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The association between gestation at birth and maternal sensitivity: An individual participant data (IPD) meta-analysis

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ABSTRACT

Background and aim: Studies have documented differences in dyadic sensitivity between mothers of preterm (<37 weeks' gestation) and term born children, but findings are inconsistent and studies often include small and heterogeneous samples. It is not known to what extent variations in maternal sensitivity are associated with preterm birth across the full spectrum of gestational age.

Objective: To perform a systematic review and individual participant data (IPD) meta-analysis assessing variations in observed dyadic maternal sensitivity according to child gestational age at birth, while adjusting for known confounders correlated with maternal sensitivity.

Method: We harmonised data from 12 birth cohorts from ten countries and carried out one-stage IPD meta-analyses ($N = 3951$) using mixed effects linear regression. Maternal sensitivity was z-standardised according to the scores of contemporary term-born controls within each respective cohort. All models were adjusted for child sex, age at assessment, neurodevelopmental impairment, small for gestational age birth, and maternal education.

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Results: The fixed linear effect of the association between gestation at birth and maternal sensitivity across all 12 cohorts was small but stable (0.02 per week [*95 % CI* = 0.01, 0.02], $p < .001$). The binary effects of maternal education (0.32 [0.24, 0.40], $p < .001$) and child neurodevelopmental impairment (−0.33 [−0.50, −0.17], $p < .001$) were associated with maternal sensitivity.
Interpretation: Gestational age at birth is positively associated with dyadic maternal sensitivity, however, the size of the effect is small. Over and above gestation, maternal education and child neurodevelopmental impairment appear to affect sensitivity, highlighting the importance of considering these factors in future research and intervention designs.

1. Introduction

Globally, >13 million infants (>10 % of all births) are born preterm (<37 weeks gestational age (GA)) every year [1,2]. With improvements in antenatal and neonatal care, more infants born very preterm (VP, <32 weeks of GA) and extremely preterm (EP, <28 weeks GA) survive. However, increased survival has not been accompanied by equally improved long-term outcomes [3,4]. Children born preterm today still experience increased risk for a range of neurodevelopmental and psychological problems including difficulties with attention, emotion regulation, social behaviour, and cognition [5].

As a result, there is strong clinical and public health interest in identifying modifiable contextual factors in postnatal environments that can improve the developmental trajectories of children born preterm and foster resilience, despite their early-life adversity [6–9]. One well-documented example of such a protective factor is sensitive parenting behaviour [8,10,11]. Sensitivity in parenting involves well-attuned (i.e., both appropriate and prompt) and emotionally warm responses to infant or child cues [12]. Sensitivity is by definition bi-directional and reciprocal, and therefore assessed with observations of dyadic interactions between an adult caregiver (e.g., mother or father) and their child. Accordingly, while observational assessments of sensitivity may focus on the adult in the dyad, behaviour is always coded within the dynamic bi-directional context of child behaviour, i.e., sensitive responses cannot be assessed by observing a parent alone. Most studies have focused on maternal sensitivity, although fathers' interactive behaviours with their children are also critically important [13,14]. Previous studies of the association between preterm birth and sensitive parenting have delivered mixed evidence, with some studies reporting mothers of children born preterm to be less sensitive and others not, possibly explained by small and heterogeneous study samples, different approaches to observation and coding, as well as different sets of confounders included in analyses.

In 2015, Bilgin & Wolke published a two-stage meta-analysis of thirty-four dyadic interaction studies [15]. Results showed that mothers of preterm children were as sensitive as mothers of term-born children [15]. However, while heterogeneity in the association between preterm birth and maternal behaviour between studies was high and not explained by known confounders such as degree of prematurity or infant age [15], it could not be further investigated with the aggregate data two-stage meta-analytic approach. Relatedly, in a separate meta-analysis examining maternal controlling behaviour, mothers of children born preterm were found to be at higher risk for engaging in controlling parenting strategies than mothers of children born full-term [16]. Similarly, in adulthood, individuals born preterm recall more controlling and overprotective parenting behaviour in childhood than term-born peers [17]. To take a resilience-oriented approach and determine how best to foster positive development in children born preterm, here we focus on better understanding the relationship between preterm birth and maternal sensitivity.

The goal of this current study is to employ a one-stage meta-analysis approach using harmonised individual participants' data (IPD) to test the independent association of child gestational age across the whole range of preterm birth with observed dyadic maternal sensitivity, after adjusting for known confounders of this association including child sex, age, neurodevelopmental impairment, and mother's level of education.

2. Methods

The study was registered as an IPD meta-analysis with the International Prospective Register of Systematic Reviews PROSPERO (protocol #CRD42021256436).

2.1. Search strategy and study selection criteria

A two-step process was applied to identify and select studies for inclusion. First, a systematic literature search was conducted in English in 11.2021 in PubMed and Web of Science using the keywords “preterm” OR “low birth weight” AND “parenting behaviour/behaviour” OR “observed parenting” OR “parenting quality” OR “parent-child dyad” OR “mother-child dyad” OR “parent-child interaction” OR “parent-child relationship” OR “synchrony” OR “parental sensitivity” OR “maternal sensitivity”.

Inclusion criteria were:

1) sample of children with gestational age <37 weeks and/or birth weight <2500 g;
2) sample of children with normal birth weight (>2499 g) and/or term-born (≥37 weeks) forming a contemporaneous comparison group;
3) assessment of dyadic parent-child interaction between age 3 months and 6 years using standardised behaviour observation and coding protocols.

Studies of selective cohorts (i.e., randomised controlled trials) were excluded. There was no restriction for year of birth or publication date. Only studies published in English were included. Title and abstract screening, duplicate removal, full-text screening for eligibility, and inclusion/exclusion decisions were carried out by two independent reviewers (JJ, KT) in Covidence between 11.2021 and 06.2022. Conflicts were discussed and resolved jointly. A total of 83 publications were identified, Fig. 1 shows a flow diagram of study eligibility. Of these, 58 publications were deemed eligible for inclusion in the IPD harmonisation process based on similar constructs, definitions, and measures used for the assessment of maternal sensitivity including expression of well-attuned positive emotions.

The authors of these publications were invited to participate in August 2022 by the first author. By April 2024, 12 cohort study teams had signed data sharing agreements with the University of Oulu, Finland. Reasons for not participating in this IPD study included author nonresponse ($n = 25$), lack of ethical permission to share data ($n = 3$), disagreements about data ownership between original study authors ($n = 2$), and lack of institutional leaderships' willingness to sign data share agreements ($n = 2$).

Secondly, members of the Adults born Preterm International Collaboration (APIC, www.apic-preterm.org) were presented with the study protocol in October 2022 and invited to contribute. One additional cohort was identified, but institutional legal agreements were not signed.

Accordingly, the following 12 cohorts from 10 countries were included in the data harmonisation and pooling process:

a. Germany: The Bavarian Longitudinal Study (BLS) included a whole-population sample of neonatal at-risk children born in Southern Bavaria in 1985–86 (n = 563) and a healthy term-born normal birthweight (NBW) comparison group (n = 876) [18]. At 6 years of age, maternal sensitivity was rated with the Assessment of Mother-Child-Interaction with the Etch-a-Sketch (AMCIES) [10,19]. Neurodevelopment was assessed at 24 months corrected age (CA) using the Griffiths Scales of Infant Development [20].
b. Germany: The Mannheimer Study of Children at Risk (MSCR) cohort included neonatal at-risk children born in the Rhine–Neckar region in 1986–1988 (n = 111) and a term-born comparison group (n = 273). At 3 months CA, maternal sensitivity was assessed with the Mannheim Rating System for Mother–Infant Interaction [21,22] and neurodevelopment with the Bayley Scales of Infant Development [23].
c. Denmark: The study cohort included infants with a birth weight <1501 g treated at Rigshospitalet in Copenhagen (n = 99), infants born at 1501–2300 g (n = 132), and a NBW comparison group (n = 92), all born in 1980–1982. Of these, 195 were born preterm and 128 at term. At around 52 months of age, maternal sensitivity was assessed with the Parental Sensitivity Assessment Scale [24] and neurodevelopment with the McCarthy Scales [25].
d. Australia: The Victorian Infant Brain Studies 2 (VIBeS2) cohort included all livebirths <30 weeks gestation at the Royal Women's Hospital in Melbourne in 2011–2014 (n = 134) and a term-born NBW comparison group (n = 122) [26,27]. At 12 and 24 months CA, maternal sensitivity was assessed with the Emotional Availability (EA) scales [28]. Neurodevelopment was assessed at 24 months CA with the Bayley Scales of Infant and Toddler Development-Third Edition (Bayley-III) [29].
e. Australia: The Victorian Infant Brain Studies (VIBeS) cohort included all livebirths <30 weeks gestation or with a birth weight <1250 g at the Royal Women's Hospital in Melbourne in 2001–2004 (n = 165) and a NBW term-born comparison group (n = 51). At 24 months CA, maternal sensitivity was assessed using a parent-child interaction paradigm that was rated according to an observational coding scheme [11,30,31] and neurodevelopment using the Bayley Scales of Infant Development-Second Edition (BSID-II) [32].
f. The Netherlands: The Study on Attention of Preterm children (STAP) cohort included children born at 32–37 weeks gestation in nine hospitals around Utrecht in 2010–2011 (n = 116) and a term-born comparison group (n = 98) [33]. At 18 months CA, maternal sensitivity was assessed with the Coding Interactive Behaviour Manual [34], neurodevelopment was assessed at 24 months CA with the Bayley-III [29].
g. Israel: The Preterm Early Development Study (PEDS) included infants born in the Southern Region of Israel in 2009–2011 between 28 and 33 weeks gestation with low medical risk and birth weight

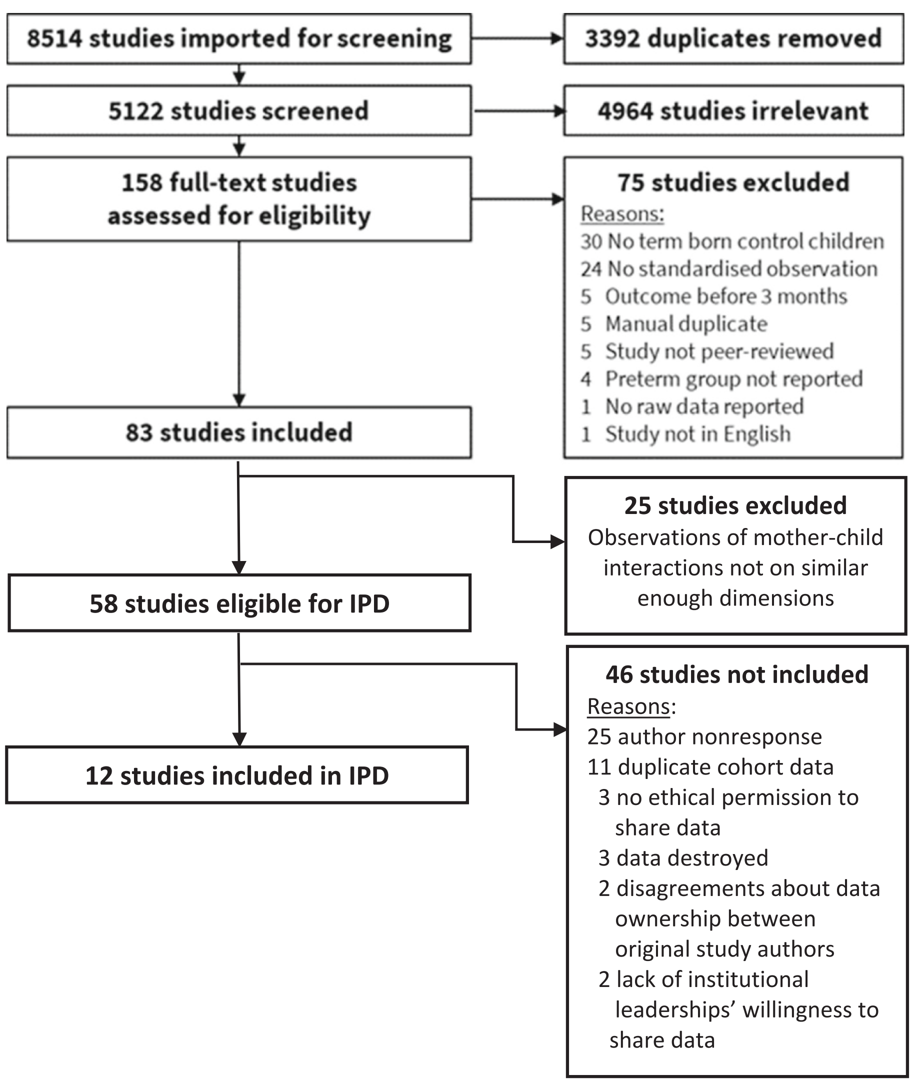

Fig. 1. Flow diagram of study eligibility.

>1000 g ($n = 121$), and a term-born comparison group ($n = 67$) [35]. At six months CA, maternal sensitivity was assessed with the EA scales [28]. Neurodevelopment was assessed at 12 months CA with the Bayley-III [29].

h. New Zealand: The Canterbury Preterm (CPT) Study included a regional cohort of all livebirths ≤32 weeks gestation and/or <1500 g in 1998–2000 ($n = 101$) and a full-term comparison group ($n = 105$). At 24 and 48 months CA, maternal sensitivity was assessed using a parent-child interaction paradigm that was rated according to an observational coding scheme [30,31,36]. Neurodevelopment was assessed at 24 months CA with the BSID-II [29].
i. Italy: The University Service for Psychological Support in Infancy (SUAPI) cohort included infants <32 weeks gestation and with a birth weight <1500 g hospitalized at Bufalini Hospital in Cesena in 2010–2013 ($n = 80$) and a term-born NBW comparison group ($n = 113$) [37–39]. Maternal sensitivity was assessed with the Global Rating Scales for Mother–Infant interaction [40] at 3 months CA and with the Child-Adult Relationship Experimental (CARE) Index [41] at 9 months CA. Neurodevelopment was tested using the Griffiths Mental Development Scales-Revised version [42] at 3 and 9 months CA, respectively.
j. United Kingdom: The Growth in At-risk INfants (GAIN) Study included infants born <32 weeks gestation or with a birth weight <1500 g in three neonatal units in Southeast England in 2001–2004 ($n = 65$) and a term-born comparison group ($n = 101$) [43]. At 18 months CA, maternal sensitivity was assessed with the Play Observation Scheme and Emotional Rating [44] and neurodevelopment with the BSID-II [29].
k. Finland: The PIPARI cohort (Development and Functioning of Very Low Birth Weight Infants from Infancy to School Age) included all live births <32 weeks gestation or with a birth weight <1500 g at Turku University Hospital in 2001–2005 ($n = 35$) and a term-born comparison group ($n = 46$) [45]. At 6 months CA, maternal sensitivity was rated with the parent child early relational assessment (PCERA) [46]. Neurodevelopment was rated with the BSID-II [29] at 24 months CA.
l. USA: The study cohort included infants born ≤32 weeks and with a birth weight <1800 g in the Western United States in 2008–2013 ($n = 33$) and a term-born NBW comparison group ($n = 33$) [47]. At 22 months CA, maternal sensitivity was assessed with structured observational coding [47] and neurodevelopment at 18 months CA with the Bayley-III [29].

2.2. Data extraction, harmonisation, and analysis

All procedures were performed in compliance with relevant laws and institutional guidelines and have been approved by the appropriate institutional committees. Specifically, participating groups ($n = 12$) had obtained ethical permissions for the original data collection, the privacy rights of human subjects have been observed and informed consent was obtained. Each group completed a data sharing agreement with the University of Oulu, Finland, to transfer non-identifiable individual level data for the analysis. Groups were requested to provide infant neonatal and demographic data (e.g., infant gestational age at birth (weeks), birth weight (grams), sex (binary coded), maternal education, scores for maternal sensitivity, and neurodevelopmental information.

Data was harmonised in SPSS 27. The content of the dyadic behaviour observation coding dimensions was compared to confirm that these assessed the same construct, i.e. sensitivity (see Appendix Table 1 for details). Sensitivity and neurodevelopmental global index test scores were z-standardised according to each cohort-specific contemporaneous term-born comparison group before pooling. Participants with standardised neurodevelopmental test index scores >2 SD below their respective comparison group's mean were coded as having neurodevelopmental delay or impairment. Information about maternal education was binary coded according to the International Standard Classification of Education (ISCED) [48] into medium/low vs. high=“completion of upper secondary education, high school degree or equivalent, allowing unrestricted university entrance, ≥ ISCED 3”. Small for gestational age (SGA, <10. centile by sex) birth was coded according to Fenton [49].

One-stage IPD meta-analyses were performed as mixed-effects linear regressions in Stata 17 (StataCorp LLC; Texas USA). All models were controlled for fixed effects of infant sex, age at assessment (CA if applicable), maternal education, and neurodevelopmental impairment, as well as the nestedness of data in cohorts (i.e., including a random effect representing study site and year of birth). The fixed and random effects of gestational age on maternal sensitivity in dyadic interactions are reported, along with fixed effects of confounders. As part of a stepwise process, random effects of child sex, age, neurodevelopmental impairment, and mother's education were additionally included, and model fit was evaluated using log-likelihood goodness of fit tests. However, none of these random effects improved overall model fit and were thus not retained to keep with statistical parsimony. In addition, we explored fixed interaction effects of gestation by sex, gestation by child age, gestation by maternal education, and maternal education by cohort. None of these were significant and were not retained. Finally, we were also interested in differences according to preterm birth groups, i.e., EP (<28 weeks), VP (28 to <32 weeks), and moderate to late preterm (MLP, 32 to <37 weeks) and repeated the model with a fixed effect of preterm birth group instead of the continuous effect of gestation. As sensitivity analysis, we tested the association between gestation at birth and dyadic sensitivity without including control variables.

3. Results

Individual cohort sample sizes ranged from 66 to 1439 participants (Table 1). There was substantial variation between cohorts in child gestational age and weight at birth, sex, ages at assessment, level of maternal education, as well as rates of neurodevelopmental impairment, SGA births, single mothers, and multiple births.

3.1. One-stage IPD meta-analysis

Mixed effects linear regression models indicated heterogeneity between study cohorts (i.e., significant log-likelihood chi-squared tests), supporting the use of mixed effects models as opposed to linear models without random effects. Model 1 in Table 2 shows the fixed effect of the association between gestation at birth and maternal sensitivity across all 12 cohorts [*coefficient* = 0.02 per week, *95 % confidence interval* = [0.01, 0.02], $p < .001$), adjusted for child age, sex, neurodevelopmental impairment, SGA birth, and mother's education, supporting our hypothesis. The random effect of gestation was estimated at $SD = 0.00$ [0.00, 0.01], indicating little variation between cohorts in the relationship between these two variables. Maternal education (0.32 [0.24, 0.40], $p < .001$), child neurodevelopmental impairment (−0.33 [−0.50, −0.17], $p < .001$) and SGA birth (−0.18 [−0.36, −0.01], $p = .038$) were also associated with maternal sensitivity. Fig. 2 displays the forest plot of the effect of gestation at birth on dyadic sensitivity by cohorts. In Model 2, because some cohorts had not assessed multiple birth status and mothers' age, we repeated the analysis with the respective available subsample ($n = 10$ cohorts) including these additional covariates. The fixed effect of gestation on maternal sensitivity remained stable ([0.02 [0.02, 0.03], $p < .001$).

We were also interested in differences according to preterm birth groups, i.e., EP (<28 weeks), VP (28 to <32 weeks), and moderate to late preterm (MLP, 32 to <37 weeks). Repeating the Model 1 analysis with this preterm group variable as a fixed effect instead of gestation in weeks showed that mothers of infants born EP ([−0.28 [−0.43, −0.14], $p < .001$) and VP ([−0.15 [−0.25, −0.06], $p = .002$) received lower sensitivity ratings than mothers of infants born at term, and they also received lower sensitivity ratings than mothers of infants born MLP (EP

Table 1
Descriptive characteristics by cohort (preterm / term-born samples).

	BLS, Germany (n = 563 / 876)	MSCR, Germany (n = 111 / 273)	Denmark (n = 195 / 128)	VIBeS2, Australia (n = 134 / 122)	VIBeS, Australia (n = 165 / 51)	STAP, Netherlands (n = 116 / 98)	PEDS, Israel (n = 121 / 67)	CPT, NZ (n = 101 / 105)	SUAPI, Italy (n = 80 / 113)	GAIN, United Kingdom (n = 65 / 101)	PIPARI, Finland (n = 35 / 46)	Western USA (n = 33 / 33)
Year(s) of birth	1985–1986	1986–1988	1980–82	2011–2014	2001–2004	2010–2011	2009–2011	1998–2001	2010–2013	1998–1999	2001–2005	2008–2013
Child assessment age[a]	6;3 years	3 months	52 months	12, 24 months[f]	24 months	18 months	6 months	24, 48 months[f]	3, 9 months[f]	18 months	6 months	22 months
Female	47.4 % / 50.6 %	55 % / 50.5 %	45.6 % / 46.1 %	51.3 % / 50.2 %	45.5 % / 52.9 %	43.1 % / 56.1 %	46.3 % / 53.7 %	48.6 % / 46.8 %	36.5 % / 52.2 %	47.4 % / 43.6 %	54.3 % / 50.0 %	42.4 % / 45.5 %
Gestation (weeks)	32.3 / 39.5	33.1 / 39.5	32.1 / 39.5[d]	27.8 / 39.8	27.5 / 39.3	34.7 / 39.5	33.1 / 39.4	28.0 / 39.6	28.7 / 39.8	29.2 / 39.5[d]	28.7 / 39.5[d]	29.6 / 40.0
Birthweight (g)	1717 / 3270	1785 / 3172	1598 / 2713	1029 / 3496	951 / 3315	2601 / 3575	1913 / 3329	1091 / 3599	1081 / 3456	1269 / 3232	1077 / 3597	1242 / 3510
Multiple birth	16.9 % / 2.6 %	0.0 % / 0.0 %	24.6 % / 14.1 %	45.1 % / 1.5 %	36.4 % / 3.9 %	0.0 % / 0.0 %	0.0 % / 0.0 %	34.9 % / 1.8 %	28.1 % / 13.0 %	27.7 % / 27.7 %	0.0 % / 0.0 %	- / - [e]
SGA birth	22.7 % / 19.0 %	36.0 % / 26.7 %	13.3 % / 28.1 %	12.3 % / 5.8 %	13.9 % / 11.8 %	0.0 % / 0.0 %	25.6 % / 13.4 %	14.5 % / 2.0 %	13.5 % / 6.7 %	10.8 % / 15.8 %	17.1 % / 6.5 %	15.2 % / 9.1 %
Mothers with upper secondary education[b]	18.5 % / 20.5 %	9.0 % / 9.9 %	34.4 % / 44.5 %	96.1 % / 99.1 %	86.4 % / 98.0 %	91.4 % / 96.9 %	77.7 % / 88.1 %	61.5 % / 80.8 %	75.5 % / 89.4 %	32.3 % / 35.8 %	78.8 % / 32.6 %	100.0 % / 100.0 %
Mother's age (years)	29.2 / 28.4	27.6 / 27.1	- / - [e]	32.9 / 33.0	29.9 / 32.1	31.2 / 32.6	31.0 / 30.5	30.7 / 31.0	33.7 / 33.0	30.8 / 30.9	28.5 / 28.2	- / - [e]
Single mother	6.9 % / 3.9 %	12.6 % / 10.6 %	- / - [e]	8.3 % / 4.8 %	9.7 % / 5.9 %	0.9 % / 2.0 %	0.0 % / 0.0 %	18.3 % / 11.7 %	0.0 % / 0.0 %	- / - [e]	0.0 % / 0.0 %	- / - [e]
Neurodev. < -2SD[c]	4.9 % / 0.0 %	1.8 % / 1.5 %	17.0 % / 1.6 %	2.3 % / 1.6 %	20.1 % / 0.0 %	1.8 % / 0.0 %	6.2 % / 4.8 %	11.8 % / 2.9 %	6.8 % / 2.2 %	27.7 % / 8.9 %	22.9 % / 4.4 %	9.1 % / 0.0 %
Maternal sensitivity[c]	−0.32 / -0.16	−0.04 / 0.00	0.02 / 0.00	−0.13 / 0.00	−0.41 / 0.00	−0.18 / 0.00	−0.24 / 0.00	−0.27 / 0.00	−0.21 / 0.00	−0.30 / 0.00	−0.06 / 0.00	−0.33 / 0.00

Please note: The sample size reported for each cohort may differ from the respective cohort-specific publications since only cases with complete data on all variables in analysis Model 1 were included. BLS=Bavarian Longitudinal Study; MSCR = Mannheimer Risikokinderstudie; STAP=Study on Attention of Preterm children; VIBeS=Victorian Infant Brain Studies; VIBeS2 = Victorian Infant Brain Studies 2; PEDS=Preterm Early Development Study; CPT = Canterbury Preterm Study; SUAPI=University Service for Psychological Support in Infancy Studies; GAIN = Growth in At-risk INfants; PIPARI=Development and Functioning of Very Low Birth Weight Infants from Infancy to School Age; SGA = small for gestational age at birth.

[a] CA or chronological age depending on cohort (see cohort descriptions in the text for details).
[b] Harmonised according to the International Standard Classification of Education (ISCED $\geq$3, completion of upper secondary education with unrestricted university entrance qualification).
[c] Values z-standardised according to cohort-specific healthy term-born controls.
[d] Set to constant.
[e] Information not available.
[f] Not all participants were assessed at both timepoints.

Table 2
Multilevel mixed-effects model results (One-stage IPD) showing associations of child gestational age and other covariates with maternal sensitivity during dyadic interactions.

Dependent variable Maternal sensitivity	Model 1 (dyad N = 3951; cohort N = 12; dyad avg. per cohort = 329) coefficient (95 % CI)	Model 2 (dyad N = 3534; cohort N = 10; dyad avg. per cohort = 353) coefficient (95 % CI)
Fixed effects		
Gestation	0.02 (0.01, 0.02)***	0.02 (0.01, 0.02)***
Female	0.06 (−0.01, 0.12)	0.07 (−0.00, 0.14)
Child age	−0.00 (−0.00, 0.00)	−0.00 (−0.01, 0.00)
Mother's education	0.32 (0.24, 0.40)***	0.37 (0.28, 0.46)***
Neurodev. impairment	−0.33 (−0.50, −0.17)***	−0.48 (−0.66, −0.30)***
SGA birth	−0.18 (−0.36, −0.01)*	−0.17 (−0.35, 0.01)
Multiple birth	–	0.06 (−0.06, 0.18)
Mother's age	–	0.00 (−0.00, 0.01)
Random effects by Cohort		
SD (Gestation)	0.00 (0.00, 0.00)	0.00 (0.00, 125.20)
SD (Residual)	1.04 (1.02, 1.06)	1.04 (1.02, 1.06)
Log-likelihood	−5763.25	−5165.99

* $p < .05$.
*** $p < .001$.

= [−0.27 [−0.43, −0.11], p = .001; VP = [−0.14 [−0.26, −0.03], p = .016, respectively). In contrast, there was no difference between mothers of infants born MLP and those born at term ([−0.01 [−0.11, 0.09], p = .828) nor between mothers of infants born EP and those born VP ([−0.13 [−0.27, 0.01], p = .075), respectively. All other model coefficients remained stable.

As sensitivity analysis, we tested the association between gestation at birth and dyadic sensitivity without including control variables. Effects remained stable (fixed effect = 0.02 per week [0.01, 0.03], random effect SD = 0.00 [0.00, 00]).

4. Discussion

In this IPD meta-analysis of twelve preterm birth cohort studies from ten different countries across Europe, North America, and Oceania, born between 1980 and 2014, we found evidence that gestational age was positively associated with maternal sensitivity, albeit with a small effect size. This finding is different from a previous two-stage meta-analysis that reported preterm children's mothers to show similar levels of sensitivity as term-born children's mothers [15]. Our results are not only based on a different subset of studies, but, more importantly, the one-stage IPD meta-analysis approach allowed us to account for heterogeneity between studies and known confounders, in particular child neurodevelopmental impairment and maternal education which both had substantial effects on maternal sensitivity. The distribution of cohort participants across gestation at birth allowed us to also test differences according to preterm birth groups. At a subgroup level, mothers of infants born EP and VP received lower sensitivity ratings than mothers of infants born MLP or at term. This supports the view that EP and VP dyads' interactive behaviours may be particularly vulnerable to the experiences surrounding preterm birth.

The continuous fixed effect of gestation on sensitivity was small but stable across all models, with some variation between cohorts. For instance, if all other covariates in Model 1 were held stable, a difference of 10 gestational weeks at birth would result in an average difference of 0.10 to 0.20 SD in maternal sensitivity. When EP, VP, and MLP birth were considered as categorical groups, only mothers of EP (−0.28 SD) and VP (−0.15 SD) children showed significantly lower sensitivity during dyadic interactions. Given that maternal sensitivity represents a critical environmental experience that can serve as a protective factor, especially for the most vulnerable of infants [8,10,50,51], our findings offer important pointers for identifying target groups for intervention to enhance parental sensitivity and foster healthy developmental

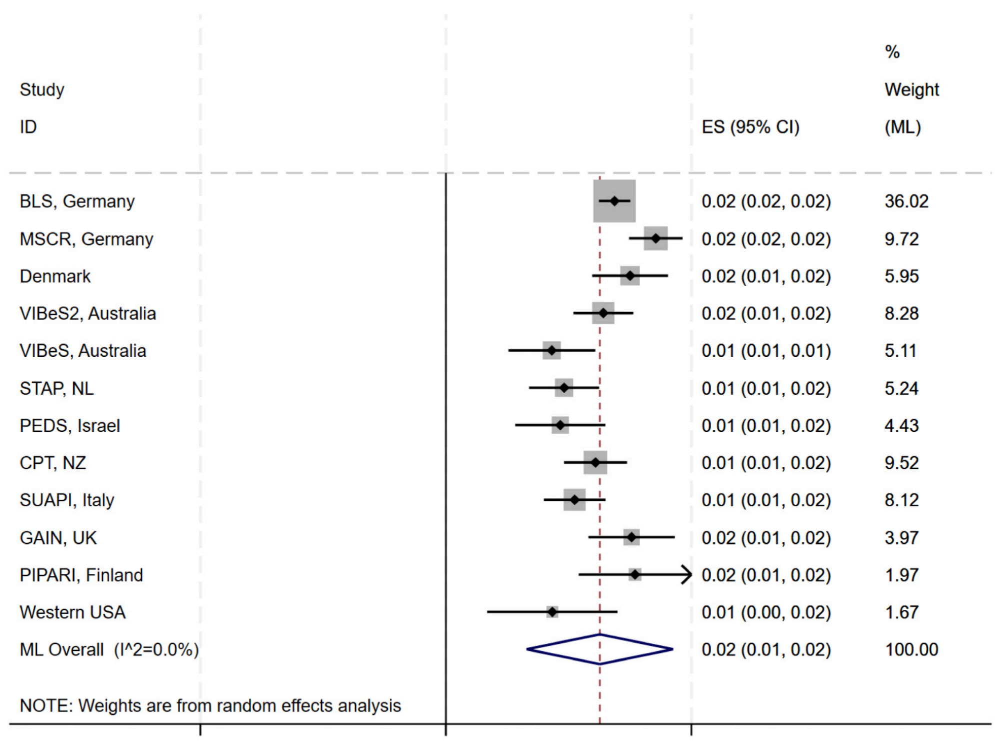

Fig. 2. Forest plot showing adjusted one-stage IPD meta-analysis effect of child gestation at birth (coefficients and 95 % CIs) on maternal sensitivity during dyadic interactions.
Note: Weights reflect individual study n while accounting for within-study variability and between-study variance.

trajectories [52–54].

Over and above the effect of gestation, we found two strong and stable covariate effects across all models: mothers with completed upper secondary education showed higher levels of sensitivity, whereas mothers of children with neurodevelopmental impairments, most of whom were born preterm, were observed to be less sensitive when interacting with their child. In comparison, when adjusted for each other, the effects of maternal education and child neurodevelopment impairment on maternal sensitivity were of similar size as having a child born EP.

While these findings have clear implications for future studies and intervention planning, limitations also need to be considered. Although data on mothers' levels of education were harmonised using ISCED levels [48], some structural differences between education systems are not fully eliminated, as has been previously reported for similar international birth cohort comparisons [55]. Successfully graduating from secondary school can include various education levels and pathways within a given country. In Germany, for instance, entering vocational training after 9 or 10 years of schooling has long been typical and well-respected for large parts of the population. The situation is similar in the UK, with secondary school graduates choosing between A-levels and O-levels. In the United States, on the other hand, completing high school allows general university entrance. The harmonised data was coded accordingly, and this explains some of the differences between cohorts in the proportions of mothers with completed upper secondary education. The large harmonised IPD dataset provides a good distribution of cases across analysis matrix cells and allows us to draw some more generalised conclusions, especially with regards to the confounding roles of maternal education and neurodevelopmental impairments. Considering the bi-directional nature of observational assessments of maternal sensitivity here, further research is still needed to better understand the role of the child in these interactions. Neurodevelopmental impairment was often assessed at the same time as sensitivity, at a very young age, and in three studies even a few months after the sensitivity assessment. Accordingly, we cannot infer directionality, while sensitivity can only be assessed in relation to the child's behaviours during a given situation, which may be less reciprocal when neurodevelopmental impairments are present. Although the current study does not present data on child outcomes, in this context it is important to caution against unsubstantiated claims that low levels of sensitivity may be an adaptive behaviour for interacting with infants and children born preterm [56]. Children's neurodevelopmental impairments may affect sensitive responses of their mothers, but the verdict of what kind of child behaviours allow their mothers to be optimally sensitive and of what level of sensitivity might most benefit children born preterm has yet to be established [8,56].

Especially in the context of EP and VP birth, the early environment in the neonatal intensive care unit (NICU) may contribute to increased vulnerability of the mother-child relationship through increased and prolonged stress, maternal postpartum depression [57], separation, and infants' painful experiences, for example, which can cause disruptions to mother-infant connection. However, the NICU environment in most countries has changed considerably since the data for many of the studies included here were collected, especially with the introduction of individualised and family-centred care. While our results suggest that despite variations, maternal sensitivity to infant cues is overall remarkably robust, even after the potentially traumatic experiences surrounding preterm birth, post-discharge interventions may further help increase sensitivity [58]. In addition, research shows that sensitivity can be increased in mothers with low education [59] and those with low sensitivity [53]. Nevertheless, evidence also cautions against widespread beliefs about the payoffs of early intervention for long-term development [60], which is why randomised-controlled studies of preterm populations with long follow-up periods are critically needed.

4.1. Strengths and limitations

Our IPD meta-analysis confirms the positive association between gestational age and maternal sensitivity during dyadic interactions across different preterm birth cohorts sampled in different birth epochs and world regions. Using pooled IPD provided a large sample size and allowed stricter adjustment for confounding bias than a standard meta-analysis. Strengths include the representation of the whole range of gestational ages at birth, the consistent assessment of maternal sensitivity through standardised coding tasks during dyadic interactions, and the inclusion of contemporaneous term-born comparison children in all studies. Data harmonisation and analysis protocols returned stable models that allowed reliable operationalisation of constructs and accounted for the heterogeneity between cohorts. Nevertheless, the specific dimensions included in the coding of maternal sensitivity varied across studies, possibly deviating from the “orthodox” definition of sensitivity [12] towards a focus on emotional support and synchrony (see Appendix Table 1). While this was a prerequisite for carrying out the intended data pooling, it cannot be guaranteed that the different measures of maternal sensitivity included here were assessing exactly the same construct or had the same level of sensitivity [61]. What's more, studies have found that maternal behaviour varies between situations of free play and more structured tasks [62], both of which were included in the pooled assessments of sensitivity in this IPD study. In addition, neurodevelopment was not assessed before or concomitantly with sensitivity by all studies. Moreover, the dyads included in the dataset covered a very wide age range from three months to six years, but our models showed surprisingly little variation by assessment age. While this can be interpreted as confirming high stability of maternal sensitivity, we also hypothesise that assessments and coding protocols were adapted in each study to operationalise the construct of sensitive maternal behaviour according to age- and developmentally appropriate variations. There is some risk of study selection bias: As noted in the Methods, our literature search identified 58 eligible publications but only 12 studies participated in the IPD. Each of the co-authors of this current study were involved in at least one of the original cohort publications, and a formal investigation of the original data for risk of bias issues was not performed. Finally, despite spanning three continents, all cohorts were from WEIRD (i.e., Western, educated, industrialised, rich, democratic) settings [63], a limitation of most preterm birth follow-up studies [5,64]. This is especially true for data based on standardised behaviour observations which require a high level of resources to collect and code.

5. Conclusions

Gestational age at birth is positively associated with maternal sensitivity, however, the size of the linear effect is small. Results from this IPD meta-analysis confirm that mothers of children born EP and VP tended to interact with their children in a less sensitive manner than mothers of children born MLP and at term. Over and above gestational age, sensitivity was consistently associated with maternal education and child neurodevelopmental impairment, highlighting the importance of these factors for future studies and intervention designs. Ultimately, if higher levels of maternal sensitivity are associated with improved child outcomes (e.g., [8,11]) then investment in interventions that support parents to increase their sensitivity, especially after EP and VP birth, may promise valuable returns.

CRediT authorship contribution statement

Julia Jaekel: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Visualization, Writing – original draft. **Peter J. Anderson:** Conceptualization, Data curation, Resources, Writing – review & editing. **Dieter Wolke:** Data curation, Resources, Writing – review & editing. **Günter Esser:**

Data curation, Resources, Writing – review & editing. **Gorm Greisen:** Data curation, Resources, Writing – review & editing. **Alicia Spittle:** Data curation, Resources, Writing – review & editing. **Jeanie Cheong:** Data curation, Resources, Writing – review & editing. **Anneloes L. van Baar:** Data curation, Resources, Writing – review & editing. **Marjolein Verhoeven:** Data curation, Resources, Writing – review & editing. **Noa Gueron-Sela:** Data curation, Resources, Writing – review & editing. **Naama Atzaba-Poria:** Data curation, Resources, Writing – review & editing. **Lianne J. Woodward:** Data curation, Resources, Writing – review & editing. **Erica Neri:** Data curation, Resources, Writing – review & editing. **Francesca Agostini:** Data curation, Resources, Writing – review & editing. **Ayten Bilgin:** Data curation, Resources, Writing – review & editing. **Riikka Korja:** Data curation, Resources, Writing – review & editing. **Elizabeth C. Loi:** Data curation, Resources, Writing – review & editing. **Karli Treyvaud:** Conceptualization, Data curation, Methodology, Resources, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Appendix Table 1
Dyadic behaviour observation scales for assessing maternal sensitivity.

Study cohort, age at assessment	Measure	Maternal Sensitivity Scale construct dimensions
a. Germany: BLS, 6 years (chronological age)	Assessment of Mother-Child-Interaction with the Etch-a-Sketch (AMCIES) [10,19]	Subscales: Dyadic harmony; Verbal Control (r); Non-Verbal Control (r); Criticism (r)
b. Germany: MSCR, 3 months corrected age (CA)	Mannheim Rating System for Mother–Infant Interaction [21,22]	Subscales: Emotions; Warmth; Verbal stimulation; Verbal control (r); Authenticity; Variability; Responsivity; Stimulation
c. Denmark: Copenhagen study cohort, 52 months (chronological age)	Parental Sensitivity Assessment Scale [24]	Subscales: Attention/availability towards the child; Acceptance of child's emotional expressions; Emotional tone towards child; Support of child's independent behaviours
d. Australia: VIBeS2 cohort, 12 and 24 months CA	Emotional Availability (EA) scales [28]	Sensitivity (dyadic, appropriate, and positive emotional exchanges)
e. Australia: VIBeS cohort, 24 months corrected age (CA)	Structured observational coding [11]	Sensitivity (expressions of positive regard and praise, being warm, available, and emotionally supportive)
f. The Netherlands: STAP cohort, 18 months CA	Coding Interactive Behaviour Manual [34]	Subscales: Acknowledging; Positive Affect; Appropriate range of affect; Elaborating; Resourcefulness; Supportive presence
g. Israel: PEDS Study, 6 months CA	EA scales [28]	Sensitivity (dyadic, appropriate, and positive emotional exchanges)
h. New Zealand: CPT cohort, 24 months CA, 48 months (chronological age)	Structured observational coding [36]	Sensitivity (expressions of positive regard and praise, being warm, available, and emotionally supportive)
i. Italy: SUAPI cohort, 3 months CA	Global Rating Scales for Mother–Infant interaction [40]	Sensitivity (mother's ability to understand infant's signals and appropriately respond, with adequate levels of acceptance, affection and warmth)
j. Italy: SUAPI cohort, 9 months CA	Child-Adult Relationship Experimental Index – CARE Index [41]	Sensitivity (any pattern of behaviour that pleases the infant, increases comfort and attentiveness and reduces distress and disengagement)
k. United Kingdom: GAIN Study, 18 months CA	Play Observation Scheme and Emotional Rating [44]	Subscales: Maternal positive emotion expression; Sensitivity; Appropriateness of play
l. Finland: PIPARI cohort, 6 months CA	Parent Child Early Relational Assessment (PCERA) [46]	Subscales: Maternal positive affective involvement; Maternal positive communication
m. USA: Preterm cohort, 22 months CA	Structured observational coding [47]	Subscales: Sensitivity/Responsiveness; Verbal Elaboration on Topics; Intrusiveness (r)

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