternal warmth was evaluated using the Family Affective Attitude Rating Scale. Toddlers' outcomes at 18 months were assessed with the Bayley Scales of Infant and Toddler Development, Third Edition, the Early Childhood Behaviour Questionnaire, the Child Behaviour Checklist, and the Quantitative Checklist for Autism in Toddlers. Principal component analysis derived latent outcome dimensions, and analyses of covariance examined associations between maternal warmth and toddlers' outcomes, adjusting for maternal depressive symptoms measured by the Edinburgh Postnatal Depression Scale and neighbourhood deprivation indexed by the Index of Multiple Deprivation, with interactions explored by gestational age group (preterm vs term).

Three latent outcome domains were identified: 'affective', 'neurocognitive', and 'surgency'. Maternal warmth was significantly associated with affective regulation in toddlers ($F(2, 272) = 6.72, p = .001$), with this association being stronger in preterm than in term children ($F(2, 272) = 3.76, p = .024$). Maternal warmth was not significantly associated with neurocognitive outcomes ($F(2, 272) = 0.41, p = .665$) or surgency ($F(2, 272) = 1.61, p = .201$). Instead, higher maternal depressive symptoms and greater neighbourhood deprivation were associated with poorer neurocognitive outcomes ($F(1, 272) = 10.33, p = .001$ and $F(1, 272) = 14.72, p < .001$, respectively). In addition, higher maternal depressive symptoms were independently associated with greater difficulties in affective regulation ($F(1, 272) = 4.61, p = .033, \eta^2 = .016$).

These findings highlight the role of emotionally responsive caregiving in early regulatory development, particularly among children born preterm.

Introduction

Affective regulation and neurocognitive functioning develop rapidly during infancy and early childhood, shaped by both biological maturation and early caregiving experiences. Affective regulation refers to the ability to monitor, evaluate, and modify emotional states to meet situational and social demands (Cruz et al., 2024; Gross & John, 2003), which develops alongside neurocognitive functions, such as attention, working memory, and executive control together supporting the flexible modulation of emotional responses (Rodas et al., 2024). These interconnected systems are supported by developing prefrontal and fronto-limbic brain networks (Pessoa, 2008). This period of heightened neural plasticity leaves them highly sensitive to environmental influences (Bechara et al., 2000; Davis & Panksepp, 2011; Schore, 2001).

Early caregiving is among the most important environmental influences on regulatory and neurocognitive development. Responsive, emotionally attuned caregiving scaffolds emerging attention regulation, working memory, and inhibitory control, supporting later academic achievement and social competence (Bosquet Enlow et al., 2019; Devine et al., 2016; Hughes et al., 2023). Maternal warmth, characterised by expressions of affection, empathy, and positive regard, may be particularly influential during toddlerhood, when children increasingly rely on caregivers to regulate emotions and navigate social interactions (Beeghly & Tronick, 2011). Consistent with attachment theory, warm and responsive caregiving has been associated with more effective emotion regulation, attentional control, and executive functioning (Ainsworth et al., 1991; Bernier et al., 2010).

In contrast, maternal psychological distress and socioeconomic disadvantage may increase developmental risk. Maternal depressive symptoms have been associated with less optimal parent–child interactions and poorer emotional and cognitive outcomes in offspring (Fan et al., 2024; Urizar & Muñoz, 2021), while neighbourhood deprivation has been linked to disparities in early cognitive development and school readiness (Minh et al., 2017). Together, these factors contribute to the broader emotional climate in which regulatory capacities emerge.

Children born preterm may be particularly sensitive to these environmental influences. Preterm birth, defined as delivery before 37 weeks of gestation, affects approximately 10.6% of births worldwide (Cao et al., 2022; Liang et al., 2024) and is associated with elevated risk for emotional, behavioural, and neurocognitive difficulties (Barroso et al., 2015; Clark et al., 2008; Sandoval et al., 2022). These neurodevelopmental sequelae are thought to reflect disruptions to brain development during the final trimester of gestation, a critical period of rapid growth and neural network organisation, when the developing brain may be vulnerable to the extra-uterine world and early exposure to medical stressors (Dubois et al., 2014). Developmental psychopathology and differential susceptibility frameworks suggest that children exposed to early biological adversity may be particularly responsive to caregiving environments, experiencing both greater vulnerability under adverse conditions and greater benefit from supportive caregiving (Belsky et al., 2007; Belsky & Pluess, 2009). Preterm birth may therefore increase sensitivity to variations in maternal warmth during sensitive periods of affective and neurocognitive development.

The family emotional climate can be assessed through expressed emotion (EE), a framework that captures caregiver warmth, criticism, and emotional over-involvement (Sameroff, 1975; Vaughn & Leff, 1976). Higher caregiver warmth has been associated with emotional security, more adaptive affect regulation, and stronger cognitive outcomes, while criticism has been linked to behavioural dysregulation and poorer cognitive adjustment (Goodman et al., 2011; Hooley et al., 2009). Notably, maternal warmth may be particularly important for children born preterm, for whom supportive caregiving may buffer early biological risk (Hadfield et al., 2017).

Despite substantial evidence linking caregiving quality and family emotional climate to child development, relatively **few studies have examined maternal warmth during toddlerhood in relation to**

affective regulation and neurocognitive functioning in cohorts that include children born preterm. The present study therefore investigates the associations between maternal warmth at 18 months and latent behavioural and cognitive outcomes in offspring, while accounting for maternal depressive symptoms and neighbourhood deprivation. We further examine whether these associations differ between children born preterm and those born at term (see Figure 1 for a visual summary of the study design and main findings).

Methods

Participants

Participants were enrolled in the Developing Human Connectome Project (dHCP, <http://www.developingconnectome.org/>) and received magnetic resonance imaging (MRI) at term (37–44 weeks' postmenstrual age). Exclusion criteria for the dHCP were contraindications to MRI, infants being too unwell to tolerate MRI and language difficulties preventing parental informed consent (Edwards et al., 2022). Seven hundred eighty-three toddlers were invited to the Centre for the Developing Brain, St Thomas' Hospital, London, for neurodevelopmental assessment at 18 months post-expected delivery date. Appointments were scheduled at a convenient time for participating families, as close to 18 months as possible, between 2015 and 2020. The final study sample consisted of 297 toddler–mother dyads including 223 term-born and 74 preterm infants (born <37 weeks' gestation).

Ethical Approvals

This study was approved by the UK National Research Ethics Authority (14/LO/1169) and conducted in accordance with the World Medical Association's Code of Ethics (Declaration of Helsinki). Written informed consent was given by children's carer(s) at recruitment into the study.

Behavioural Measurements

Maternal Variables

Self-reported age at conception was collected at enrolment. Self-reported ethnicity was defined according to United Kingdom census categories (Edwards et al., 2022).

Maternal depressive symptoms at term were measured using the Edinburgh Postnatal Depression Scale (EPDS) (Cox et al., 1987), a 10-item questionnaire completed by mothers, with higher scores reflecting a higher likelihood of depressive disorders; it is used as a screening tool for depression in antenatal and postnatal populations. A score of 13 is used as a cut-off indicating high-level symptoms (Levis et al., 2020). Reported EPDS sensitivity and specificity has been between 70% and 85%, depending on the cut-off point used to define clinical significance (Levis et al., 2020).

The Index of Multiple Deprivation (IMD) was computed from the child's postcode at birth using the 2019 IMD classification; it combines locality-specific information about income, employment, education,

health, crime, housing and living environment, thus providing a proxy for family socioeconomic status (Department for Communities and Local Government, 2011; <https://tools.npeu.ox.ac.uk/imd/>).

The Family Affective Attitude Rating Scale (FAARS)- Parental expressed emotion (EE) was assessed using the Family Affective Attitude Rating Scale (FAARS), based on the revised Five-Minute Speech Sample (FMSS) procedure. At toddlerhood assessment, caregivers were asked to speak uninterrupted for five minutes about their child and their relationship, following a standardised script administered in a quiet room without the child present. Speech samples were audio-recorded, transcribed verbatim, and coded using both the recordings and transcripts. EE coding focused on global ratings capturing the emotional climate of the caregiver-child relationship. These included the caregiver’s initial statement about the child (rated as positive, neutral, or negative), warmth (rated as low, moderate, or high based on tone of voice, spontaneity, empathy, and expressions of affection), and relationship quality (rated as positive, neutral, or negative based on statements describing shared enjoyment or relational closeness). Emotional over-involvement was also coded, reflecting excessive self-sacrificing or over-protective attitudes and reduced objectivity. In addition, the frequency of positive and negative comments was recorded. These counts captured descriptive statements indicating approval or criticism of the child’s behaviour or personality.

The primary variable of interest was maternal warmth, conceptualised as an index of positive emotional engagement and emotional availability toward the child. FAARS-derived EE measures have demonstrated good reliability and validity in assessing caregiving emotional attitudes in early childhood and have been widely used to characterise family emotional climate in non-clinical samples (See Table 1 for detailed scoring categories of expressed emotion and Figure 2 for detailed explanation of maternal warmth, with examples).

Table 1. Detailed information about Expressed Emotion scoring

CATEGORY	ASPECTS INCLUDED IN FMSS
Initial Statement	First thought or idea expressed about the child; rated as Positive, Negative, or Neutral.
Warmth	Based on tone of voice, spontaneity, concern, and empathy; rated as High, Moderate, or Low.
Relationship	Statements describing parent-child relationship; rated as Positive, Neutral, or Negative.
Emotional Over-Involvement	Over-protective/self-sacrificing behaviour and emotional displays.
Negative Comments	Frequency count of statements finding fault with the child (e.g., aggression, irritability).
Positive Comments	Frequency count of statements of praise, approval, or appreciation (e.g., intelligence, sociability).

Inter-rater reliability

Coding of the PFMSS was done by trained coders (MV, ACH, and ML) who were blind to participants’ EPDS scores. The coders had received training by an independent experienced coder and joint coding was conducted on 10% of the sample before proceeding independently. 25% of the sample was then randomly selected and rated by all coders to establish inter-rater reliability, examined using Cohen’s κ for Initial Statement (IS), Warmth (W), and Relationship (R), and Spearman’s rho for Negative Comments (CC) and Positive Comments (PC). Results are presented in Table 2.

Table 2. Inter-rater reliability of EE components as measured using the pFMSS Inter-rater reliability

	<i>Inter-rater reliability κ</i>
Initial Statement (IS)	0.94**
Warmth (W)	0.89**
Relationship (R)	1**
Critical Comments (CC)	0.94 **
Positive Comments (PC)	0.96**
Overall (average)	0.94

Results

The sample comprised 297 toddler-mother dyads (223 term-born, 74 preterm). The two groups were comparable in terms of demographic characteristics (Table 3 and 4). Age at assessment was similar in term and preterm participants, as was maternal age at birth and sex distribution.

Preterm toddlers showed significantly lower performance than term toddlers across multiple domains of the BSID-III: cognition, expressive language, fine and gross motor skills.

Behavioural, emotional functioning and autism traits (as indexed by the CBCL, ECBQ and Q-CHAT) did not differ significantly between groups.

Table 3. Demographic and Developmental Characteristics of Term and Preterm Toddlers

Variable	Term (n = 223) M ± SD	Preterm (n = 74) M ± SD	Test Statistic	p
Age at assessment (months)	18.4	18.5	—	> .05
Gestational age at birth (weeks)	39.9	32.6	—	< .001
Maternal age at infant birth (years)	23.0	25.0	—	> .05
Male, n (%)	52.3%	46.8%	χ^2	> .05
Female, n (%)	49.0%	53.2%	χ^2	> .05
BSID-III Cognition	53.92 ± 4.70	53.31 ± 5.83	$t(281) = -3.10$	< .002
BSID-III Expressive Language	21.21 ± 4.70	19.53 ± 5.24	$t(281) = -4.87$	< .001
BSID-III Fine Motor	35.97 ± 2.66	34.97 ± 2.31	$t(281) = -5.16$	< .001
BSID-III Gross Motor	50.64 ± 3.42	49.34 ± 3.93	$t(281) = -4.33$	< .001
CBCL Dysregulation Profile	-0.52 ± 7.97	-0.25 ± 8.48	$t(281) = 0.23$	.824
ECBQ Surgency	5.18 ± 0.69	5.13 ± 0.82	$t(281) = -0.45$	.655
ECBQ Negative Affectivity	2.59 ± 0.63	2.57 ± 0.75	$t(281) = -0.65$	.514
ECBQ Effortful Control	4.52 ± 0.65	4.56 ± 0.59	$t(281) = 0.58$	.562
Q-CHAT Total Score	-0.41 ± 8.64	0.78 ± 9.90	$t(281) = 1.02$	.309

Note. Values are presented as means ± standard deviations unless otherwise indicated. BSID-III = Bayley Scales of Infant and Toddler Development, Third Edition; ECBQ = Early Childhood Behaviour Questionnaire; CBCL = Child Behaviour Checklist; Q-CHAT = Quantitative Checklist for Autism in Toddlers. *Preterm toddlers showed significantly lower motor, cognitive scores. No significant differences were observed for age, maternal age, sex distribution, language, behavioral dysregulation, effortful control, negative affectivity, or autistic traits.*

Table 4. Maternal Characteristic of Term and Preterm Toddlers

	Term (n=223)	Preterm (n=74)
Maternal Ethnicity		
White British	125	49
White Irish	9	2
White and Asian	73	13
White and Black Caribbean	11	3
White and Black African	7	0
Any Other Mixed/Multiple Ethnic Background	67	28
IMD score		
Least deprived 1	30	13
2	28	15
3	57	20
4	92	11
Most deprived 5	75	11
Maternal Depressive EPDS score	4 (0–28)	2.5 (0–28)

Note Distribution of maternal ethnicity, neighbourhood deprivation as measured by the Index of Multiple Deprivation (IMD), and maternal depressive symptoms as measured by the Edinburgh Postnatal Depression Scale (EPDS) among mothers of term-born (n = 223) and preterm-born (n = 74) children. Ethnicity is presented as frequency (n). IMD categories range from 1 (least deprived) to 5 (most deprived). EPDS scores are presented as median (range). *EPDS score above clinical cut-off (≥ 13);

Results of PCA identified three significant components (PC1, PC2 and PC3), jointly explaining 79.5% of the total variance, as reported previously (Viragova et al., 2025). PC1 was labelled 'Neurocognitive' and comprised negative loadings for BSID-III scores: cognition, receptive language, expressive language, fine motor and gross motor, positive loadings for Q-CHAT scores. PC2 was labelled 'Affective Regulation' and comprised positive loadings for CBCL dysregulation profile and positive loadings for ECBQ negative affectivity. PC3 was labelled 'Surgency' and comprised positive loadings for ECBQ surgency. Independent-samples t-tests were conducted to examine whether PCA component scores differed between term and preterm toddlers. Results indicated a significant group difference for PC1, with preterm toddlers demonstrating higher scores ($M = 1.01$, $SD = 2.20$) compared to term toddlers ($M = -0.14$, $SD = 1.60$), $t = 3.79$, $p < .001$. Given that PC1 loaded negatively on cognitive performance

measures, such that lower scores reflected better performance, the higher PC1 scores observed in the preterm group suggest greater cognitive difficulties compared with the term group. No significant group differences were observed for PC2, although a trend-level effect was present, with preterm toddlers showing lower scores ($M = -0.41$, $SD = 1.36$) relative to term toddlers ($M = -0.03$, $SD = 1.26$), $t = -1.96$, $p = .053$. Similarly, PC3 scores did not significantly differ between groups, with preterm toddlers ($M = 0.12$, $SD = 1.14$) showing comparable scores to term toddlers ($M = -0.05$, $SD = 0.95$), $t = 1.07$, $p = .288$.

Three analyses of covariance (ANCOVAs) were conducted to examine the association between maternal warmth (low, moderate, high) and offspring outcomes: affective regulation neurocognitive functioning and surgency. In all analyses, maternal depressive symptoms (EPDS) and neighbourhood deprivation (IMD) were included as covariates (Table 5).

Table 5. ANCOVA results examining the effects of maternal warmth on offspring Affective regulation, Neurocognitive outcomes, and Surgency

(full ANCOVA statistics, including degrees of freedom and effect sizes, are reported in Table S2)

	F	p-value
Affective Regulation		
Warmth	6.720	0.001***
EPDS	4.610	0.033***
IMD	0.386	0.535
Birth Group	1.707	0.192
Warmth x Birth Group	3.764	0.024**
Neurocognitive outcomes		
Warmth	0.441	0.665
EPDS	10.330	0.001***
IMD	14.722	0.001***
Birth Group	22.825	0.001***
Warmth x Birth Group	0.644	0.526
Surgency		
Warmth	1.614	0.201
EPDS	0.791	0.374
IMD	2.469	0.117
Birth Group	1.211	0.272
Warmth x Birth Group	0.771	0.464

Affective regulation

ANCOVA results showed a significant main effect of maternal **warmth** on offspring affective regulation outcomes ($F(2, 272) = 6.72, p = .001$). Bonferroni-adjusted post hoc comparisons showed that offspring in the **low warmth** group exhibited significantly higher affective regulation difficulties than those in the **high warmth** group (mean difference = 0.87, $p < .001$) (full pairwise comparison statistics are reported in Table S3). No significant differences were observed between the **moderate** and **high warmth group** or between **low** and **moderate warmth** group ($ps > .05$). The assumptions of homogeneity of variance were met (Levene's test, $F(5, 274) = 0.82, p = .536$).

There was a significant maternal **warmth × group** interaction ($F(2, 272) = 3.76, p = .024, \eta^2 = .025$), indicating that the association between maternal warmth and affective regulation differed for

preterm and **term** children (Figure 3) (full simple effects statistics are reported in Table S4). Lower affective regulation scores reflect fewer dysregulation problems, whereas higher scores indicate greater dysregulation difficulties. Among preterm children, affective regulation scores were lowest in the high warmth group ($M = -0.99$, $SE = 0.25$), followed by the moderate warmth group ($M = -0.36$, $SE = 0.28$), and highest in the low warmth group ($M = 0.52$, $SE = 0.34$). In contrast, affective regulation scores among term-born children varied little across warmth groups (high: $M = -0.11$, $SE = 0.13$; moderate: $M = -0.08$, $SE = 0.14$; low: $M = 0.12$, $SE = 0.18$).

Follow-up pairwise comparisons revealed that within the **preterm group** there was **greater variability in affective regulation across levels of warmth**: Tukey-corrected comparisons showed that children in the low warmth group had significantly higher affective scores that is, more problems than those in the high warmth group, $t(272) = 3.67$, $p < .001$, 95% CI [0.31, 1.42]. The moderate versus high comparison was not significant, $t(272) = 1.57$, $p = .352$, 95% CI [-0.16, 0.82], and the low versus moderate comparison approached significance but did not survive correction, $t(272) = 2.21$, $p = .084$, 95% CI [-0.04, 1.12]. Together, these findings indicate that low maternal warmth was associated with poorer affective regulation among preterm children, whereas high maternal warmth was associated with the most favourable affective regulation outcomes.

Maternal depressive symptoms were significantly associated with offspring affective regulation outcomes ($F(1, 272) = 4.61$, $p = .033$, $\eta^2 = .016$), whereas neighbourhood deprivation was not ($F(1, 272) = 0.39$, $p = .535$, $\eta^2 = .001$). The main effect of **birth status** was not significant ($F(1, 272) = 1.71$, $p = .192$, $\eta^2 = .006$).

Neurocognitive outcomes

ANCOVA results showed that maternal warmth was not significantly associated with offspring neurocognitive outcomes after controlling for maternal depressive symptoms and socioeconomic deprivation when combining birth groups ($F(2, 272) = 0.41$, $p = .665$). In contrast, maternal depressive symptoms ($F(1, 272) = 10.33$, $p = .001$), and neighbourhood deprivation ($F(1, 272) = 14.72$, $p < .001$), were both significantly associated with poorer neurocognitive outcomes. A significant main effect of birth group was also observed ($F(1, 272) = 22.83$, $p < .001$) indicating poorer neurocognitive outcomes among preterm compared with term children. However, the warmth $\times$ birth group interaction was not significant, ($F(2, 272) = 0.64$, $p = .526$), suggesting that the relationship between maternal warmth and neurocognitive outcomes was similar in preterm and term children.

Levene's test indicated heterogeneity of variance, $F(5, 274) = 2.81$, $p = .017$, therefore, non-parametric analyses were conducted to assess the robustness of findings. Kruskal–Wallis tests confirmed the absence of differences in neurocognitive outcomes across warmth groups, $H(2) = 0.01$, $p = .994$, and the presence of significant differences between preterm and term children, $H(1) = 14.84$, $p < .001$ (see Table S5).

Surgency

ANCOVA revealed no significant main effect of maternal warmth and surgency ($F(2, 272) = 1.61$, $p = .201$). Maternal depressive symptoms, $F(1, 272) = 0.79$, $p = .374$, neighbourhood deprivation, $F(1, 272) = 2.47$, $p = .117$, and birth group, $F(1, 272) = 1.21$, $p = .272$, were also not significantly associated with surgency outcomes.

The warmth $\times$ birth group interaction was not significant ($F(2, 272) = 0.77$, $p = .464$), indicating that associations between maternal warmth and surgency did not differ between preterm and term children.

Because Levene's test indicated heterogeneity of variance, $F(5, 274) = 5.76$, $p < .001$, supplementary non-parametric analyses were performed. Kruskal–Wallis tests confirmed the ANCOVA findings, showing no significant differences in surgency across warmth groups, $\chi^2(2) = 1.82$, $p = .403$, or birth groups, $\chi^2(1) = 0.66$, $p = .416$ (see Table S5).

Overall, these findings suggest that surgency was relatively stable across levels of parental warmth and did not differ between preterm and term children, with no evidence that preterm status moderated the association between Warmth and Surgency.

Discussion

This study examined associations between maternal warmth and toddlers' affective regulation, neurocognitive functioning, and surgency at 18 months, while accounting for individual- and area-level contextual factors (e.g., maternal depressive symptoms and neighbourhood deprivation). Findings revealed domain-specific patterns of early environmental influences that varied by gestational age. Affective regulation in toddlers was associated with maternal warmth with stronger associations observed among children born preterm. Children exposed to lower levels of maternal warmth exhibited greater difficulties regulating emotional responses than those exposed to higher levels of warmth. In addition, poorer affective regulation was also independently associated with higher levels of maternal depressive symptoms, even after accounting for maternal warmth. Although neurocognitive outcomes were poorer in preterm compared to term toddlers, at the whole-group level these were associated with maternal depressive symptoms and neighbourhood deprivation, but not with maternal warmth. Finally, surgency showed no significant associations with maternal warmth, maternal depressive symptoms, or neighbourhood deprivation. Surgency outcomes were similar in preterm and term toddlers. Together, these results highlight distinct early developmental pathways through which caregiving quality and broader contextual factors shape affective and cognitive outcomes in toddlerhood. In early childhood, affective regulation may be particularly dependent on the quality of caregiver-child interactions, whereas neurocognitive abilities and temperament-related characteristics such as surgency may be influenced by a broader range of biological and environmental factors.

Maternal Warmth and Affective Regulation

Affective regulation was particularly sensitive to variation in maternal warmth. Toddlers exposed to lower levels of maternal warmth exhibited greater difficulties in regulating emotional responses than those exposed to high warmth caregiving environments.

These findings align with developmental theories that emphasise the central role of caregiver-child interactions in the emergence of affective regulation (Schore, 2001; Thompson & Goodman, 2010). Through repeated emotionally salient exchanges, children gradually internalise strategies for managing emotional arousal, frustration, and distress. During the second year of life, caregivers remain key external regulators of children's emotional experiences, supporting both the modulation of affect and recovery from challenging situations. Warm and emotionally responsive caregiving may therefore foster the development of adaptive regulatory capacities (Bernier et al., 2010; Eisenberg et al., 2010). In contrast, lower levels of emotional engagement may reduce opportunities for toddlers to develop effective strategies for managing frustration, distress and behavioural dysregulation.

Importantly, maternal warmth was associated specifically with affective regulation, but not with neurocognitive outcomes or surgency. These findings are consistent with developmental models proposing that emotional and cognitive systems differ in their developmental trajectories, plasticity, and sensitivity to environmental inputs (Raver et al., 2017; Tottenham, 2020).

The present findings may have important implications for later emotional development. Although difficulties regulating anger, frustration, and irritability are common during toddlerhood, they have also been identified as early indicators of vulnerability to later emotional difficulties, including depression (Liu et al., 2025; Vidal-Ribas Belil et al., 2016). Within this context, warm and emotionally attuned caregiving may help prevent early difficulties in emotional regulation from becoming consolidated and contributing to maladaptive emotional or interpersonal patterns across development. Maternal warmth may therefore function as an early protective factor, promoting emotional security, resilience and adaptive emotional functioning over time.

Preterm Birth and Environmental Sensitivity

The association between maternal warmth and affective regulation was further moderated by gestational age, with the effects of warmth being most pronounced among children born preterm, despite no overall differences in affective regulation between preterm and term children. Within the preterm group, children exposed to low levels of maternal warmth showed significantly poorer affective regulation compared to those exposed to high levels of warmth, indicating heightened sensitivity to the emotional caregiving environment. In contrast, affective regulation amongst term children remained relatively stable across maternal warmth levels. These findings suggest that emotionally responsive caregiving may be particularly important for supporting affective development among biologically vulnerable children (Lionetti et al., 2025). The observed pattern is broadly consistent with differential susceptibility frameworks, which propose that some children may be more developmentally sensitive to environmental input than others (Belsky & Pluess, 2009). One possible explanation is that preterm birth may increase sensitivity to caregiving environments because premature delivery disrupts critical periods

of late gestational brain development, particularly within prefrontal and fronto-limbic systems implicated in emotional regulation (Dubois et al., 2014; Pessoa, 2008). As a result, preterm children may be more dependent on supportive external regulation provided through caregiver responsiveness and emotional attunement, making the quality of the caregiving environment especially relevant for the development of affective regulatory capacities.

The association between maternal warmth and affective regulation may also reflect early foundations of interpersonal sensitivity. Research in older children and adolescents indicates that exposure to critical or emotionally unsupportive environments is associated with heightened sensitivity to rejection and increased attentional bias toward negative emotional cues (Davies et al., 2020; Minihan et al., 2023; Rudolph & Zimmer-Gembeck, 2014). These patterns have been linked to elevated risk of depressive symptoms. From this perspective, maternal warmth may function as an early protective factor by fostering emotional security and reducing hypervigilance to perceived interpersonal threat. Such processes may begin to emerge during toddlerhood, when children are rapidly forming expectations about their caregivers' emotional availability and responsiveness (Gravener et al., 2012). Warm caregiving may help establish expectations of caregiver availability and emotional security that support adaptive socioemotional development, particularly among children already facing biological vulnerability.

Maternal Depressive Symptoms

Maternal depressive symptoms were independently associated with poorer offspring affective regulation, whereas neighbourhood socioeconomic deprivation was not. This pattern suggests that affective regulation during toddlerhood may be particularly sensitive to proximal emotional processes within the caregiving relationship, rather than to broader contextual influences. Furthermore, mothers experiencing depressive symptoms may still express warmth and emotional responsiveness toward their child, whereas low warmth may occur in the absence of clinically elevated depressive symptoms (Evans & Kim, 2013). Together, these findings suggest that both maternal psychological wellbeing and the quality of caregiver-child interactions make unique contributions to early affective development.

Several mechanisms may account for associations between maternal depression and child affective difficulties. Maternal depression has been consistently linked to poorer infant and child outcomes (Fan et al., 2024; Urizar & Muñoz, 2021), with studies suggesting these effects may operate through reduced emotional expressiveness, diminished contingent responsiveness, and disruptions in dyadic synchrony (Murray et al., 2011; Pearson et al., 2016). Such disruptions may interfere with the development of predictable and emotionally secure interaction patterns that support emerging regulatory capacities. Maternal depression may also reduce opportunities for caregivers to scaffold children's emotional experiences during moments of frustration, distress or heightened arousal.

However, maternal depression and maternal warmth represent related but distinct aspects of the caregiving environment. Although maternal depression may reduce emotional availability, maternal warmth represents a more specific relational characteristic that may directly support early emotional development (Gravener et al., 2012). EE research further indicates that high levels of criticism or hostility

are not solely explained by socioeconomic adversity, but are also shaped by caregivers' beliefs, expectations, and interpretations of children's behaviour (Hooley, 2007; Nelson et al., 2003). Caregivers who display greater warmth may be more likely to interpret toddler behaviour as situational and developmentally appropriate, thereby responding with greater sensitivity, tolerance and empathy, and thus supporting the development of adaptive emotional regulation.

Neurocognitive Outcomes and Contextual Adversity

In contrast, our findings show that neurocognitive functioning at 18 months, which was lower in preterm compared to term children in line with previous work (Christensen et al., 2023), displayed limited variation as a function of maternal warmth alone. This suggests that early neurocognitive development may be influenced by a broader range of biological and environmental factors rather than being primarily driven by emotional caregiving quality. Instead, maternal depressive symptoms and socioeconomic deprivation emerged as robust correlates of poorer neurocognitive development. Maternal depression affects cognitive development by reducing caregiver engagement, limiting cognitive stimulation and disrupting the consistency of early learning experiences, thereby constraining the development of attention and executive processes (Hackman et al., 2021). This interpretation is consistent with prior evidence linking maternal depression to impairments in offspring early cognitive and executive functioning (Murray et al., 2011; Pearson et al., 2016). Similarly, socioeconomic deprivation may restrict access to cognitively enriching environments and increase exposure to chronic stressors, both of which can adversely affect early learning, cognitive development and brain maturation (Hackman et al., 2015; Noble et al., 2021).

Surgency

Surgency appeared relatively stable across variations in maternal warmth and did not differ between preterm and term toddlers. Surgency, typically characterised by approach behaviour, activity level, and positive affect, may reflect temperamental tendencies that are more constitutionally based and less directly shaped by variation in emotional caregiving quality during toddlerhood. Unlike affective regulation, which relies heavily on caregiver-mediated co-regulation, surgency may be more strongly influenced by early biological dispositions and temperamental reactivity that show moderate stability across early development (Putnam et al., 2008). The absence of warmth effects on surgency suggests that not all domains of early emotional functioning are equally sensitive to the emotional climate of caregiving at this age. Instead, maternal warmth may play a more specific role in shaping regulatory capacities rather than broader temperamental traits.

Limitations

Several limitations should be considered when interpreting these findings. First, maternal warmth was assessed using an EE framework, which captures caregivers' underlying emotional attitudes toward the child rather than real-time parent-child interactions. Although EE has been shown to relate to observed caregiving behaviours and child outcomes, it does not permit direct observation of how caregivers respond to children's behaviour moment-to-moment (Brown & Rutter, 1966; Rutter, 1989; Rutter & Brown,

1966). Future studies using observational or dyadic methods would be valuable for examining how EE-related attitudes are enacted within ongoing parent–child exchanges across development. A further limitation concerns the scope of EE research, which has historically emphasised negative dimensions such as criticism, hostility, and emotional over-involvement. Although EE coding systems include positive dimensions such as warmth, comparatively less research has examined their protective role in early childhood. The present findings add to growing evidence that positive emotional climates are important for early affective development and may be especially protective among preterm children. However, additional work is needed to more fully characterise the mechanisms through which positive EE supports developmental resilience. Additionally, although surgency was not significantly associated with caregiving or contextual factors in the present study, longer-term follow-up may clarify whether caregiving quality exerts more gradual or indirect influences on temperamental expression across development.

Strengths of the study include the use of a large, well-characterised longitudinal cohort and the assessment of maternal warmth by trained coders who were blind to maternal depression status, reducing the risk of rater bias. Finally, the focus on a non-clinical sample at 18 months provides novel insight into early, subclinical variation in caregiving and developmental outcomes during a sensitive period of emotional and neurocognitive development.

By integrating caregiving, psychological, and socioeconomic factors within a single model, the present study builds on prior research that has often examined these influences separately or at later developmental stages. Few studies have assessed maternal warmth at 18 months in a non-clinical sample, within cohorts that include children born preterm while simultaneously accounting for maternal depressive symptoms and neighbourhood deprivation. Moreover, the use of domain-specific outcome measures moves beyond global developmental indices to capture early variation in affective regulation, surgency and neurocognitive functioning. Together, this approach allows for a more nuanced understanding of early mechanisms of risk and resilience during a sensitive period of development (Bornstein, 2015; Thompson, 2008).

The present findings have important implications for early intervention and preventative approaches that focus on the emotional climate of the caregiving relationship, rather than exclusively on child behaviour management. Although parenting programmes often aim to increase positive parenting behaviours and reduce negative responses, our results suggest that maintaining maternal warmth and minimising expressions of criticism or hostility may be particularly important for supporting early affective regulation. Early interventions that provide parenting support and prioritise emotional responsiveness and warmth may play a key role in promoting adaptive affective development and strengthening parent–child relationships during toddlerhood.

Overall, the findings underscore the importance of considering both developmental domain and biological vulnerability when examining early caregiving influences.

Affective regulation appears particularly sensitive to the emotional quality of caregiving, with children born preterm showing greater responsiveness to variation in maternal warmth. In contrast, early neurocognitive outcomes appear to be more strongly influenced by maternal depressive symptoms and socioeconomic adversity, suggesting distinct pathways through which environmental factors shape child development. These findings underscore the potential value of interventions that prioritise maternal warmth and emotional responsiveness and support caregiver-child relationships, particularly for children with increased biological vulnerability.

Declarations

Competing interests

The authors declare no competing interests.

Ethics

This study was approved by the UK National Research Ethics Authority (14/LO/1169) and was conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participating families.

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Author Contribution

Author contributions M.V.: conceptualization, methodology, formal analysis, writing – original draft, writing – review & editing. M.L. and A.C.: investigation, formal analysis, writing – review & editing. A.D.E.: conceptualization, investigation, writing – review & editing, funding acquisition. P.D.: conceptualization, methodology, investigation, writing – review & editing, supervision. C.N.: conceptualization, methodology,

investigation, writing – review & editing, supervision. All authors reviewed and approved the final manuscript. All authors reviewed the manuscript.

Data Availability

Data availability Data used in this study are publicly available as part of the Developing Human Connectome Project (Edwards et al., 2022) and can be accessed at https://nda.nih.gov/edit_collection.html?id=3955.

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Figures

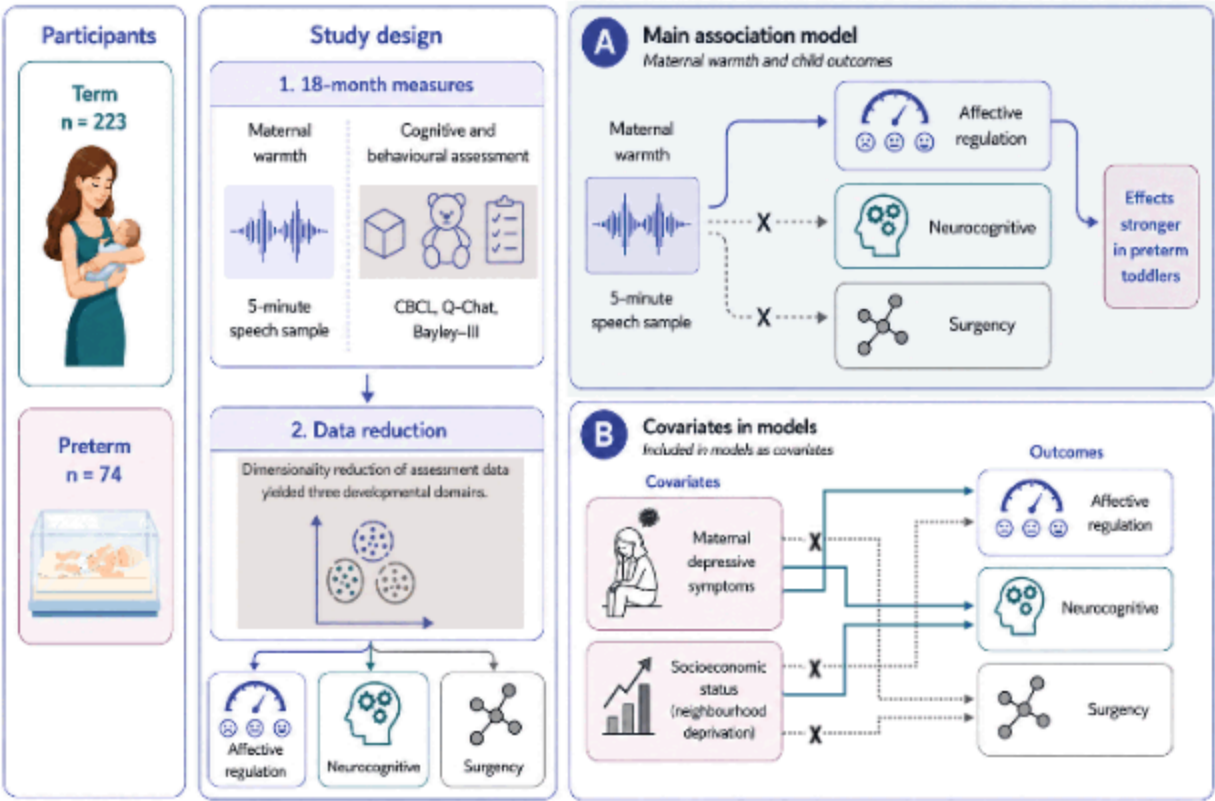


Figure 1

Visual abstract of the study design and main findings. Maternal warmth was assessed at 18 months using a 5-minute speech sample coded with the Family Affective Attitude Rating Scale. Child developmental outcomes were assessed using cognitive, behavioural, and socio-emotional measures and reduced using principal component analysis into three latent domains: affective regulation, neurocognitive functioning, and surgency. (A) Main association model. Maternal warmth was significantly associated with better affective regulation, with stronger effects observed in preterm than

term toddlers. No significant associations were identified between maternal warmth and neurocognitive functioning or surgency. (B) Model covariates. Maternal depressive symptoms and neighbourhood deprivation were included as covariates in all models. Higher maternal depressive symptoms were associated with greater difficulties in affective regulation, while both maternal depressive symptoms and neighbourhood deprivation were associated with poorer neurocognitive outcomes. No significant associations were observed with surgency.

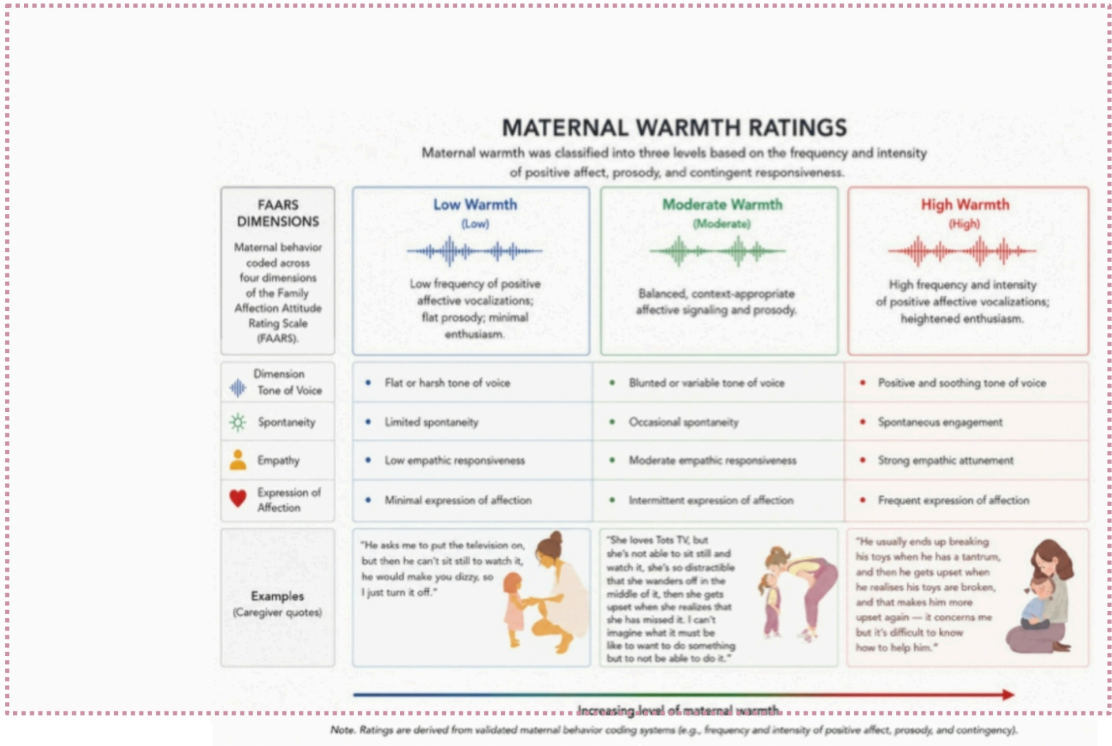


Figure 2

Operationalization of Maternal Warmth via the Expressed Emotion Framework: Conceptual Model. Maternal warmth was operationalized using the Family Affective Attitude Rating Scale (FAARS) derived from the Five-Minute Speech Sample. Trained coders ($\kappa = 0.89$, blind to depression status) rated warmth (Low, Moderate, High) based on tone of voice, spontaneity, empathy, and expressions of affection. The figure illustrates the conceptual dimensions and behavioural indicators associated with each warmth level, demonstrating systematic variation in emotional engagement and responsiveness. Low warmth reflects minimal emotional engagement; moderate warmth reflects adequate emotional availability; and high warmth reflects rich emotional investment and frequent affectionate expression. See Table 1 for complete expressed emotion coding categories.

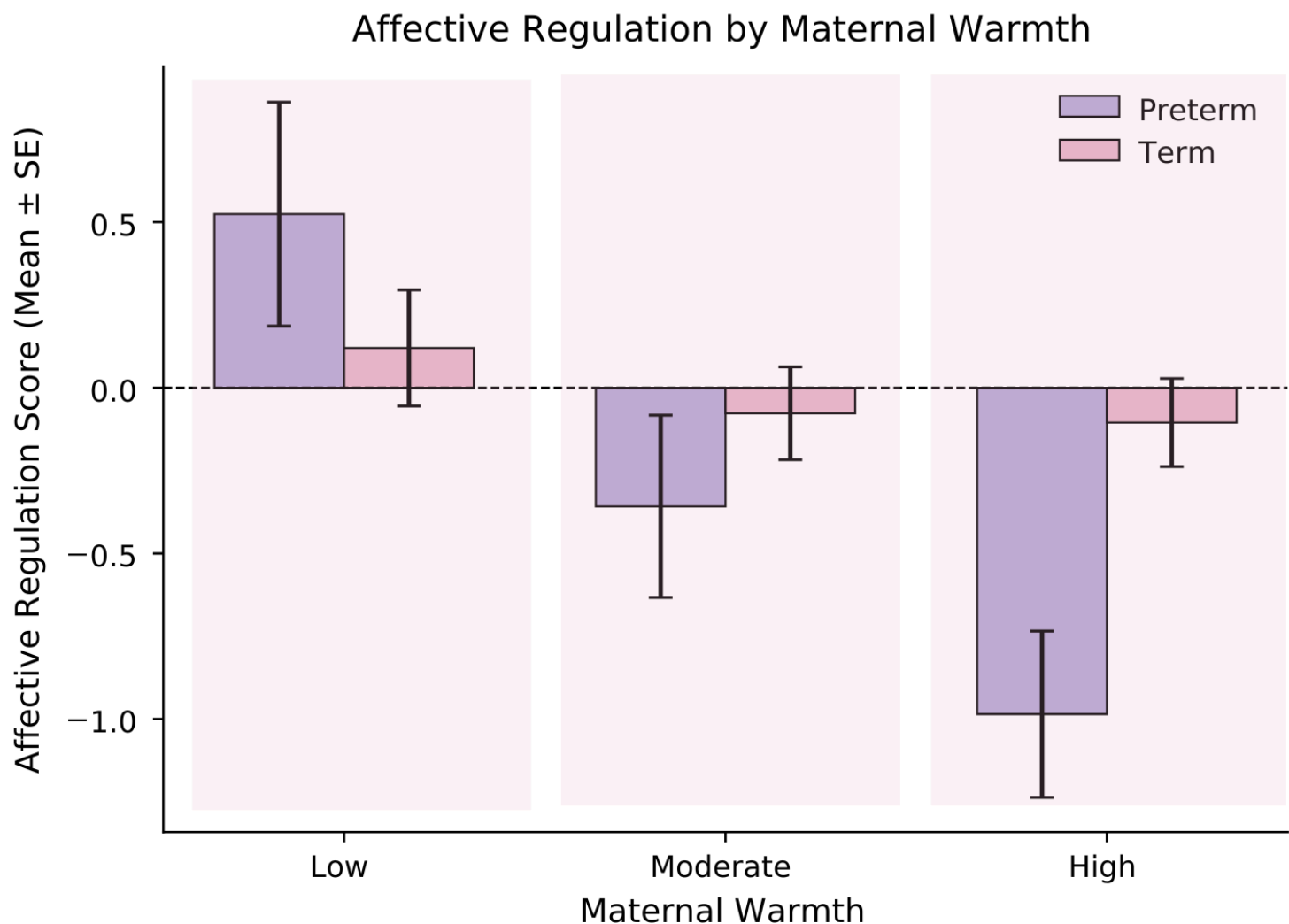


Figure 3

Interaction between maternal warmth and birth group on affective regulation. Values represent estimated marginal means from the ANCOVA model controlling for maternal depressive symptoms (EPDS) and neighbourhood deprivation (IMD). Error bars represent standard errors. Lower affective regulation scores indicate more favourable outcomes. A significant Maternal Warmth × Birth Group interaction was observed, $F(2, 272) = 3.76, p = .024, \eta^2 = .025$, indicating that the association between maternal warmth and affective regulation differed by birth group. Among preterm toddlers, higher maternal warmth was associated with lower affective regulation scores (i.e., more favourable affective regulation), whereas affective regulation scores varied little across maternal warmth groups among term-born children.

Supplementary Files

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