Regulation of stress physiology across social contexts in prematurely born toddlers

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Abstract

Premature birth increases risk for socio-emotional difficulties and altered autonomic regulation, yet because physiological regulation supports development, dysregulation may have lasting consequences. We evaluated social functioning and physiological regulation in 70 preterm children aged 5.5 years compared to 32 matched full-term controls (Total sample: 59 boys, 43 girls; 98% White). Heart rate and heart rate variability (HRV) were recorded during rest and structured social interactions with the mother and a stranger, including eye contact, conversations, and triadic play. Preterm children demonstrated significantly greater social difficulties and internalizing problems than full-term peers. Across conditions, they exhibited consistently elevated heart rate, whereas HRV patterns were comparable between groups. Specifically, RMSSD-HRV varied by interaction partner (stable with mother, fluctuating with stranger), while HF-HRV reflected general condition effects independent of partner familiarity. Conversation tasks elicited the strongest autonomic activation, with pronounced vagal withdrawal during negative exchanges. In conclusion, preterm children show persistent cardiac hyperarousal and social-behavioral difficulties, yet maintain context-dependent autonomic regulation similar to full-term peers. The distinct sensitivity of HRV indices suggests preserved regulatory mechanisms, indicating that prematurity's physiological signature may reflect heightened baseline arousal rather than impaired regulation.

Introduction

Each year, an estimated 15 million infants are born prematurely (<37 weeks gestation) (1–3). Although advances in neonatal care have improved survival, preterm children frequently exhibit the "preterm behavioral phenotype", marked by attentional difficulties, socio-emotional challenges, and elevated risk of neurodevelopmental disorders, with lower gestational age conferring greater vulnerability (4–11). The autonomic nervous system (ANS) is a core mechanism supporting self-regulation, social engagement and environmental adaptation (12). Examining autonomic functioning in preterm children is critical for elucidating the neurobiological basis of their socio-emotional difficulties.

The ANS regulates stress responses through its sympathetic (fight-or-flight) and parasympathetic (rest and recovery) branches (13). Heart rate (HR) is a general index of physiological arousal influenced by both autonomic and non-autonomic factors, while heart rate variability (HRV), the intervals between consecutive heartbeats, indexes parasympathetic cardiac regulation (14). Higher HRV is associated with better stress resilience, self-regulation, and cognitive flexibility, whereas lower HRV indicates maladaptive cardiac stress responses and has been linked to psychological vulnerability (15,16).

The third trimester of gestation is a critical window for maturation of endocrine and autonomic stress-regulatory systems (17). Premature birth interrupts this developmental trajectory (18,19) (20), with lasting implications for stress regulation across the lifespan (18). Neonatal intensive care unit (NICU) environmental stressors may further compromise ANS development (21). Procedural pain from skin-breaking interventions (22,23), caregiver separation, and sensory overstimulation can disrupt sleep-wake cycles (18) and destabilize physiological functions (24). Prolonged stress may overwhelm regulatory capacities, disturb homeostasis (18), and impair physiological, emotional, attentional, and

self-regulatory development (17). Supportive interventions such as kangaroo care (KC, skin-to-skin contact) may mitigate these effects by reducing pain, enhancing neurological development, and supporting autonomic maturation (20, 22, 25,26, 29).

Preterm infants typically show reduced HRV during NICU hospitalization (27–29), yet whether these alterations persist into later life remains unclear. While preterm infants initially show lower RSA compared to term-born peers, this difference appears to diminish by age two when accounting for maturational delays (30). Similarly, parasympathetic normalization by this age has been reported in frequency-domain HRV measures (31). During early childhood, a NICU-based family nurture intervention improved autonomic regulation at 4-5 years of age (32), while school-age children born moderate-to-late preterm showed comparable HRV to term-born peers (33). However, persistent HRV alterations have been reported in adolescence (34,35), and these reductions appear to extend into adulthood, particularly in males (36,37). Inconsistencies are amplified by methodological heterogeneity, including differing recording techniques (e.g. polysomnography (29,38,39) versus ambulatory (31,40–45)) and diverse assessment protocols (42,43,44,45). This variability limits cross-study comparability and synthesis. Notably, little attention has been given to the social contexts shaping physiological adaptation, despite their critical relevance.

Our two primary objectives are: (1) to clarify inconsistent findings on ANS regulation beyond infancy by comparing HR and HRV in preterm and full-term 5-year-olds, and (2) to implement standardized real-life interaction paradigms to investigate physiological adaptation in naturalistic social contexts. To our knowledge, this is the first study to assess both sympathetic and parasympathetic functioning in preterm versus full-term children during rest and structured social interactions with their mother or a stranger. We hypothesized that (a) social interactions would elicit greater physiological arousal

(higher HR) and reduced parasympathetic regulation (lower RMSSD-HRV and HF-HRV) compared to rest, (b) arousal would be stronger during interactions with a stranger than with the mother, (c) non-contingent (e.g. replay) and negative affect conditions would elicit greater arousal than contingent and positive interactions, and (d) preterm children would exhibit heightened arousal and reduced regulation across contexts compared to full-term peers. Understanding ANS regulation at this critical developmental stage may inform interventions that support self-regulatory development in preterm populations.

Methods

This research is part of the Resilience project, a longitudinal cohort study monitoring preterm infants from initial NICU admission at University Hospital Leuven, Belgium.

Participants

The study sample comprised 102 children (mean age 5.5 years), all native Dutch speakers with normative or corrected hearing and vision, and IQ scores above 80. The sample consisted of 59 boys and 43 girls. With regard to race and ethnicity, the majority of participants were White (98%), with one participant of African and one of North African descent. Children with major cerebral complications (grade III-IV intraventricular hemorrhage, periventricular leukomalacia) or diagnosed neurological conditions (e.g., cerebral palsy, epilepsy) were excluded. The preterm cohort consisted of 70 preterm-born children (49), defined by gestational age (GA) <37 weeks and birth weight (BW) <2500g. This group was stratified as moderate-to-late preterm (*n*=37, GA 32-36 weeks), very preterm (*n*=21, GA 28-31 weeks), and extremely preterm (*n*=12, GA <28 weeks). The comparison group comprised 32 full-term participants, recruited through local schools, and matched for age and sex (**Table 1**). Full-term inclusion criteria were GA 37-42 weeks, BW >2500g, and absence of Autism Spectrum Disorder (ASD), Attention-Deficit/Hyperactivity Disorder (ADHD), or a first-degree family history of these conditions. Maternal and family

demographic information are provided in **Table 2**.

[Insert Table 1]

[Insert Table 2]

The study was approved by the [Ethics committee and reference number removed], and written informed consent was obtained from all parents, adhering to the Declaration of Helsinki.

Questionnaires

The Social Responsiveness Scale (SRS-2) is a 65-item parent-report measure assessing autism-related social impairments (50). The Child Behavior Checklist (CBCL 1.5-5) is a parent-report questionnaire quantifying behavioral problems and competencies in young children, yielding scores on internalizing problems (emotionally reactive behavior, anxiety/depression, somatic complaints, withdrawal) and externalizing problems (attention problems, aggressive behavior) (51).

Experimental procedure

The experimental set-up (**Figure 1**) employed a two-way videocall configuration, adapted from Hessels et al. (2018) (52). Child and mother/stranger were seated in the same room, each in front of a wooden box with a half-silvered see-trough mirror, allowing them to see each other and interact verbally. Web cameras behind the mirrors were placed at eye level, thereby allowing natural interaction and eye contact (52). The dyadic setup enabled simultaneous ECG, EEG, galvanic skin response, audio/video, and eye-tracking measurements. The present report focuses solely on the ECG measurements of the child.

[Insert Figure 1]

Conditions

A series of naturalistic interactions were conducted between child-mother and child-stranger (i.e. a female experimenter). Mothers were carefully instructed prior to testing, ensuring full procedural transparency and adherence while maintaining naivety in the

children. Child-mother interactions comprised six conditions in fixed order: (a) 2 minutes eyes-closed rest, (b) 2 minutes eyes-open (silent visual contact), (c) 2 minutes replay (child viewed recording of mother from previous condition while believing it was live), (d) 3 minutes positive conversation about shared experience, (e) 3 minutes negative conversation about recent disagreements, (f) 3 minutes triadic conversation with dragon puppet. The child-stranger protocol comprised three conditions in fixed order: (a) 2 minutes eyes-closed rest, (b) 2 minutes eyes-open, (c) 3 minutes conversation about school and activities. Order of mother and stranger interactions was counterbalanced.

ECG recording

Electrocardiographic (ECG) data were acquired using the ActiveTwo BioSemi system (Biosemi, The Netherlands) at 512 Hz sampling rate. For mother-child dyads, the Common Mode Sense (CMS) and Driven Right Leg (DRL) electrodes from the EEG cap served as references. Two external ECG electrodes were positioned on the thorax: the negative electrode medial to the right coracoid process, inferior to the clavicle, and the positive electrode on the lower left ribcage, approximating a simplified lead II configuration. Conductive paste and adhesive rings were used to ensure stable, high-quality signals. For strangers without EEG caps, four external electrodes were applied following similar placement principles.

Child HR and HRV analysis

HRV was assessed using both time- and frequency domain metrics. In time-domain analysis, the root mean square of successive differences (RMSSD) was calculated, a well-established index of vagally-mediated HR fluctuations that strongly correlates with high-frequency (HF) power (13,15). The primary outcomes of the study were heart rate (bpm), RMSSD-HRV (ms), reflecting beat-to-beat variability and the natural logarithm of absolute HF-HRV power (0.24-1.04 Hz). Data were preprocessed using MATLAB (R2021b) and Kubios HRV Scientific (v4.1, University of Eastern Finland). R-peaks were detected using

the Pan-Tompkins algorithm, with artifact correction based on Lipponen and Tarvainen's (2019) (53) , which identifies and corrects ectopic, missed, extra, or misaligned beats, and automatically detects noisy segments at moderate sensitivity thresholds. All recording were additionally subjected to visual inspection, and irregularities were manually annotated.

Statistical Analyses

Outliers were identified using Cook's Distance and excluded prior to group-level analyses. Outlier percentages varied by parameter and model: HR (7.67%- 8.08%), RMSSD-HRV (7.67%- 6.47%), and HF-HRV (8.58%- 9.24%). Linear mixed models (LMMs) were run with the 'Afex' package (v1.2-1) (54) in R (v4.2.0) (55).

Two LMMs were implemented. The first model (mother-only) included *Condition* (eyes closed, eyes open, replay, positive/negative/triadic conversation) as within-subject factor and *Group* (preterm vs. full-term) as between-subject factor. The second model (mother-stranger) incorporated *interaction partner* as an additional within-subject factor (mother vs. stranger), comparing three conditions (eyes closed, eyes open, and positive/neutral interaction). Both models included random intercepts per participant. Post-hoc pairwise comparisons used Bonferroni corrections and Kenward-Roger approximation for degrees of freedom ('emmeans' package, v1.8.5) (56).

Spearman correlations were computed between physiological parameters (HR, RMSSD-HRV, HF-HRV) and developmental variables . In the preterm group, correlations included prematurity indices (GA, BW, SBP, KC) and behavioral measures (SRS-2, CBCL). In the full-term group, only associations with behavioral measures (SRS-2, CBCL) were tested. Significance for these multiple correlations was set at $p<.01$.

Group differences in participant characteristics were analyzed with Welch's *t*-test or Wilcoxon rank-sum test, depending on normality. Sex ratio was compared using chi-square tests. Significance for group comparisons was set at $p<.05$.

Results

Questionnaire Data

Preterm children scored higher on SRS-2 (M=52.56, SD=9.38) than full-term children (M=46.91, SD=6.46; w=615, p=.001) and showed elevated CBCL internalizing problems (M=49.92, SD=11.60 vs M=43.97, SD=9.31; w=705.5, p=.007). No group differences emerged for externalizing problems (p=.38).

Physiological regulation in preterm and full-term children while interacting with mother

Heart rate

Analysis of HR measurements revealed significant main effects of group (F(1,388)=5.77, p=.017) and condition (F(5,320)=3.27, p=.007), with no significant group-by-condition interaction (F(5,320)=1.56, p=.17). The preterm group consistently exhibited higher HR than the full-term group, with a mean difference of 1.87 bpm (95% CI: 0.34, 3.40) (**Figure 2A**). These findings indicate that preterm children exhibit consistently elevated cardiovascular arousal across all conditions.

[Insert Figure 2]

Post-hoc comparisons showed that the negative conversation elicited significantly higher HR compared to both the eyes open (95% CI: 0.55, 4.23, t(323)=3.024, p=.032) and the triadic condition (95% CI: 0.44, 4.12, t(321)=2.977, p=.037), suggesting that this negative conversation elicited heightened cardiovascular arousal across both groups.

RMSSD-HRV

Analysis of RMSSD-HRV revealed a significant main effect of condition (F(5,318)=5.47, p<.001), with no significant main effect of group (F(1,392)=0.61, p=.437) or group-by-condition interaction (F(5,318)=0.87, p=.502). Post-hoc comparisons showed that RMSSD

values were significantly lower during the negative conversation than during eyes closed ($t(323)=4.300$, $p= .003$), eyes open ($t(323)=3.960$, $p= .001$), and triadic condition ($t(322)=-3.409$, $p= .009$) (**Figure 2B**). These findings demonstrate that parasympathetic regulation was sensitive to emotional interaction quality, with reduced RMSSD during negative conversation suggesting decreased vagal tone across both groups.

HF-HRV

Analysis of HF-HRV revealed a significant main effect of condition ($F(5,316)=7.93$, $p<.001$), while no significant effect of group ($F(1,395)=1.15$, $p=.289$), nor group-by-condition interaction (F(x)=x) were observed (**Figure 2C**). Post-hoc analyses demonstrated that HF-HRV during the negative conversation condition was significantly lower compared to eyes closed ($t(323)=4.821$, $p<.001$), eyes open ($t(325)=5.818$, $p<.0001$), positive conversation ($t(323)=3.143$, $p=.022$) and triadic condition ($t(321)=-3.783$, $p=.002$). HF-HRV was also lower during replay versus eyes open ($t(323)=3.423$, $p=.009$), suggesting real-time interaction supports greater parasympathetic activation.

In sum, these findings suggest that while both groups demonstrate similar capacity for autonomic regulation during maternal interactions, the nature of the social interaction significantly impacts their sympathetic response, with particularly pronounced vagal withdrawal during negative emotional exchanges.

Physiological regulation in preterm and full-term children during interactions with mother versus stranger

Heart rate

HR analysis revealed a significant main effect of condition ($F(2,309)=20.63$, $p<.001$), with no other significant main effects ($p>0.05$). Significant interactions were observed between condition and interaction partner ($F(2,309)=5.57$, $p=.004$) and between group and

interaction partner (F(1,313)=9.68, p=.002), whereas the interaction between group and condition (F(2,309)=2.88, p=.058), and the three-way interaction of group x condition x partner were non-significant (F(2,309)=0.10, p=.91) (**Figure 3A**).

[Insert Figure 3]

Follow-up analyses of the condition-by-partner interaction indicated that HR patterns during interactions with the mother remained relatively stable across conditions, whereas interactions with the stranger showed greater variability, with significantly higher HR during conversation compared to both eyes closed (95% CI: 0.59, 4.23, t(315)=2.587, p=.027) and eyes open (95% CI: 4.12, 7.36, t(311)=6.943, p<.001) . Furthermore, during the eyes open condition, HR was significantly higher when interacting with the mother than with the stranger (95% CI: 0.68, 3.96, t(312)=2.770, p=.006). Breaking down the group-by-partner interaction revealed that full-term children showed no significant difference in HR between mother and stranger interactions (t(314)=-1.690, p=.092), whereas preterm children exhibited significantly higher HR when interacting with the mother compared to the stranger (95% CI: 0.63, 2.91, t(317)=3.039, p=.003). Preterm children showed heightened cardiovascular sensitivity specifically during maternal interactions. Separately, both groups showed greater HR variability with strangers, where conversation elicited significantly higher HR than passive condition, an effect less pronounced with mothers.

RMSSD-HRV

Analysis of RMSSD-HRV revealed a significant main effect of condition (F(2,315)=16.72,p<.001), but no significant effects of group (F(1,392)=0.17, p=.68) or interaction partner (F(1,318)=1.59, p=.21). A significant condition-by-partner interaction (F(2,315)=3.52, p=.031) was observed, whereas no interactions involving group were significant (all p>.05). The condition-by-partner interaction indicates that the effect of condition varied depending on interacting with mother versus stranger (**Figure 3B**).

Specifically, interactions with mothers were characterized by relatively stable RMSSD-HRV values across conditions, with no significant differences between eyes closed, eyes open, and conversation (all $p>.05$). In contrast, interactions with strangers showed clear condition effects: RMSSD-HRV was significantly lower during conversation compared to both eyes closed ($t(320)=-3.494$, $p=.001$) and eyes open ($t(317)=-5.993$, $p<.001$). Furthermore, during the conversation condition, RMSSD-HRV was significantly lower when interacting with strangers than with mothers ($t(320)=2.649$, $p=.009$). These findings reveal partner-specific regulatory patterns: maternal presence maintained stable parasympathetic activity across tasks, while stranger interactions elicited context-dependent parasympathetic modulation, with conversation showing strongest vagal withdrawal. This suggests maternal interactions provide a regulatory buffer, whereas unfamiliar contexts demand flexible autonomic adjustment.

HF-HRV

Analysis of high-frequency HR fluctuations revealed a significant main effect of condition type ($F(2,305.95)=30.83$, $p<.001$), but no significant main effect of group ($F(1,385.49)=0.09$, $p=.76$) or interaction partner ($F(1,316.89)=1.38$, $p=.24$) (**Figure 3C**). No significant interactions were found (all $p>.05$). Post-hoc analyses revealed the following HF-HRV differences between conditions: conversation showed significantly lower values compared to both eyes closed ($t(312)=-4.877$, $p<.001$) and eyes open ($t(312)=-7.754$, $p<.001$), with eyes closed also showing significantly lower values than eyes open ($t(311)=-2.757$, $p=.017$). These findings indicate that social interaction, particularly active conversation, elicits the greatest parasympathetic withdrawal regardless of interaction partner or group status. The pattern suggests a hierarchy of autonomic regulation, with eyes open showing the highest HF power, followed by eyes closed, and conversation showing the lowest parasympathetic activity.

Correlations

Exploratory correlational analyses between physiological parameters on the one hand, and neonatal and socio-affective variables on the other revealed no significant associations (**Supplementary Tables 1-2**; all $p>.01$)

Discussion

We examined autonomic nervous system functioning in 5-year-old preterm and full-term children during rest (eyes closed) and structured social interactions with mothers and strangers, using heart rate and heart rate variability indices (RMSSD/HF). Preterm children consistently exhibited elevated HR compared to full-term peers during maternal interaction paradigms, whereas no significant between-group differences were observed in parasympathetic regulation, as indexed by RMSSD-HRV and HF-HRV.

Research has documented altered autonomic cardiovascular regulation in premature infants, characterized by elevated mean HR, reduced HRV, and differences in blood pressure (39,57–59). This physiological adaptation likely serves a compensatory role, meeting heightened metabolic demands by elevating the heart pumping frequency. Makarov and colleagues (2010) reported that term infants exhibit marked HR decreases after birth, whereas preterm neonates (28-36 weeks GA) maintain elevated HR throughout the first postnatal week (60). Notably, this elevation persists into childhood, remaining evident at age 9 (61). Our finding hereby corroborates these observations by showing consistently increased HR in 5-year-old preterms, both during rest and social interactions.

Previous research also documented reduced HRV in preterm infants (18,59,62), yet the present study found no significant group differences at age five. These findings are consistent with literature suggesting autonomic regulation in preterm children may normalize by approximately age two (31,33). However, the developmental trajectory appears complex, with evidence indicating potential deterioration during later stages.

Studies have reported reduced HRV re-emerging in adolescence and early adulthood (34,35), highlighting the need for longitudinal monitoring of autonomic functioning throughout development.

Further analysis revealed that negative conversational paradigms elicited significantly elevated HR and attenuated HRV compared to eyes-open and triadic conditions, reflecting increased cardiovascular arousal and reduced parasympathetic activity. Importantly, these effects were consistent across preterm and full-term children, indicating similar autonomic reactivity despite basic cardiac differences. This autonomic flexibility aligns with neurovisceral integration theory, which proposes that parasympathetic withdrawal represents an adaptive response to emotionally challenging stimuli, facilitating vigilance and readiness for threat or social engagement (63). The preservation of these regulatory dynamics in preterm children indicates that core autonomic mechanisms supporting emotional regulation and social engagement remain intact despite persistently elevated basic cardiac activity. These findings contribute to a growing body of evidence indicating that, while preterm birth alters basic cardiovascular function, parasympathetic regulatory flexibility appears preserved or recovered. This distinction between basic cardiac differences and preserved reactivity highlights the need for longitudinal autonomic-developmental relationships.

Another key finding is that preterm children demonstrated significantly higher HR during maternal versus stranger interactions. Notably, HR remained relatively stable across all three conditions (eyes closed, eyes open, conversation) with mothers, whereas stranger interactions elicited substantial variability. This partner-specific pattern suggests robust interaction partner effects on autonomic regulation. Consistent maternal HR elevation may reflect a "secure base" phenomenon, wherein maternal presence provides an emotional anchor stabilizing physiological arousal across varying situations. This stability could

indicate adaptive regulatory support established through secure attachment relationships. Conversely, high HR variability with strangers suggests children actively modulate physiological responses to meet changing social demands in unfamiliar contexts. These fluctuations may represent adaptive self-regulatory strategies: parasympathetic withdrawal and reduced arousal during passive conditions (eyes closed/open), followed by heightened engagement during interaction.

Lastly, we found no significant correlations between physiological parameters (HR, RMSSD-HRV, HF-HRV) and neonatal variables (BW, GA, KC, skin breaking indices) and socio-affective functioning (SRS-2, CBCL) in either group. This contrasts with prior research linking neonatal stress to poor neurodevelopmental outcomes and HRV to socio-emotional functioning in childhood (64–66). The absence of correlations, despite elevated preterm HR, suggests that early NICU interventions (e.g. KC, NIDCAP (67)), combined with exclusion of major neurological complications, may have supported autonomic regulatory development, potentially normalizing HRV trajectories while other physiological signatures of prematurity persisted.

Clinically, the persistent elevation in basic HR alongside preserved regulatory flexibility suggests that preterm children possess the fundamental mechanisms for healthy socio-emotional development, though routine cardiovascular monitoring remains warranted. Early identification during developmental transitions such as adolescence, when autonomic regulation may deteriorate, could guide targeted interventions.

Limitations

This study has several limitations. First, the cross-sectional design limits conclusions about developmental trajectories of autonomic regulation following preterm birth. Although incorporating NICU data, longitudinal assessments at multiple developmental time points are needed for a comprehensive picture. Second, while HR and HRV provide meaningful autonomic indices, additional parameters, such as gaze behavior, could offer more nuanced

understanding of social interaction dynamics. Finally, future research should include fathers and other primary caregivers to examine effect specificity and enhance ecological validity.

Conclusion

This study demonstrates that 5-year-old preterm children exhibit elevated cardiac activity during social interactions, particularly with their mothers, while preserving fundamental regulatory flexibility comparable to full-term peers. The observed pattern of stable autonomic responses with mothers versus greater variability with strangers suggests adaptive developmental compensation rather than dysregulation. These findings highlight resilience mechanisms that may inform the design of targeted interventions to support optimal socio-emotional and physiological outcomes in this vulnerable population.

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Table 1 – Participant characteristics

	Preterm (*N* = 70) Mean ± ***SD***	**Full-term (*N* = 32)** Mean ± ***SD***		***p*-**value
Sex (M:F)	43:27	16:16	$X^2(3) = 1.52$	.68
Age (years)	5.55 ± 0.09	5.62 ± 0.16	$w = 1321$	.05
Gestational age (weeks)	31.31 ± 2.74	39.35 ± 1.31	$w = 2112$	< .0001
Birth weight (g)	1615.44 ± 472.44	3646.38 ± 512.18	$w = 2048$	< .0001
# skin breakings	39 ± 19	-	-	-
# hours kangaroo care	116 ± 60	-	-	-

Table 1. Chi-Square tests were used to compare ratios and Wilcoxon Rank Sum test was used to compare group means. *Abbreviations*: M, male; F, female; # skin breakings, total amount during the first 5 days; # hours kangaroo care, total number of KC hours divided by the number of hospitalization days.

Table 2 – Maternal and family characteristics

	Family Preterm (*N* = 70)	**Family Full-term (*N* = 32)**
Age	41.7	36.6
Monthly Netto Income	4943 EUR	5645 EUR

Maternal Education Level	**Mothers Preterm**	**Mothers Full-term**
High School	18.3%	6.5%
Bachelor Degree	33.8%	35.5%
Master Degree	28.2%	51.6%
PhD	8.4%	6.4%
Other	9.3%	0%

Table 2. Family demographic characteristics and maternal education level, presented as percentages or means by group. *Abbreviations:* PT, preterm; FT, full-term; EUR, euros.

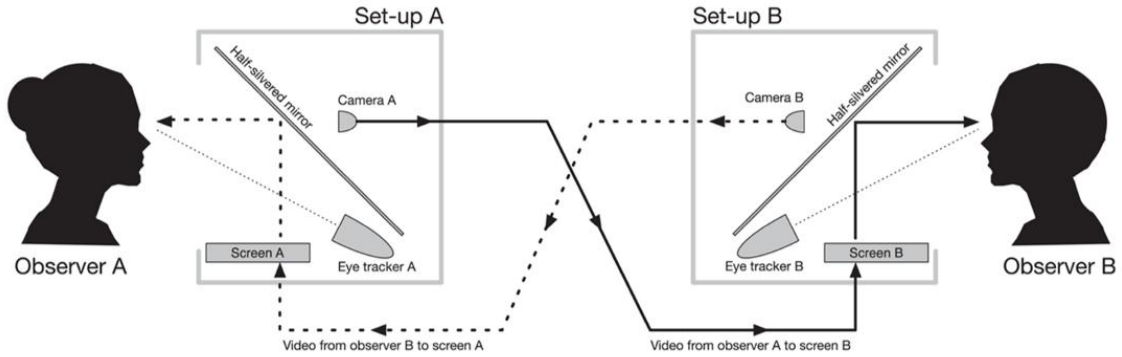

Figure 1. Schematic representation of the dual-camera experimental configuration. The mother is positioned at side A and filmed by camera A, which is mounted behind a one-way mirror. The solid arrow indicates the video transmission pathway from the mother to the child, with maternal recordings displayed on monitor B for the child's viewing. The child is situated at side B and captured by camera B, likewise positioned behind a one-way mirror. Child recordings are transmitted to the mother via monitor A, as depicted by the dotted arrow. Both participants remain within the same experimental room throughout the session. Height-adjustable platforms enable direct eye-level contact between mother and child, facilitating naturalistic gaze interaction. Adapted from Hessels et al. (2018) (52).

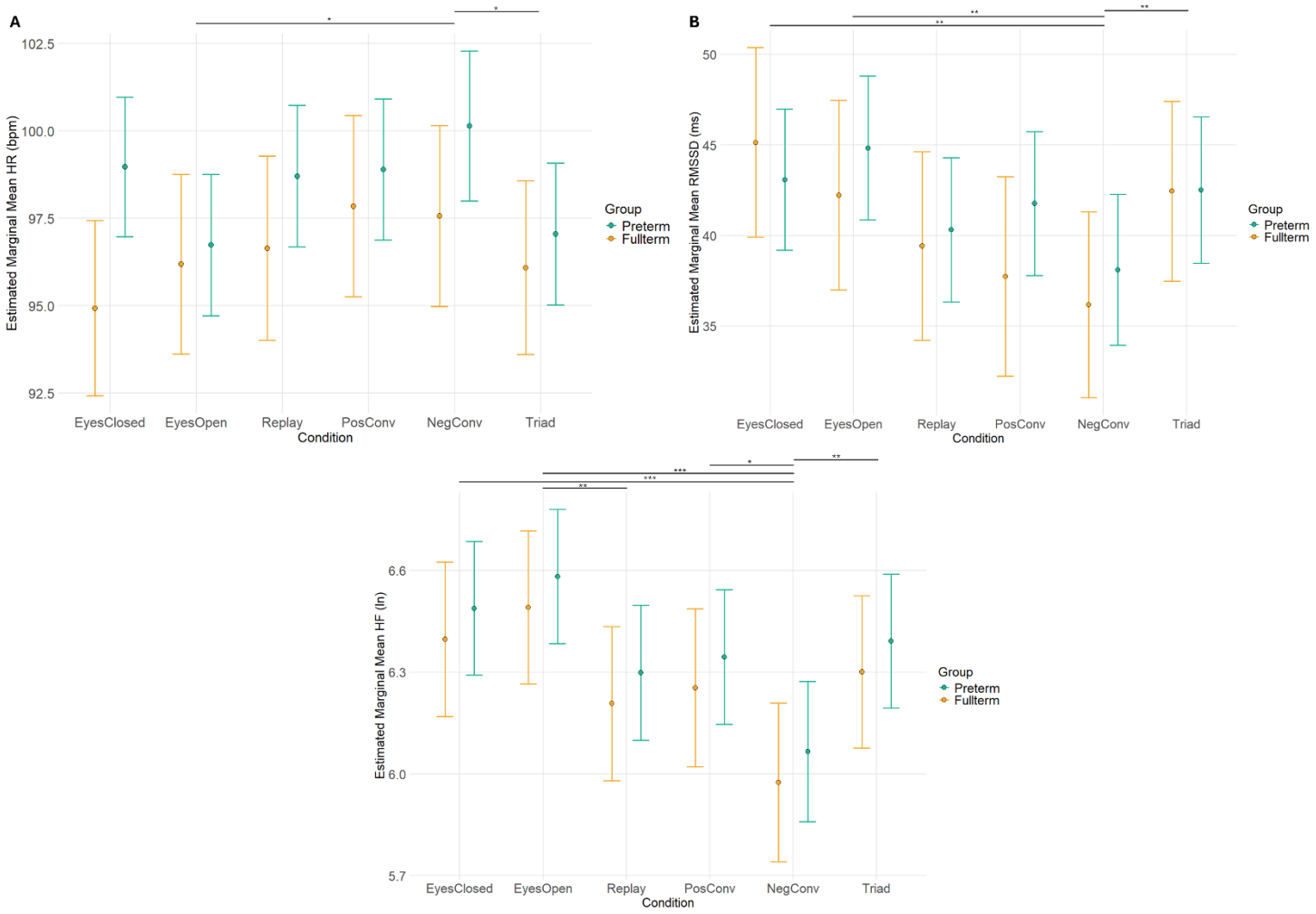

Figure 2. Physiological responses of preterm and full-term children across interaction conditions with their mother. **(A)** Mean heart rate (HR, bpm), **(B)** root mean square of successive differences (RMSSD, ms), and **(C)** high-frequency heart rate variability power (HF, ln ms^2). Points represent estimated marginal means with error bars indicating 95% confidence intervals. *Abbreviations:* PosConv = positive conversation, NegConv = negative conversation, Triad = triadic conversation. Asterisks denote significant differences between conditions (*$p < .05$, **$p < .01$, ***$p < .001$).

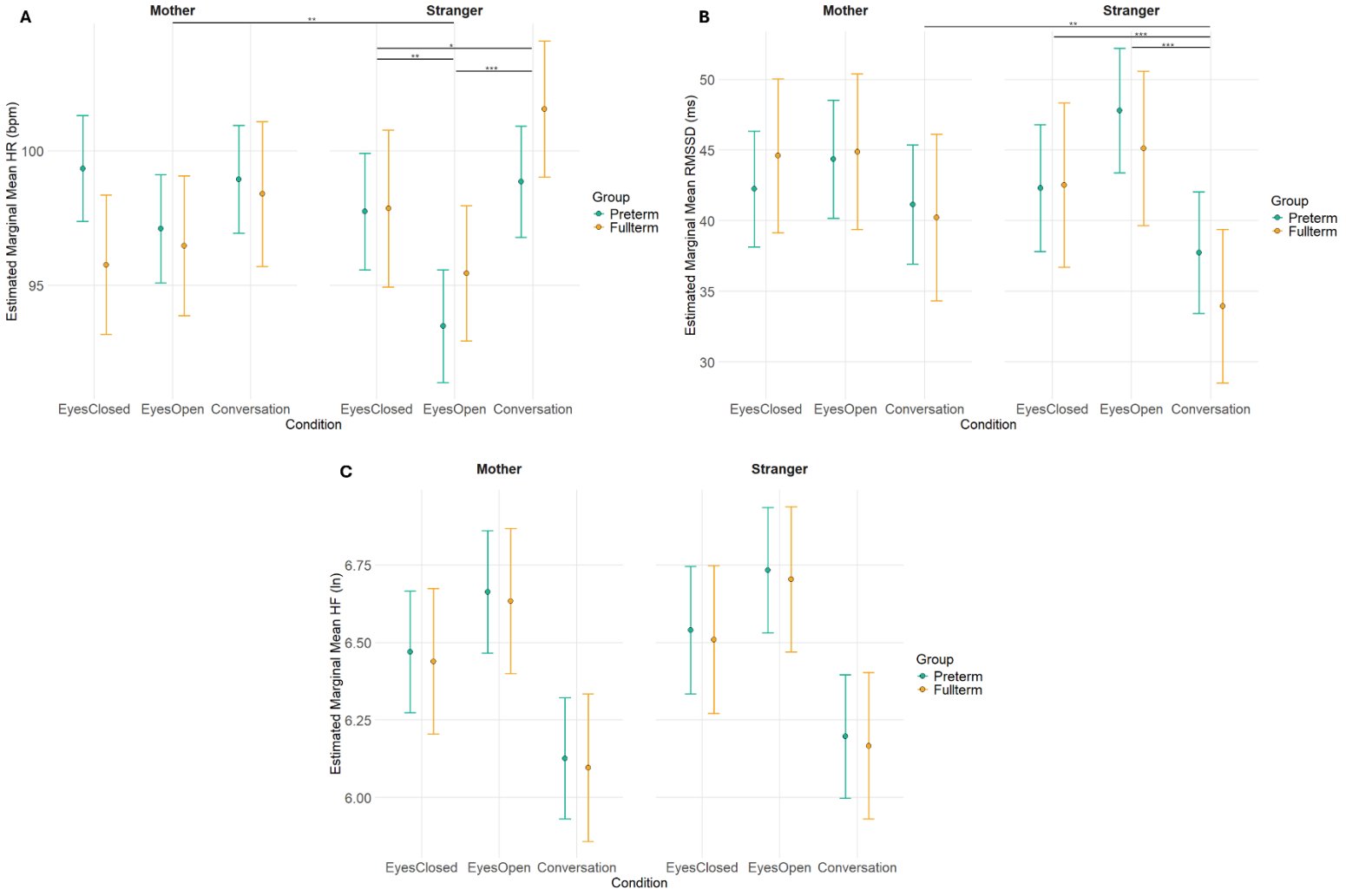

Figure 3. Physiological responses of preterm and full-term children during interactions with mother versus stranger across different conditions. **(A)** Mean heart rate (HR, bpm), **(B)** root mean square of successive differences (RMSSD, ms), and **(C)** high-frequency heart rate variability power (HF, ln ms²). Points represent estimated marginal means with error bars indicating 95% confidence intervals. Asterisks denote significant differences between conditions (*$p < .05$, **$p < .01$, ***$p < .001$).